

STUDY OF BEST PRACTICES OF GREEN ENERGY DEVELOPMENT IN THE EU COUNTRIES BASED ON CORRELATION AND BAGATOFACOR AUTOREGRESSIVE FORECASTING

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Received 17.03.2023.

Sent to review 28.03.2023.

Accepted 03.09.2023.

Original article



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JEL Classification: M4, M42

Doi: 10.2478/eoik-2023-0029

UDK: 502.131.1:620.9(477)

ABSTRACT

Russia's military aggression against Ukraine has undermined the global energy system, leading to high energy prices and increased concerns about the EU's energy security EU leaders have adopted a number of laws and developed the REPowerEU plan to reduce dependence on Russian energy imports by accelerating the transition to clean energy and creating a more sustainable energy system in Europe. The plan includes measures to save energy, diversify supplies and rapidly replace fossil fuels with clean energy sources, as well as prioritizes equity and solidarity, taking into account the energy balances of each EU member state. It builds on the Fit for 55 proposals and supports the ambitious goal of achieving at least -55% net greenhouse gas emissions by 2030 and climate neutrality by 2050. The aim of the article is to study the use of renewable energy in the European Union, the application of autoregressive models to predict the development of renewable energy. The results and conclusions. As a result of the study, based on the methodology of transients, a model of change in the volume of investment in wind energy was developed in the form of a differential equation. It was proved that the transition process is stable, even with time constraints or reduction of investment in the development of wind energy over time it will return to a stable growing trend (which was obtained by means of bagatofactor autoregressive models).

Keywords: renewable energy sources, wind energy, autoregressive models, investment, transition process

1. INTRODUCTION

Over the past few years, renewable energy has continued to show rapid growth and successful development in the energy sector. The introduction of a record number of new renewable capacities demonstrates that many countries around the world are recognizing the importance of transitioning to a more sustainable and environmentally friendly energy sector. Solar and wind power continue to be the two most successful sources of renewable energy. Together, they account for nearly 90% of all new renewable capacity additions, indicating that these technologies still have enormous potential for further growth and development.

This is due to the growing demand for clean energy from consumers and corporations. Many companies in various industries are beginning to switch to renewable energy sources as part of their corporate responsibility and sustainability strategy.

Thus, renewable energy continued to show growth in the energy sector in 2021, showing that the transition to greener energy is becoming increasingly real and necessary to address global environmental issues.

This is indeed a positive trend, but there is still much work to be done to increase the share of renewable energy in global energy production and reduce greenhouse gas emissions. There is a need to accelerate the adoption of renewable energy sources and reduce dependence on fossil fuels.

One of the keys to accelerating the transition to renewable energy is to increase investment in this area, including in developing countries. It was also important to develop effective support and incentive mechanisms for renewable energy, including removal of fossil fuel subsidies and carbon pricing.

Technological advances and the development of efficient energy storage systems that will ensure the reliability and flexibility of renewable energy are also essential.

Finally, it is important to promote public awareness and awareness of the benefits of renewable energy and its impact on the environment. This can be achieved through education and awareness campaigns that help people better understand why switching to renewable energy is an important step in combating climate change and creating a more sustainable future.

As noted, increasing installed renewable energy capacity is a positive trend, but there is a need for a more ambitious effort to achieve net zero emissions by 2050. This requires not only an increase in installed renewable energy capacity, but also improvements in energy efficiency, energy conservation and the use of new technologies.

In addition, it is important to note that the installed capacity of SPPP and wind power represents only a fraction of the world's total power generation capacity. Other sources, such as hydro-power, nuclear power, and the use of fossil fuels, also play an important role in energy security and sustainability.

Finally, it should be noted that the development of renewable energy sources should not block access to energy for those countries that still face energy constraints. Therefore, it is important to develop and implement energy technologies and solutions that can be affordable and economically beneficial for all countries and regions.

2. LITERATURE REVIEW

The analysis of processes in the energy sector includes components of the development and implementation of renewable energy sources. The statistical information published by the International Monetary Fund and the International Energy Agency is an important source of data on many countries, as well as on the state of global commodity markets, including the energy market. The available forecasts of energy indicators of countries provided by the International Monetary Fund can be used in the future to extrapolate the dynamics of the energy sector development in Ukraine. The developed methods and models relate to both the calculation of indicators and the development of recommendations for energy sector development policy at the international, European, national and local levels, determination of supply and demand in the energy market, assessment of the impact of energy on the environment and human health, interaction of energy and environment. Olena Trofymenko, (Olha Ilyash, Serhii Voitko, Tetiana Dluhopolska, Serhii Kozlovskyi, Svitlana Hrynkevych. (2022))

Considerable attention is paid to methods of analyzing the introduction of renewable energy sources, as energy policy involves long-term strategic planning at all levels of government. The development of energy development strategies and planning for the introduction of renewable

energy sources, increasing the share of joint energy production should include important principles of environmental acceptability, development of competitive and affordable energy markets under conditions of energy security and independence of countries, development of energy efficiency and creation of energy reserves. Determining the optimal directions of energy development at the macro level requires the development and implementation of effective methods for determining the dependencies and links between different elements of the energy system of the country's economy, links with other countries, the impact of external factors, and forecasting the development of such a system (Laitner J.A., DeCanio S.J., Coomey J.G., Sanstand A.H. (2003), Helm D. (2002)).

Today, capital-intensive and long-term energy projects have become more affordable. Understanding the importance of climate change requires long-term planning of the consequences of energy use in general and the introduction of renewable energy sources. This has led to the development of long-term analysis covering periods from 20 to 100 years (Huntington H.G., Weyant J., Sweeney J.L. (1982), Worrel E., Ramesohl S., Boyd G. (2004)).

Particularly noteworthy is the work by Jonn Kilstam and Christer Thornqvist, which examines the problems of sustainable development of society, the conflict between ecology and the economy, the role of corporate social responsibility of businesses and large corporations in addressing the global climate crisis (Thörnqvist, C. & Kilstam, J. (2021)).

Management decision on the development of green energy in Ukraine can be developed on the basis of the model of marginal utility in decision-making presented by the authors Ilhom Abdulloev Gil S. Epstein Ira N. Gang in (Abdulloev, I., Epstein, G. & Gang, I. (2020)).

Statistical information published by the International Monetary Fund and the International Energy Agency is an important source of data on the macroeconomic situation in Ukraine and many other countries, as well as on the state of global commodity markets, including the energy market. The available forecasts of the energy situation of countries provided by the International Monetary Fund can be used in the future to extrapolate the dynamics of the development of the energy sector in Ukraine. The statistical study of energy independence of countries involves the use of the following statistical methods (Yeliseieva O.K., Khazan P.V. (2017)).

- The method of generalized indicators (allows to assess the efficiency of FER use in the Ukrainian economy and to identify weaknesses of enterprises and organizations that hinder further development of the energy situation in the country and to develop necessary measures to eliminate them).

Growth curves describing the regularities of the phenomenon are obtained by analytical smoothing of time series. In most cases, smoothing the series with the help of certain functions proves to be a convenient means of describing empirical data characterizing the development of the phenomenon under study over time. The obtained models, subject to a number of conditions, can be used to forecast the smoothing of series using certain functions in most cases proves to be a convenient means of describing empirical data characterizing the development of the phenomenon under study over time. The resulting models can also be used for forecasting if a number of conditions are met.

The process of smoothing time series consists of two main stages:

- selecting the type of curve whose shape corresponds to the nature of the change in the time series or the type of growth process;
- determining the numerical values (estimation) of the curve parameters.

The found function allows you to get the leveled or, as they are sometimes called, theoretical values of the time series levels. The same function is also used for extrapolation. The question

of choosing the type of curve is the main one when leveling a series. All other things being equal, an error in choosing the shape of the growth curve when solving this issue is more significant in its consequences (especially for forecasting) than an error associated with statistical parameter estimation.

Adaptive methods of modeling and forecasting are based on preserving the inertia of development, but taking into account the factor of “aging” of data, i.e., the model adapts with the help of special parameters to the conditions prevailing at each moment of time, allow building self-correcting models that, taking into account the result of the forecast (or alignment) made in the previous step and the different information value of the members of the dynamic series, are able to respond quickly to changing conditions and, on this basis, give more accurate forecasts for the near future. (Olena Trofymenko, Olha Ilyash, Serhii Voitko, Tetiana Dluhopolska, Serhii Kozlovskiy, Svitlana Hrynkevych. (2022)).

3. RESEARCH OBJECTIVES

On the basis of statistical data on the development of renewable energy, the main components and dynamics of investments in the development of renewable energy sources in the world, in particular wind power, are considered and analyzed.

Through the study of autocorrelation functions, the expediency of using autoregressive forecasting models and the choice of the number of periods of shift of the initial data to form an array of input variables for the application of multifactorial multiplicative autoregressive forecasting is substantiated.

The expediency of applying the mathematical apparatus of transient analysis (in particular, the construction of a differential model, transfer, impulse transient and transition functions) to study the process of changing the use of wind power and the volume of investment in this type of renewable energy sources in the world is substantiated.

By constructing the amplitude-phase frequency response (APFR) of the modeled transient process of Wind power change and constructing the Nyquist frequency hodograph, the stability of the studied process is assessed and the dependence between the dynamic states of Wind power is determined to be resistant to external disturbances and force majeure.

4. METHODS

To model dynamic economic systems, one approach is to use a complex transfer function obtained through applying the Laplace transform to the differential equation that describes the relationship between influencing and studied variables (Worrel E., Ramesohl S., Boyd G. (2004)).

A structural diagram with typical links and operator forms of differential equations is used to depict the system. The transfer function $W(s)$ represents the relationship between the input (influencing variable) and output (studied variable). The impulse and transient functions of the system are related by the relation:

$$h(t) = \int_0^t w(\tau) d\tau \quad (1)$$

Due to its widespread use in the study of the stability of dynamic economic systems and the development of control actions, frequency response characteristics (FRC) have become widespread. If a harmonic signal is applied to the input of a system with a transfer function $W(s)$, then the following theorem is true: if the system under study is stable, then the response of the

output variable to the harmonic effect is a function of the same frequency with amplitude and relative phase shift.

The frequency response $W(i)$ of a stationary dynamic system is the Fourier transform of the transition function

The relationship between the complex transfer function and the frequency response is defined by the following relation:

$$W(S)|_{s=i\omega} = W(i\omega) \quad (2)$$

At a fixed value of ω , the frequency response is a complex number, and thus can be represented in terms of the following components:

$A(\omega)$ - Amplitude-frequency response (frequency response);

$U(\omega)$ - Phase-frequency response (PFR);

$P(\omega)$ - Real frequency response (RFR);

$Q(\omega)$ - Imaginary frequency response (IF).

The geometric location of the points $W(i)$ on the complex plane when changing from 0 to 1 is called the amplitude-phase response (APR) or Nyquist frequency response.

The autocorrelation function of an economic indicator is given by the formula:

$$\rho_{xx}(\tau) = \frac{\sum_{i=1}^n (x_{i-\tau} - \bar{x}) * (x_i - \bar{x})}{\delta_x^2 * (n - \tau)} \quad (3)$$

The autocorrelation function reflects the degree of influence of the previous values of the studied indicator on its current value. A slowly decreasing autocorrelation function indicates that the indicator has significant inertia in time, and its current values are highly dependent on its previous values. autocorrelation is one of the most important elements of time series analysis. Autocorrelation is a phenomenon where the current level of a time series is correlated. In particular, a well-studied and identified autocorrelation can be used for short-term forecasting of certain indicators (Pina A., Silva C., Ferrao P. (2011), Yelisieieva O.K., Khazan P.V. (2017)).

To do this, in the autoregression equation, the value of the studied indicator for previous years is substituted, and thus the predicted value of the indicator for the near future, usually for the next year, is obtained.

The intercorrelation function is as follows:

$$\rho_{xy}(\tau) = \frac{\sum_{i=1}^n (x_{i-\tau} - \bar{x}) * (y_i - \bar{y})}{\delta_x * \delta_y * (n - \tau)} \quad (4)$$

Where, τ is the time shift under study.

The construction of intercorrelation functions allows us to determine which of the previous periods of the influential indicator has the greatest impact on the one under study. That is, according to the above example, the current amount of wind energy produced (used) may be most influenced by investments in the development of relevant sources in the previous or the year before last, which is determined in numerical form based on the analysis of the obtained values of the correlation function.

5. RESULTS

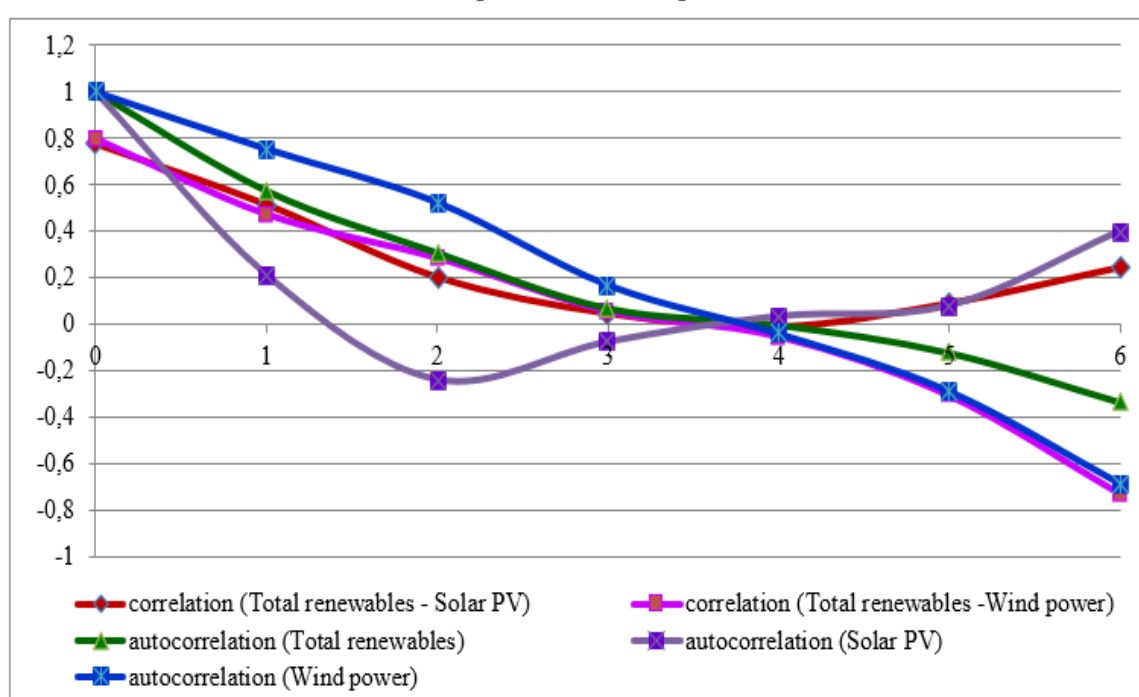
The correlation and autocorrelation functions are defined by the following formulas:

$$\rho_{xy}(\tau) = \frac{\sum_{i=1}^n (x_{i-\tau} - \bar{x}) * (y_i - \bar{y})}{\delta_x * \delta_y * (n - \tau)} \quad (5)$$

$$\rho_{xx}(\tau) = \frac{\sum_{i=1}^n (x_{i-\tau} - \bar{x}) * (x_i - \bar{x})}{\delta_x^2 * (n - \tau)} \quad (6)$$

where τ is the lag (shift period of the studied data); X is the influencing variable; Y is the studied variable; n is the number of periods of the studied data; δ_x is the standard deviation of X, δ_y is the standard deviation of Y.

Figure 1. Correlation and autocorrelation functions for Total renewables, Solar power and Wind power



Source: Author's calculation based on Helm D. (2002), Huntington H.G., Weyant J., Sweeney J.L. (1982)

The autocorrelation functions for Total renewables and Wind power are slowly decreasing, which indicates the high inertia of these indicators and a significant level of dependence of current values of Total renewables and Wind power on their values in previous years, which allows the use of autoregressive multivariate models for their forecasting.

As for the Solar PV indicator, its autocorrelation function is more rapidly decreasing (it goes to a negative value from the 2nd shift period, unlike the previous two functions, which acquire a negative value only at the 4th shift period). Thus, it can be preliminarily noted that the expediency of autoregressive multifactor forecasting of Solar PV is less appropriate, since the resulting models will provide a lower level of adequacy of the built model.

Based on the data in Fig. 3, it is advisable to choose three-factor models for building autoregressive forecasts, where:

Y_i - data of the indicator without a shift (i.e., for the current year);

$Y_{(i-1)}$ - data of the indicator with the 1st shift period (i.e. for the previous year);

$Y_{(i-2)}$ - data of the indicator with the 2nd shift period (i.e., for the year two periods earlier than the current one);

$Y_{(i-3)}$ - data of the indicator with the 3rd shift period (i.e., for the year that is three periods earlier than the current one).

Two approaches have been used to build the autoregressive models: the multi-factor forecast and the multiplicative forecast. For total renewables, the three-factor autoregressive model has the following form:

$$Y_i^* = \sqrt[3]{(131.2 + 0.721 \cdot Y_{i-1}) \cdot (142.66 + 0.598 \cdot Y_{i-2}) \cdot (158.12 + 0.555 \cdot Y_{i-3})} \quad (7)$$

The accuracy of the model 92.98%

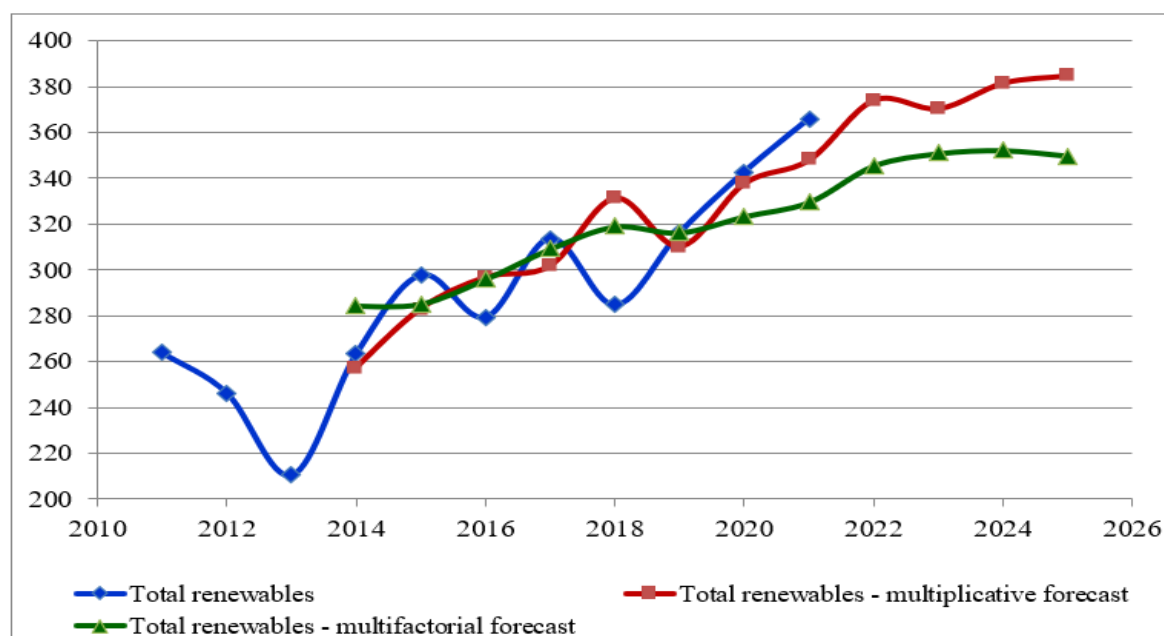
For Total renewables, the three-factor multiplicative autoregressive model has the following form:

$$Y_i^* = (131.2 + 0.721 \cdot Y_{i-1}) \cdot (0,948 + 0,000186 \cdot Y_{i-2}) \cdot (0,766 + 0,000865 \cdot Y_{i-3}) \quad (8)$$

The accuracy of the obtained model is 93.45%

The high accuracy of the resulting autoregressive forecasting models for total renewable energy allows them to be used for practical forecasting of global renewable energy investment values up to and including 2025 (Fig. 2 and Table 1).

Figure 2. Results of multivariate autoregressive forecasting Total renewables, billion USD



Source: Author's calculation

For wind power, the three-factor autoregressive model has the following form:

$$Y_t^* = \sqrt[3]{(51.44 + 0.651 \cdot Y_{t-1}) \cdot (60.92 + 0.624 \cdot Y_{t-2}) \cdot (48.36 + 0.812 \cdot Y_{t-3})}$$

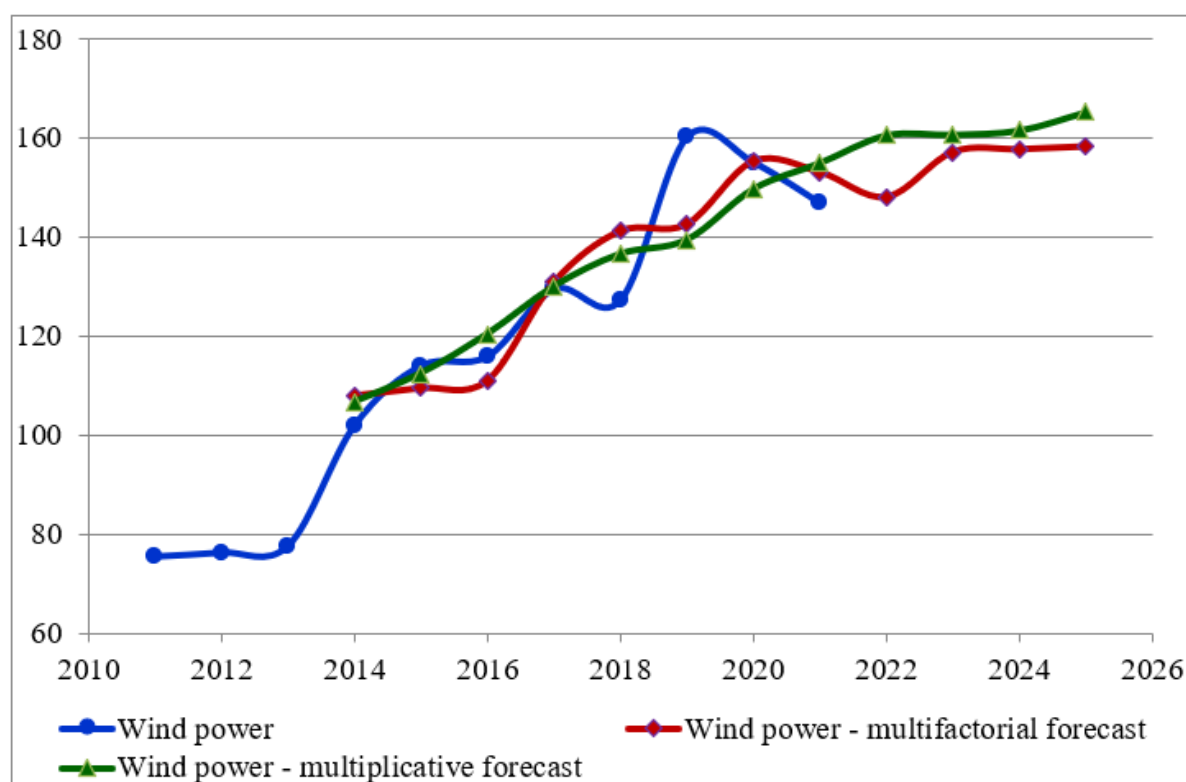
The accuracy of the obtained model is $R^2 = 93.09\%$

For wind power, the three-factor multiplicative autoregressive model has the following form:

$$Y_t^* = (0.967 + 0.000327 \cdot Y_{t-1}) \cdot (0.997 - 0.0000306 \cdot Y_{t-2}) \cdot (48.36 + 0.812 \cdot Y_{t-3})$$

$$(R^2 = 93.26\%)$$

Figure 3. Results of multivariate autoregressive forecasting Wind power, billion USD



Source: Author's calculation

The high accuracy of the obtained autoregressive forecast models for wind power allows them to be used for practical forecasting of Global Investment in Wind power up to 2025 inclusive - Fig. 3 and Table1.

Table 1. Forecast of global investments in renewable energy sources, 2022-2025, billion USD

	Total renewables - multiplicative forecast	Total renewables - multifactorial forecast	Wind power - multifactorial forecast	Wind power - multifactorial forecast
2022	374,2032	345,4489	148,0936	160,6159
2023	370,5088	350,8131	157,1871	160,7246
2024	381,7005	352,152	157,7138	161,5889
2025	384,8814	349,7626	158,2649	165,3121

Source: Author's calculation

According to Table 1, all the studied indicators have a fairly stable upward trend in the overall trend dynamics, which is confirmed by the high levels of approximation obtained (more than 90% for wind power and total renewables).

The differential modeling of the studied indicators is carried out using the methodology of transient analysis (Chermack T.J., Lynham S.A. & Ruona W.E.A. A (2001)).

Based on the constructed correlation functions, a system of equations is written to obtain the values of the impulse transient functions for each indicator, which has the form:

$$\{\rho_{xy}(t - k) = \sum_{i=0}^n w_i * \rho_{xx}(\tau - i)\} \quad (9)$$

In other words, it is necessary to create two such systems of equations, each with 5 equations and 5 variables, solve all these equations and obtain the values of the impulse transition functions for each indicator. The number of 5 variables is chosen based on the data in Fig. 1, where we can see from the correlation functions that it is better not to use the 6th shift point in further modeling. To model transient processes, the amount of data remaining in the calculation after the shift, the value $(n-\tau)$, should be greater than or equal to τ ; at the boundary values, the choice is made based on the correlation functions.

Since the statistics of the indicators for 11 years (2011-2021) were used as input data, for a shift of 6 periods, only 5 periods remain for calculation, and at this point the correlation functions rapidly decrease and approach the minimum value:

For Wind power $= -0,308$ д.о., $a = -0,731$ д.о

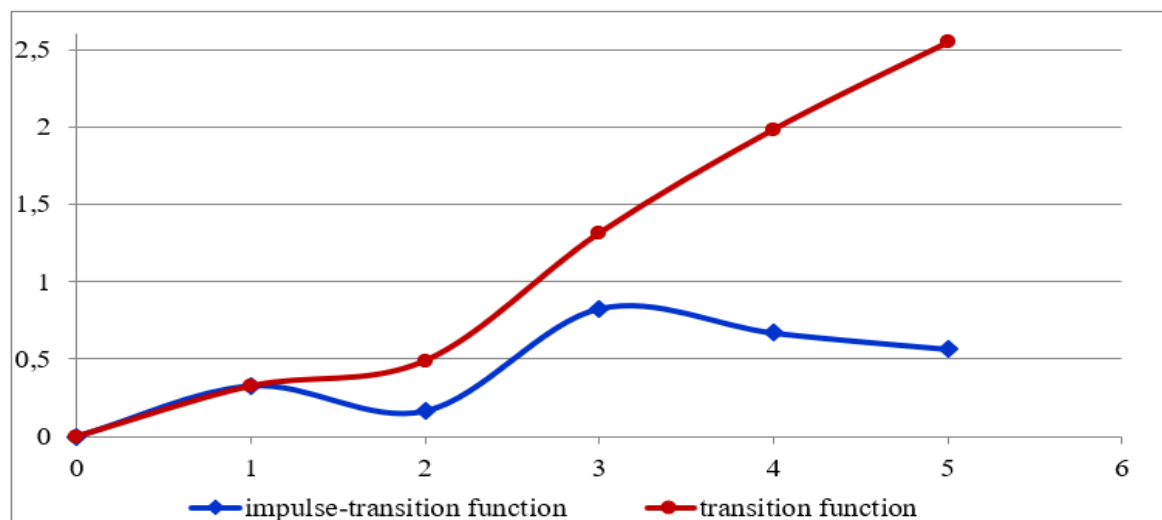
Based on the constructed correlation and autocorrelation functions (Fig. 1), we write a system of equations for Wind power to find the values of the impulse-transient function.

Having solved the system of equations, we obtain the value of the impulse-transient function

$$\left\{ \begin{array}{l} 0,795 = 1 * \omega_0 + 0,755 * \omega_1 + 0,525 * \omega_2 + 0,169 * \omega_3 - 0,040 * \omega_4 - 0,288 * \omega_5 \\ 0,471 = 0,755 * \omega_0 + 1 * \omega_1 + 0,755 * \omega_2 + 0,525 * \omega_3 + 0,169 * \omega_4 - 0,040 * \omega_5 \\ 0,284 = 0,525 * \omega_0 + 0,755 * \omega_1 + 1 * \omega_2 + 0,755 * \omega_3 + 0,525 * \omega_4 + 0,169 * \omega_5 \\ 0,055 = 0,169 * \omega_0 + 0,665 * \omega_1 + 0,755 * \omega_2 + 1 * \omega_3 + 0,755 * \omega_4 + 0,525 * \omega_5 \\ -0,054 = -0,040 * \omega_0 + 0,169 * \omega_1 + 0,525 * \omega_2 + 0,755 * \omega_3 + 1 * \omega_4 + 0,755 * \omega_5 \end{array} \right\}$$

for the process of wind power change and calculate the transient function as the sum of the previous values of the impulse transient at each point - Fig. 4.

Figure 4. Impulse response and transient functions for wind power



Source: Author's calculation

To find the coefficients of the differential equation, three auxiliary quantities, re used, which are related to the coefficients of the differential equation by the following dependencies (Maryuta A.N., Ekimov S.V. (2005)).

$$\left\{ \begin{array}{l} a_1 = b_1 + F_1 \\ a_2 = b_2 + F_2 + F_1 * b_1 \\ a_3 = b_3 + F_3 + b_2 * F_1 + F_2 * b_1 \end{array} \right\} \quad (10)$$

In this case, there are the following rules that define the form of the differential equation depending on the values of F_1 ; F_2 ; F_3 (Global Energy Assessment. Toward a Sustainable Future. Key Findings Summary for Policymakers Technical Summary. (2012))

1. If $F_3 < 0$ the process is described by a second-order differential equation with the first transformation coefficient and the first-order output:

$$a_2 \frac{d^2 y}{dt^2} + a_1 \frac{dy}{dt} + y = b_1 \frac{dx}{dt} + b_0 x \quad (11)$$

2. If $F_2 > F_3$ then the process is described by a second-order differential equation with the first transformation and a simple step:

$$a_2 \frac{d^2 y}{dt^2} + a_1 \frac{dy}{dt} + y = b_0 x \quad (12)$$

3. If $F_1 < F_2 < F_3$ then the process is described by a third-order differential equation with the first transformation and a simple step:

$$a_3 \frac{d^3 y}{dt^3} + a_2 \frac{d^2 y}{dt^2} + a_1 \frac{dy}{dt} + y = b_0 x \quad (13)$$

For all three cases: $a_0 = 1$; $b_0 = \frac{\Delta y}{\Delta x}$; $\Delta y = y_{max} - y_{min}$; $\Delta x = x_{max} - x_{min}$

To find the conditions of F , we use the formulas:

$$F_1 = \Delta t * (\sum_{i=1}^n (1 - x_i') - 0.5 * (1 - x_1')) \quad (14)$$

where χ_i' – dimensionless value of the transition function.

Δt – the initial transformation step in the calculation of correlation coefficients.

$$F_2 = F_1^2 * \Delta Q (\sum_{i=1}^n (1 - x_i') * (1 - Q_i) - 0.5 * (1 - x_1')) \quad (15)$$

where $Q_i = \frac{t}{F_1 - n}$

$$F_3 = F_1^3 * \Delta Q (\sum_{i=1}^n (1 - x_i') * (1 - 2Q + \frac{Q^2}{2}) - 0.5 * (1 - x_1')) \quad (16)$$

Table 2. Results of determining the type of differential equation and calculating its coefficients for Wind power

Wind power			
Parameter F		Condition	Coefficients
F1=	2,451	F2 > F3	a1 = 2,45
F2=	1,732		a2 = 1,73
F3=	0,675		b0 = 0,55

Source: Author's calculation

For wind power, the differential equation for modeling the transient process of changes in wind energy investments depending on global investments in renewable energy sources is as follows:

$$1,73 \cdot \frac{d^2y}{dt^2} + 2,45 \cdot \frac{dy}{dt} + y = 0,55 \cdot x \quad (17)$$

Transfer function for Wind power:

$$\omega(p) = \frac{0,55}{1,73p^2 + 2,45p + 1}$$

The real part for the model indicator AFR for Wind power has the form of:

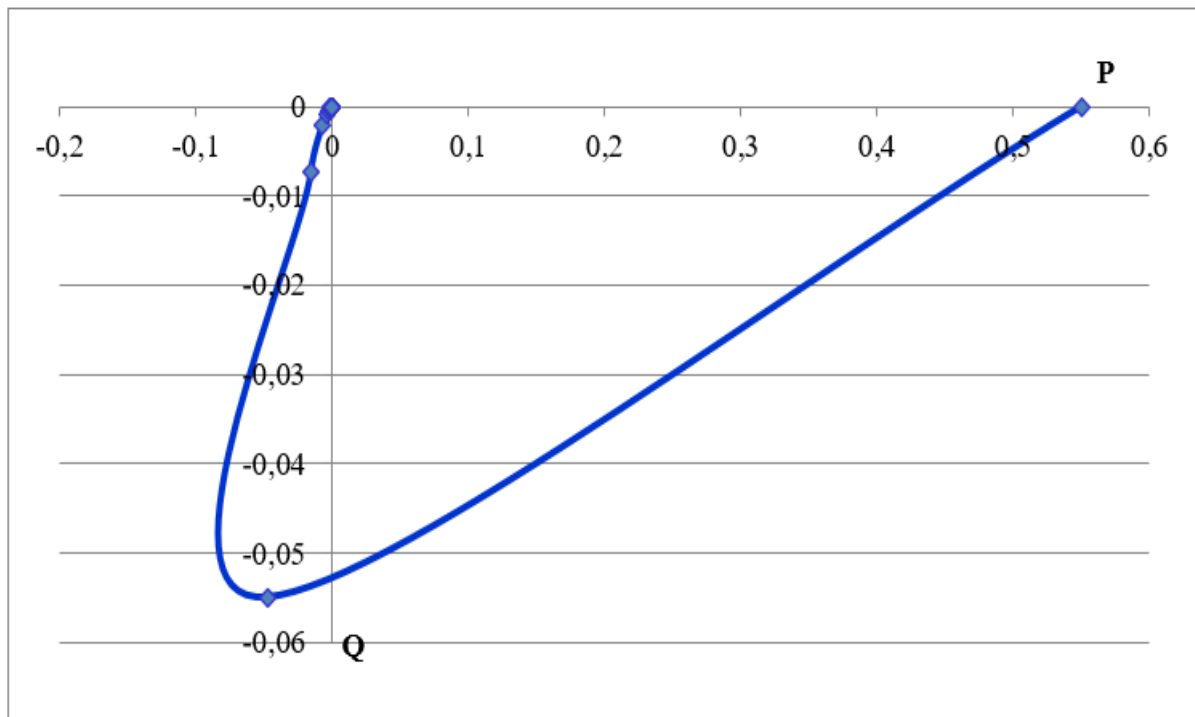
$$P = \frac{0,55 - 0,95w^2}{2,99w^4 + 2,54w^2 + 1} \quad (18)$$

The imaginary part for the model's AFR for Wind power has the form of:

$$Q = \frac{-1,35w}{2,99w^4 + 2,54w^2 + 1} \quad (19)$$

Figure AFR for Wind power is presented in Figure 5.

Figure 5. Amplitude-frequency response of the differential model for wind power



Source: Author's calculation

Since the frequency response line does not cover the point $(-1;0)$, this indicates the stability of the studied process and its ability to self-leveling in the event of random disturbances and force majeure.

Thus, from the modeling carried out using the methodology of transient analysis, a model of changes in the volume of investment in the development of wind energy in the form of a differential equation was obtained and it was found that this process is sustainable, that is, even with temporary restrictions or reductions in such investment, over time it will return to a stable upward trend (which was obtained using multivariate autoregressive models).

6. DISCUSSION

Discussion points: in the economic and mathematical forecasting of economic phenomena and processes, in order to improve the accuracy of the forecast, the quality of the model and expand the prospects for its application in practice, it is important to select influential factors when building a model. In this case, there is a need to exclude mutually influencing factors; to search for indirect influence on the indicator through third uncertain factors and the problem of obtaining forecast values for future periods - if statistics on influencing factors are known only for the past and current periods.

However, the use of autoregressive forecasting models allows simultaneously solving all three of these problems, since it is based on the study of previous values of the main indicator and, depending on the results of autocorrelation analysis, its breakdown into several conditional variables to obtain multifactor forecasting models.

In previous periods, the targeted indicator (Wind power) was affected by all the same identified and unidentified factors that will continue to operate in the future. Therefore, the values of the indicator are already formed under the influence of all the influencing factors, thus taking them into account. In addition, since autoregressive models consider an array of previous values of the indicator as influential variables, it is always possible to calculate the next value on their basis, then add it to the array of statistical data and recursively apply the resulting mathematical model for forecasting for the following periods.

Representation of Wind power development in the form of a dynamic transient process and modeling of its future states by obtaining a second-order differential equation with a simple input, a complex transfer function, and by determining the amplitude-phase frequency response (APFR) and constructing a Nyquist frequency hodograph, which showed the stability of the studied process to external disturbances.

For the first time, the development of wind power was considered as a dynamic transient process, which was represented as a complex transfer function $\omega_{(p)} = 0,55 / (1,73p^2 + 2,45p + 1)$, its real frequency response and its imaginary frequency response

$Q = \frac{-1,35w}{2,99w^4 + 2,54w^2 + 1}$, which were used to construct a Nyquist frequency hodograph, which

showed the stability of the studied process (changes in the development of wind power) to external disturbances (investment restrictions).

The possibility of applying autoregressive forecasting models to Wind power was substantiated, three-factor autoregressive and multiplicative models were obtained and compared; forecast values of Wind power until 2025 were calculated.

7. CONCLUSION

In 2021, 314.5 GW of new renewable energy capacity was commissioned. Solar and wind power provided more than 10% of the world's electricity.

About 102 GW of new capacity was installed, bringing the total installed capacity of wind farms to 845 GW.

However, the introduction of new renewable energy sources lagged behind the growth in energy demand. Therefore, over the past 10 years, the share of renewable energy in global energy

production has increased from 10.6% to 11.7%, while the share of fossil fuels has only decreased from 80.1% to 79.6%.

Growth in economic activity in 2021 led to a 6% increase in CO₂ emissions compared to 2019-2020.

While \$366 billion was invested in renewable energy sources, fossil fuel subsidies alone reached \$5.9 trillion, equivalent to \$11 million per minute. Direct and indirect fossil fuel subsidies account for 7% of global gross domestic product (GDP).

Slow progress in the transition away from fossil fuels and reducing greenhouse gas emissions is a cause for concern, especially as global energy demand continues to grow. The deployment of renewable energy is growing, but not fast enough to meet the goals of limiting global warming to below 2 degrees Celsius, as required by the Paris Agreement. To reach the average of the main zero-emissions scenarios, annual renewable energy growth needs to triple (adding about 825 GW annually by 2050).

High fossil fuel subsidies are the main obstacle to the development of renewable energy. These subsidies create market distortions in favor of fossil fuels, making them economically more competitive than renewables. Eliminating these subsidies and investing in renewable energy infrastructure can accelerate the transition to a low-carbon economy.

Improving energy conservation and efficiency can also help reduce energy demand and emissions. This includes measures such as building codes requiring more energy-efficient buildings, increasing the use of public transportation, and encouraging the use of energy-efficient appliances.

Overall, the progress in renewable energy deployment in 2021 is encouraging, but more needs to be done to achieve zero emissions by 2050. This requires the adoption of laws to abolish fossil fuel subsidies, increase investment in renewable energy infrastructure, and improve energy conservation and efficiency.

Based on the results of the modeling conducted using the methodology of transitional processes, a model of changes in the volume of investment in wind energy in the form of a differential equation was obtained and it was found that this process is stable, that is, even with temporary restrictions or reductions in investment in wind energy development, it will eventually return to a stable upward trend (which was obtained using multivariate autoregressive models).

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