Forecast of Renewable Energy Generation Trend in China[1]

Zihui Ji
Ph.D Student
Sumy State University, Ukraine *(Corresponding author)*
E-mail: Sofia19941008@gmail.com
ORCID: https://orcid.org/0000-0002-3302-5138

DOI: https://doi.org/10.32782/2707-8019/2023-1-2

Abstract. *Developing and utilizing renewable energy have become a common choice for all countries to ensure energy security, cope with climate change, and achieve sustainable development. Based on the data released in the Statistical Yearbook of China 2021, this paper predicts the data trends of two indicators, installed renewable energy capacity and total electricity consumption, from 2021 to 2030 by using the grey prediction model. According to the forecast results, by 2030, China's renewable energy installed capacity will reach 19,4674 GW, and power generation will be 42,261 billion kW, while the total electricity consumption in China will rise up to 12,738.3 billion kWh. This shows that China will still be unable to achieve its nationwide carbon neutrality goal by 2030. There is still a long way to go to accomplish the whole society's electricity consumption by relying entirely on renewable energy generation, but it has a substantial reference value for China's double carbon target. The recommendations of the research include: continuous increase in the renewable energy installed capacity in the whole society; accelerating energy transformation; strengthening research on renewable energy technology and the environment; establishing a renewable energy data platform; enrichment of the research methods and models for renewable energy development.*

Keywords: *renewable energy, forecast, electricity, consumption, China.*

JEL Classification: Q47, Q43, Q28

1 Introduction

With the invention of the steam engine and the internal combustion engine, coal and oil gradually became the primary sources of energy and the objects of competition. For example, some oil-rich countries began to use oil as a bargaining chip with other countries. If there is demand, there will be supply. After the oil crisis in 1970s, people began to search for alternatives to oil. Later, renewable energy sources came into being. Today, it includes solar, wind, hydro, biomass, tidal, geothermal, and other resources that can be recycled or taken from nature. In addition, renewable energy is a clean source of power that produces no carbon dioxide when burned and is essential for improving the Earth's environment. This is why many countries are embroiled in the research and development of renewable energy.

Of course, China is not an exception to this rule. Chinese economy has been proliferating and is currently in a "new normal[2]" stage. However, China's total carbon emissions account for about 30% of the world's total emissions, which has led to growing concerns about the optimization and upgrading of China's economic structure. In September 2020, China took a commitment at the UN General Assembly to peak CO2 emissions by 2030, achieve carbon neutrality by 2060, and have non-fossil energy account for about 25% of primary energy consumption by 2030, with wind and solar total installed capacity of over 1.2 mln MW. These intentions point to the strategic direction of China's energy transition and reforms. Therefore, it is urgent to analyze the historical data of installed renewable energy capacity and total electricity consumption and to forecast the future development trends. It will help correct the present dynamics of energy development within installed goals.

Based on the data on installed renewable energy capacity and total electricity consumption in China in the past eleven years, this paper

[1] The paper is prepared within the scientific research projects “Sustainable development and resource security: from disruptive technologies to digital transformation of Ukrainian economy” (№ 0121U100470) and “Fundamentals of the phase transition to the additive economy: from disruptive technologies to institutional sociologization of decisions” (No. 0121U109557).

[2] The new normal means a return to normal after a period of abnormality.

uses a grey prediction model to forecast the development trend of installed renewable energy capacity and total electricity consumption in the next ten years, providing a basis and reference for the future deployment of renewable energy and the realization of the Chinese dual carbon plan. The forecast results show that by 2030, China's renewable energy generation capacity will still not be able to meet the electricity demand of the whole society. The projections also show that with an increase of renewable energy generation and the rapid development of carbon-neutral technologies, CO_2 emissions will be reduced year by year, and the double carbon plan will be realized as scheduled.

2 Literature review

At the present stage, the promotion of green power has played a crucial role in the overall development of China, especially the deployment of renewable energy. Referring to the literature related to the progress in renewable energy in recent years, the following aspects are summarized.

In terms of economic growth, (Apergis et al., 2010) examine the causal relationship between renewable energy consumption and economic growth for 13 Eurasian countries over the period of 1992–2007 using a multivariate panel data framework. The paper demonstrates that there is a two-way causal relationship between renewable energy consumption and economic growth in the short and long term. (Menegaki, 2011) is an empirical study on the causal relationship between economic growth and renewable energy for 27 European countries for the period 1997–2007 involving a random effect model and including final energy consumption, greenhouse gas emissions, and employment as additional independent variables in the model, unlike previous renewable energy consumption-growth studies. (Apergis et. al., 2012) examine the relationship between renewable and non-renewable energy consumption and economic growth for 80 countries during 1990–2007. The contribution of (Tugcu et al. 2012) is investigation of the long-run and causal relationships between renewable and non-renewable energy consumption and economic growth. They applied classical and augmented production functions and made a comparison between renewable and non-renewable energy sources in order to determine which type of energy consumption is more important for economic growth in G7 countries for 1980–2009 period. As a contribution to the development program of remote areas in Jordan, (Al-Smairan et al., 2016) present two energy supply alternatives for a remote house equipped with a photovoltaic system and a diesel generator to provide electricity for a family house according to their energy requirements. (Bhattacharya et al., 2016) aim to investigate the effects of renewable energy consumption on the economic growth of major renewable energy-consuming countries in the world. The research subject of (Inglesi-Lotz, 2016) is to estimate the impact of renewable energy consumption on economic welfare by employing panel data techniques.

In terms of environmental protection, (Chen et al., 2019) proved that non-renewable power and GDP increase would raise carbon dioxide emissions, while green energy and foreign trade can reduce them. (Usman et al., 2020) applied an autoregressive distributed lag (ARDL) model to obtain the long-run and short-run dynamic coefficients. Based on them, the authors recommended country-specific energy policies that increase the share of renewable energy in the energy portfolio.

In terms of energy policy, (Zhao & Luo, 2017) showed that employment could promote renewable energy development, and the impact of employment would decrease with income growth. These conclusions will help the government to identify and take effective measures to promote green power enhancement. In terms of the energy transition, (Gielen et al., 2019) pointed out that energy efficiency and renewable energy technologies are the core of the power sector transformations.

In terms of renewable energy forecasts (Wu et al., 2019), use a novel nonlinear grey Bernoulli model to predict the total renewable energy, hydropower, wind and solar consumption, indicating the future increase trend of China's renewable energy (Ma et al., 2018) applied a machine learning forecasting algorithm involving massive independent variables and assumptions to model and to forecast renewable energy consumption (REC) in the US. (Brodny et al., 2020) present the results of the analysis of energy production from renewable sources in Poland and the forecasts with artificial neural networks for this production until 2025.

The novelty of this paper is the use of the grey model to forecast the trend of installed capacity and electricity consumption of renewable energy in China from 2021 to 2030. Our results show that there is still a long way to go to achieve the whole society's electricity consumption by relying entirely on renewable energy generation, but the future trends have a strong reference value for China's double carbon target.

3 Research methodology

In this paper, the grey model GM (1,1) (Wang et al., 2018)was used for analysis. Grey system theory is a system control theory with incomplete or uncertain information. It was developed by Chinese cybernetics expert Professor Deng Julong (Julong, n.d.) in 1982. In cybernetics, grey model is often used to represent the system with clear and unclear information. A grey prediction model is to make use of this and builds differential equations to generate the predicted data according to the original data sequence, among which GM (1,1) model is a more commonly used type.

The research data in this paper is based on the data from 2010 to 2020 to predict installed renewable energy capacity and total electricity consumption for China from 2021 to 2030. There is not much data involved, but the required prediction accuracy is high, so the grey model becomes the first choice for this study.

Forecast of China's installed renewable energy capacity 2021–2030. Before deciding to use the GM (1,1) model, it is necessary to perform a data-level test to determine the feasibility of the model. According to the data published in China Statistical Yearbook in 2021, the data of China's installed capacity are sorted out as shown in Table 1.

Table 1 China's installed renewable energy capacity, 2010–2020

Year	Installed capacity (GW)
2010	24589
2011	28144
2012	31430
2013	37284
2014	42629
2015	49248
2016	55585
2017	63625
2018	71119
2019	77113
2020	90512

Source: (China Statistical Yearbook in 2021)

Due to the grey prediction model, the formula $\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}, k=2,3,...,n$ is needed to be computed. When $\lambda(k)$ lies between $(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+2}})$, this means that GM(1,1) can be use. Otherwise, GM(1,1) cannot be used. Where k is the k-th value in the original sequence, k-1 is the (k-1)-th value in the original sequence, and n is the total number of data in the sequence from Table 1. There are eleven indicators in the original sequence; the first number is 24589, the second number is 28144 and so on. The eleventh number is 90512. The results of the rank ratio test are shown in Table 2. Since the feasibility columns in Table 2 are all "yes", the use of the GM (1,1) model is allowed.

Next, the GM (1,1) model is used for data prediction and includes the following steps.

The first step is to give the observation sequence x^0:

$$x^0 = \{x^0(1), x^0(2), x^0(3), \ldots, x^0(n)\}, \quad (1)$$

where $x^0, x^0(1), x^0(2), x^0(3), \ldots, x^0(n)$ are original data; n is the serial number of the original data.

Let them produce the sequence x^1. Follow $x^1(1) = x^0(1), x^1(2) = x^1(1) + x^0(2), \ldots, x^1(11) = x^1(11-1) + x^0(11)$, and then get a new sequence x^1.

$$x^1 = \{x^1(1), x^1(2), x^1(3), \ldots, x^1(11)\}, \quad (2)$$

where $x^1, x^1(1), x^1(2), x^1(3), \ldots, x^1(11)$ are the new sequence generated by accumulating indicators:

$$x^1(i) = \sum_{j=1}^{11} x^0(j), \quad (3)$$

where j= 1,2,3... , 11. i is the sequence number of the new sequence, j is the value of each element in new sequence.

As it is shown at Figure 1, the fluctuation of the original series is weakened after a new sequence has been accumulated (it produces a graph of a

Table 2 Results of the rank ratio test for installed renewable energy capacity

$k = 2,3,...,n$	$\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}$	$(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+2}})$	Feasibility(yes/no)
2	0.8736	(0.846, 1.166)	Yes
3	0.8954		Yes
4	0.8429		Yes
5	0.8746		Yes
6	0.8655		Yes
7	0.8859		Yes
8	0.8736		Yes
9	0.8946		Yes
10	0.9222		Yes
11	0.8519		Yes

Source: calculated by the author

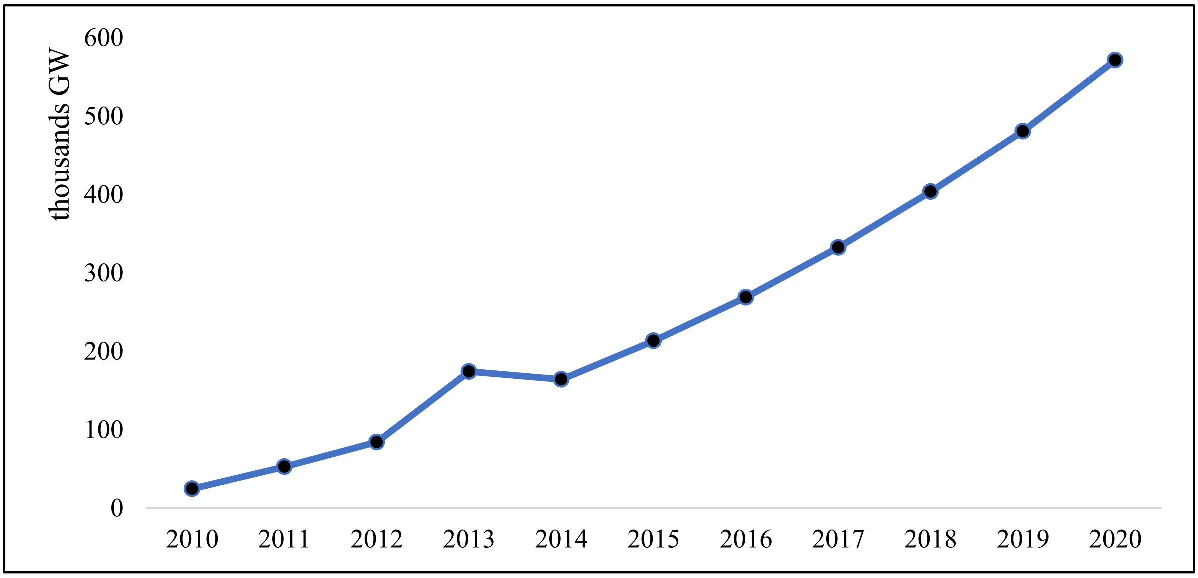

Figure 1 The sequence x^1 of trend plot

Source: developed by the author

function that approximates a straight line), and the new series presents a gradual increase (where the function graph gradually rises from the left to the right).

The second step is to assume that x^1 satisfies the first-order differential equation to construct a first-order ordinary differential equation and to solve the functional expression of the fitted curve:

$$\frac{dx^1}{dt} + ax^1 = u\,, \qquad (4)$$

where a and u are constants.(To get x^1, need to get the values of a and u).

The third step uses the least square method (LSM) (Björck, 1990) to obtain estimates for a and u. So that the new formula for matrix is:

$$\widehat{U} = \left[\hat{a},\hat{u}\right]^T = \left(B^T B\right)^{-1} B^T Y, \qquad (5)$$

where $\widehat{U}$ is a parameter vector (estimation value), $\hat{a}$ is estimates the value of a, $\hat{u}$ is the estimates value of u, Y is original sequence. B^T is B transpose (For details, see the basic LSM principles). The discrete solution of the original differential equation is:

$$\hat{x}^{(1)}(k+1) = \left[x^0(1) - \frac{\hat{u}}{\hat{a}}\right]e^{-\hat{a}k} + \frac{\hat{u}}{\hat{a}}, \qquad (6)$$

where k = 1,2,3, … ,n. k is the serial number of the data, $\hat{x}^{(1)}(k+1)$ is solution of $\frac{dx^1}{dt} + ax^1 =$ u.

In this paper, when k = 1,2,3,..11 in the equation, it is the fitted value, and when it is greater than or equal to 11, it is the predicted value. If we take k=10 or k=9, respectively, then we will get $\hat{x}^{(1)}$ (11) and $\hat{x}^{(1)}$(10); then you can predict the data of the eleventh year, that is, $\hat{x}^{(0)}(11) = \hat{x}^{(1)}(11) - \hat{x}^{(1)}(10)$. Here $\hat{x}^{(0)}(11)$ is the 11th number in the original sequence, $\hat{x}^{(1)}(11)$ is the 11th number in the new sequence. Finally, the forecast values of China's installed renewable energy capacity in 2021–2030 are shown in Table 3.

Table 3 Forecast of China's installed renewable energy capacity in 2021–2030

Year	Installed capacity (GW)
2021	95933
2022	104948
2023	114400
2024	124309
2025	134696
2026	145587
2027	157003
2028	168972
2029	181520
2030	194674

Source: calculated by the author

As can be seen from the forecast results in Table 3, China's installed renewable energy capacity will reach 194674 GW in 2030, and will increase by 104162 GW in the decade from 2020 to 2030, which exceeds the total installed capacity in 2021.

Forecast of China's total electricity consumption in 2021–2030. Similarly, before deciding to use the GM (1,1) model, we will perform data-level tests in order to guarantee reliability. Table 4 shows the data of China's total electricity consumption from 2010–2020.

Table 4 China's total electricity consumption in 2010–2020

Year	Electricity consumption (billion kWh)
2010	41999
2011	47026
2012	49657
2013	53423
2014	55637
2015	56933
2016	59747
2017	63625
2018	69002
2019	72486
2020	75110

Source: (China Statistical Yearbook in 2021)

Using the same way, the result of therank ratio test is presented in Table 5.

The GM (1,1) model was used to predict according to formulas (1) – (6), and the forecast results are shown in Table 6.

According to the data analysis shown in Table 6, China's social and economic development is slowing down gradually, but the total consumption of electricity is still huge. It is estimated that the total consumption of electricity in China will reach 127383 billion kWh in 2030. With the continuous increase in the total electricity demand, it is inevitable that the electricity generation volumes and installed capacity should grow continuously.

As follows from Figure 2, China's renewable energy generation will still not be able to meet the electricity demand to some extent.

For China, it will face many challenges to achieve the dual-carbon target (peak carbon

Table 5 Results of the rank ratio test for total electricity consumption data

$k = 2,3,\ldots,n$	$\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}$	$(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+2}})$	**Feasibility (yes/no)**
2	0.8931	(0.846, 1.166)	Yes
3	0.9470		Yes
4	0.9295		Yes
5	0.9602		Yes
6	0.9772		Yes
7	0.9529		Yes
8	0.9390		Yes
9	0.9221		Yes
10	0.9519		Yes
11	0.9651		Yes

Source: calculated by the author

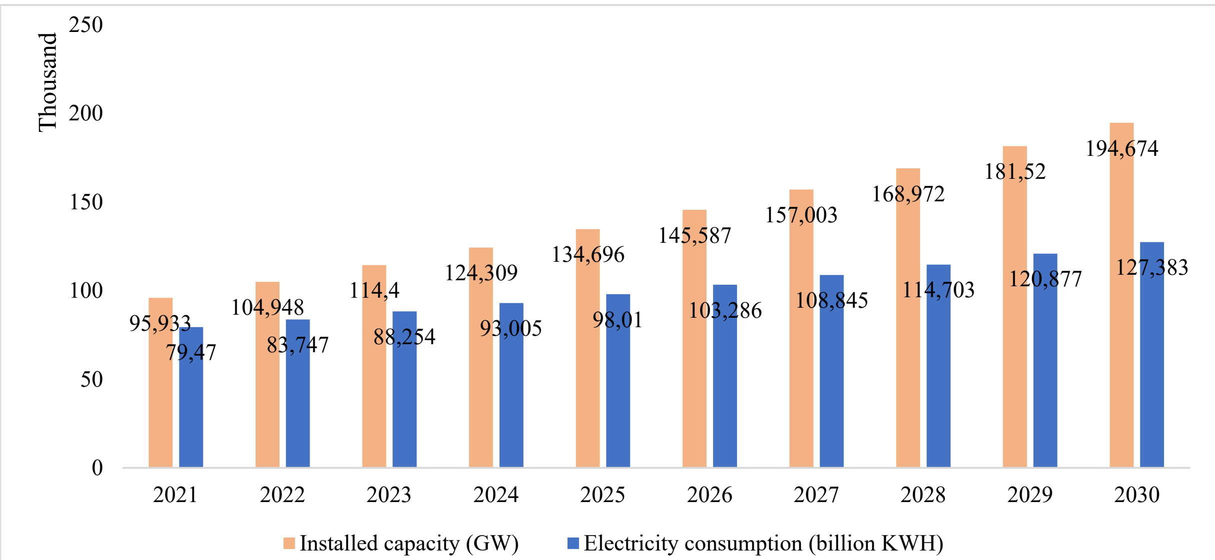

Figure 2 Projections of China's electricity generation and consumption for 2021–2030

Source: calculated by the author

by 2030 and carbon neutral by 2060), but with the continuous development of carbon capture technologies and the increasing installed capacity of renewable energy, it will only be a matter of time before the dual-carbon target is achieved.

Table 6 Forecast of total electricity consumption in China from 2021 to 2030

Year	Electricity consumption (billion kWh)
2021	79470
2022	83747
2023	88254
2024	93005
2025	98010
2026	103286
2027	108845
2028	114703
2029	120877
2030	127383

Source: calculated by the author

4 Conclusion

This paper forecasts the installed renewable energy capacity and total electricity consumption in China from 2021 to 2030 based on the data on installed renewable energy capacity and total electricity consumption in China from 2010 to 2020. From the forecast results, it is expected that China's installed renewable energy capacity will reach 194,674 GW and electricity consumption will reach 12,7383 billion kWh by 2030.

The contibution of this paper is the use of the grey model to forecast the trend of the indicators of installed capacity and electricity consumption of renewable energy in China from 2021 to 2030. Based on the forecast, we can conclude that by 2030, the installed capacity of renewable energy in China will reach 194674 GW, and the total electricity consumption in China will reach 127,383 billion kWh. This shows that China will still not be able to achieve its nationwide carbon neutrality goal by 2030. There is still a long way to go to achieve the whole society's electricity consumption by relying entirely on renewable energy generation, but the forecast has a strong reference value for China's double carbon target.

Gives the obtained forecast results, it is expedient to offer the following suggestions for China to accelerate the implementation of the dual-carbon target:

(1) Continuously increase the installed capacity of renewable energy in the country. At present, China has the largest installed capacity for hydroelectric power generation. The installed capacity of other renewable energy sources, such as solar and biomass power, is relatively small, and it should be changed within the capacity to develop.

(2) Accelerate the green energy transition. According to the forecast results, China's total electricity consumption will increase, in addition to the power consumption required for economic development, partly due to the current immaturity of power generation equipment technology, electricity-using equipment which is not environmentally friendly, etc. Therefore, the energy transformation of the whole society is imminent.

(3) Strengthen the research on renewable energy technology and the environment quility. The issue of climate change is a concern for people all over the world. At present, the renewable energy development policy has been gradually improved, and the economic value of renewables is increasingly presented. However, there are no significant breakthroughs in renewable energy technologies. Many of them are still the object of the theoretical research and on the development stage, such as forest carbon sink technology (Xu et al., 2022), Carbon capture storage (Cuéllar-Franca & Azapagic, 2015), and carbon removal technology (Terlouw et al., 2021).

(4) Establish a comprehensive renewable energy statistical yearbook to provide more available information and real and reliable data for the renewable energy research.

(5) Encourage enrichment of research methods and models of renewable energy. Most of the models used in the existing renewable energy research are still dominated by traditional energy, while green power is less involved. Therefore, future research should not only cover all fields of technology, policy, economy, and the environment involved in renewable energy but also adapt to all types of renewable energy to the present and future society's needs.

References

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and growth in Eurasia. *Energy economics*, 32(6), 1392–1397.

Menegaki, A. N. (2011). Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy economics*, 33(2), 257–263.

Apergis, N., & Payne, J. E. (2012). Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. *Energy economics*, 34(3), 733–738.

Tugcu, C. T., Ozturk, I., & Aslan, A. (2012). Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. *Energy economics*, 34(6), 1942–1950.

Al-Smairan, M. (2016). Techno-Economic Feasibility of Energy Supply of Remote Zone Family House in Jordan Badia by Photovoltaic System and Diesel Generators. *Solar energy*, 3, 6.

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied energy*, 162, 733–741.

Inglesi-Lotz, R. (2016). The impact of renewable energy consumption to economic growth: A panel data application. *Energy economics*, 53, 58–63.

Chen, Y., Wang, Z., & Zhong, Z. (2019). CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renewable Energy*, *131*, 208–216. DOI: https://doi.org/10.1016/j.renene.2018.07.04

Usman, O., Alola, A. A., & Sarkodie, S. A. (2020). Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: Evidence from the US. *Renewable Energy*, 150, 266–277. DOI: https://doi.org/10.1016/j.renene.2019.12.151

Zhao, X., & Luo, D. (2017). Driving force of rising renewable energy in China: Environment, regulation and employment. *Renewable and Sustainable Energy Reviews*, *68*, 48–56. DOI: https://doi.org/10.1016/j.rser.2016.09.126

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38–50. DOI: https://doi.org/10.1016/j.esr.2019.01.006

Wu, W., Ma, X., Zeng, B., Wang, Y., & Cai, W. (2019). Forecasting short-term renewable energy consumption of China using a novel fractional nonlinear grey Bernoulli model. *Renewable Energy*, *140*, 70–87. DOI: https://doi.org/10.1016/j.renene.2019.03.006

Ma, J., Oppong, A., Acheampong, K. N., & Abruquah, L. A. (2018). Forecasting renewable energy consumption under zero assumptions. *Sustainability (Switzerland)*, *10*(3). DOI: https://doi.org/10.3390/su10030576

Brodny, J., Tutak, M., & Saki, S. A. (2020). Forecasting the structure of energy production from renewable energy sources and biofuels in Poland. *Energies*, *13*(10). DOI: https://doi.org/10.3390/en13102539

Wang, Z. X., Li, Q., & Pei, L. L. (2018). A seasonal GM (1, 1) model for forecasting the electricity consumption of the primary economic sectors. *Energy*, 154, 522–534.

Julong, D. (1989). Introduction to grey system theory. *The Journal of grey system*, 1(1), 1–24.

Björck, Å. (1990). Least squares methods. *Handbook of numerical analysis*, 1, 465–652.

Xu, C., Wang, B., & Chen, J. (2022). Forest carbon sink in China: Linked drivers and long short-term memory network-based prediction. *Journal of Cleaner Production*, 359, 132085.

Cuéllar-Franca, R. M., & Azapagic, A. (2015). Carbon capture, storage and utilisation technologies: A critical analysis and comparison of their life cycle environmental impacts. *Journal of CO2 utilization*, 9, 82–102.

Terlouw, T., Bauer, C., Rosa, L., & Mazzotti, M. (2021). Life cycle assessment of carbon dioxide removal technologies: a critical review. *Energy & Environmental Science*, 14(4), 1701–1721.