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Key Determinants of Price Setting and Change in the Carbon Market

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ABSTRACT

As greenhouse gas emissions are increasing year by year, both developed and developing countries are seeking to incentivize their reduction through emissions trading. Therefore, the price of a carbon unit becomes a driver of change in greenhouse gas emissions. In this regard, understanding how the price of a carbon unit is formed becomes particularly **relevant**. The **object** of the study is the combination of factors and conditions of formation of prices for carbon credits as tools for reducing greenhouse gas emissions. The **purpose** of the study is to identify the key determinants of establishing and changing the price of carbon credits. In the process of writing the article we used both general scientific research **methods**: analysis, synthesis, generalization and classification of data, and special economic and mathematical **methods**, including correlation and regression analysis. The article investigated the European, New Zealand and Korean carbon unit trading systems. It **was concluded** that there are clusters of volatility in their markets of carbon units. The key determinants of carbon price volatility and factors contributing to their growth were identified: the price of crude oil, gas, coal, gasoline; shocks causing recession; the total volume of carbon emission quotas on the market; the volume of free allocated quotas; the number and list of industries covered by the system of trading in quotas. As a **result**, the stages of forming a price for carbon units for the purpose of reducing greenhouse gas emissions were determined and justified. The results obtained in the course of the study and the recommendations developed are aimed at creating a market for carbon units in Russia and improving its efficiency in comparison with existing practices. The results obtained will be used for further fundamental research and practical developments in the field of greenhouse gas emissions trading.

Keywords: carbon market; carbon unit exchange trading; carbon units; greenhouse gas emission accounting; greenhouse gas market; decarbonization; sustainable development; ETS

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INTRODUCTION

Greenhouse gas (GHG) emissions worldwide, including in Russia, exceed the absorption capacity of the planet from year to year. Carbon dioxide (carbon dioxide, CO_2) and methane (CH_4) account for the largest share of total emissions. The constant increase in the concentration of CO_2 and CH_4 in the atmospheric air is caused by a high rate of increase in their emissions into the atmosphere, although after a sharp increase in this characteristic in the period from 2020 to 2022, the changes in 2023 compared with 2022 are insignificant.[1] A high concentration of greenhouse gases is the cause of climate change and provokes adverse hydrometeorological phenomena, which is especially important for Russia, since experts estimate that damage from catastrophic natural phenomena in our country annually exceeds 150 billion rubles. [1, p. 217], and according to the UN report for 2023,[2] the volume of greenhouse gas emissions per capita in the Russian Federation was more than twice the global average. Large amounts of GHG emissions, leading to an increase in

[1] The report on the peculiarities of the climate in the territory of the Russian Federation for 2023. Moscow, 2024. 104 pages. Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). pp. 87–88, 93. URL: https://www.meteorf.gov.ru/images/news/20240329/4/DOCK202344.pdf (accessed on 08.06.2024).

[2] The report on the emission gap for 2023. United Nations Environment Programme. 2023. A brief overview. URL: https://www.unep.org/interactives/emissions-gap-report/2023/ru / (accessed on 26.09.2024).

their concentration in the atmosphere, worsen the overall ecological and climatic situation in the world, which leads to an increase in the frequency and scale of natural disasters and thereby affects the process and results of financial and economic activities of economic entities. Climate change and temperature rise contribute to the displacement of climatic zones, changes in the profile types of economic activity of individual territories [2]. All of the above explains the importance of regulating greenhouse gas emissions worldwide, including in Russia.

This position is supported by the Forecast of the Long-term Socio-economic Development of the Russian Federation, developed by the Ministry of Economic Development of the Russian Federation for the period up to 2030,[3] the Forecast of Socio-economic Development of the Russian Federation for the period up to 2036,[4] as well as the Climate Doctrine of the Russian Federation[5] and the Strategy of Scientific and Technological Development of the Russian Federation.[6]

Given the global nature of the threats, the international community is actively developing measures to decarbonize the economy, usually preferring the use of financial levers to strict regulations and directives, for example, trading rights to greenhouse gas emissions (quotas). Release permits are assets that can be freely sold and bought on the market. Within the framework of such a system, the price of carbon emissions becomes a factor in the change in GHG emissions. Its growth is theoretically capable of encouraging economic entities (pollutants) to reduce emissions into the atmosphere.

In order to develop effective regulatory measures within the framework of the formation and development of the Russian carbon trading market, taking into account the accumulated experience of foreign countries, it is relevant to study how carbon unit prices are formed, considered for the purposes of this study as tools that stimulate the transition of Russian companies to the path of decarbonization.

The purpose of this study is to identify the key determinants of setting and changing prices for carbon units.

The study was conducted in accordance with the principles of the European, New Zealand and Korean Quota Trading Systems (ETSs) for greenhouse gas emissions. The choice of ETS data is dictated by access to a wider observation period (more than 5 years for each of the systems), as well as the use of free exchange trading on the secondary quota market, which provides access to daily information on market quotations and sales volumes. Unlike the selected ones, most country ETSs use auctions as a trading tool, which significantly limits the possibilities of analyzing the variability of indicators.

The variability of the prices of carbon units of selected ETSs was investigated using the ARCH- and GARCH-conditional volatility models developed by T. Bollerslev and R.F. Engle [3, 4], and the main factors influencing the price of a carbon unit were determined based on research by foreign authors [5–8]. Pricing issues in the carbon quota market were also dealt with by O.D. Ismagilova [9], M.V. Lysunets [10], N.V. Sergeeva [11], Yu.S. Tsertseil [12].

The research uses general scientific methods of data analysis, synthesis, generalization and classification, as well as economic and mathematical methods,

[3] The forecast of the long-term socio-economic development of the Russian Federation for the period up to 2030 (developed by the Ministry of Economic Development of the Russian Federation in accordance with Decree of the President of the Russian Federation dated May 7, 2012 No. 596 “On Long-term State Economic Policy”). GARANT: legal reference system.

[4] The forecast of socio-economic development of the Russian Federation for the period up to 2036 (approved at a meeting of the Government of the Russian Federation on November 22, 2018). GARANT: legal reference system.

[5] On the approval of the Climate Doctrine of the Russian Federation: Decree of the President of the Russian Federation dated October 26, 2023 No. 812. GARANT: legal reference system.

[6] On the Strategy of Scientific and Technological Development of the Russian Federation: Decree of the President of the Russian Federation dated February 28, 2024 No. 145. GARANT: legal reference system.

including correlation and regression analysis. The results obtained and the recommendations developed are aimed at creating a market for carbon units in Russia and increasing its efficiency in comparison with existing practices. They will also be used in further fundamental research and practical developments in the field of greenhouse gas emissions trading.

IDENTIFICATION OF THE MAIN DETERMINANTS OF THE CARBON UNIT PRICE

The European Emissions Trading System (ETS) has become the first full-fledged and, as a result, one of the most developed carbon trading systems in the world. In the period from 2005 to 2012, most of the EU ETS quotas were issued free of charge, so the price for them (EUA) fell to zero by 2007, and companies managed to accumulate a large reserve of emission permits, which they still use [13]. By 2013, the volume of free quotas in the European market had almost reached 2 billion (Fig. 1), having exceeded the annual volume of greenhouse gas emissions, after which more than half of the emission quotas began to be distributed through auctions.

Industrial recovery after the global economic crisis of 2008–2013 and rising natural gas prices from the 4th quarter of 2021 led to an increase in greenhouse gas emissions to 32.94 Euros per ton of CO_2 in 2020–2021.[7] Ambitious EU climate goals, confirmed at the 26th UN Climate Change Conference, led to the end of In 2022, the price remained at a high level (more than 80 Euros per ton of CO_2), but a downward trend began in 2023, which reached its minimum of 54.2 Euros per ton of CO_2 in February 2024 due to falling demand for electricity and increased production of renewable energy.

The trading system, as a market-based tool for reducing greenhouse gas emissions, operates on the principle of "cap and trade". It involves the establishment of an upper limit for total emissions in one or more sectors of economic activity, and the issuance of permits for each unit of emission, either free of charge or through purchase from the government and companies participating in the system. The New Zealand Emissions Trading Scheme (NZ ETS), introduced in 2008, is considered one of the most successful examples of such schemes. It does not impose limits on emissions, making it unique. The scheme covers a wide range of economic activities, including liquid fuels, forestry, energy production, industry, waste, and synthetic gases. However, fees for CO_2 emissions from agricultural enterprises, which account for almost half of total greenhouse gas emissions, are not yet in place. These fees are expected to begin in the fourth quarter of 2025. According to the new legislation, starting from 2025, agriculture will be required to pay for carbon dioxide (GHG) emissions in order to support the transition of farmers to new technologies. This is in addition to other measures aimed at reducing climate change. From the first quarter of 2024, farmers in New Zealand began tracking their emissions in order to recognize the carbon uptake from crops grown on their farms. This information can then be used as compensation for the emissions.[8] The current New Zealand emissions trading system requires enterprises to measure, report, and donate emission units (NZUs) to the government for every ton of greenhouse gas emitted. Companies can then pass these costs onto consumers of their final products. The supply of emission quotas on the market is unlimited, either from the government or other sources. They can be obtained through purchase from the government or on the

[7] How carbon markets work: a report. SBS Consulting. URL: https://www.sbs-consulting.ru/upload/iblock/989/9891cb9879c806dd3cec1a3577806916.pdf (accessed on 18.10.2024).

[8] International approaches to carbon pricing. Department of Multilateral Economic Cooperation of the Ministry of Economic Development of Russia. Ministry of Economic Development of the Russian Federation. p. 22. URL: https://www.economy.gov.ru/material/file/c13068c695b51eb60ba8cb2006dd81c1/13777562.pdf (accessed on 27.10.2024).

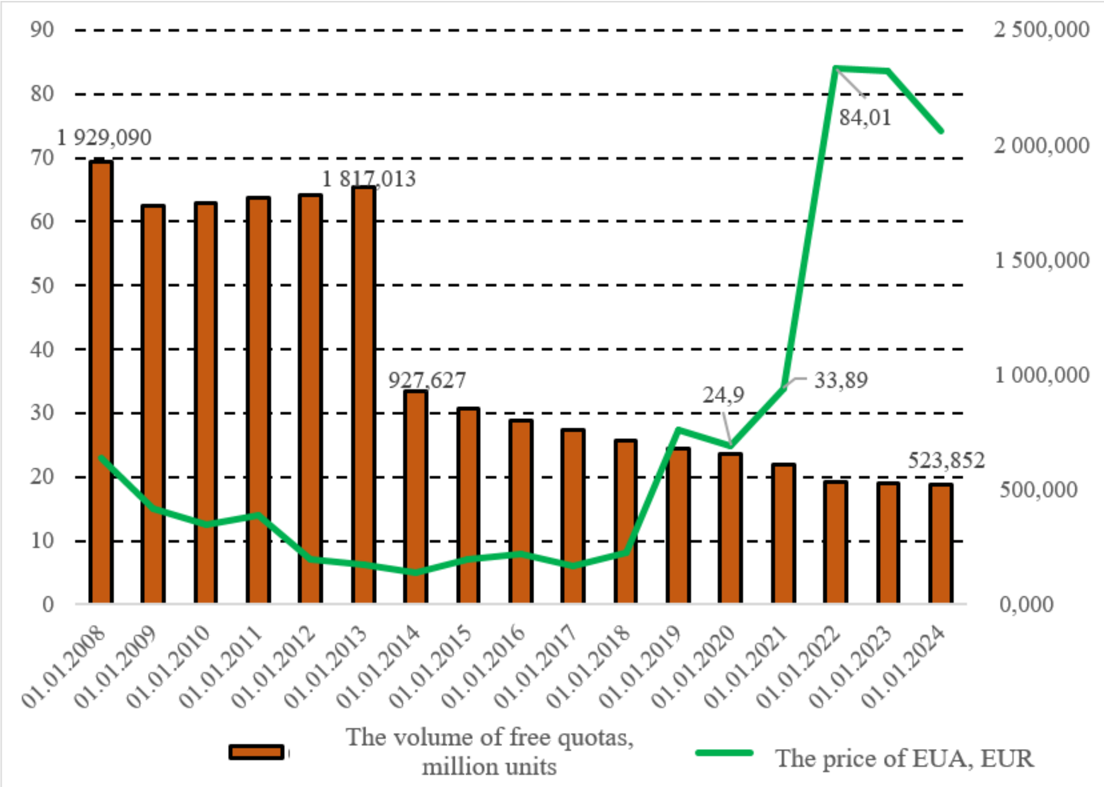

Fig. 1. **The Dynamics of Change in the EUA Price and the Volume of Free Carbon Credits in the European Market from 2008 to 2024**

Source: Compiled by the authors on the basis of research and sources data: EU carbon emission permits: European Environment Agency. URL: https://www.eea.europa.eu/en/analysis/maps-and-charts/emissions-trading-viewer-1-dashboards; https://tradingeconomics.com/commodity/carbon (accessed on 15.10.2024).

secondary market for relocation purposes, through free distribution, or as a loan, thanks to the inclusion of evidence-based forms of carbon sequestration in New Zealand's emissions trading system.

It is worth noting that the New Zealand Emissions Trading Scheme (NZ ETS) is still under development, and a single consistent approach for its development has not yet been fully determined. This is due to the fact that for a long time, the New Zealand scheme was the only one in the Asia-Pacific region, and the next quota-trading system in the region, the Korean Emissions Trading System (KETS), was not launched until 2015, seven years after the introduction of the NZ ETS. By 2017, trade volumes within the KETS had increased from 1.2 million tons per year to 5.1 million tons, comparable to the maximum emissions of the Korean system. The price of emission allowances at the Korean system ranged from US$ 8.69 per ton CO_2 equivalent in September 2015 to $ 34.79 in December 2019, with more than 14 million allowances traded during this time. Until 2017, all companies participating in the program received free quotas. Since 2018, however, a system of auctions for greenhouse gas emissions was introduced.

Thus, for all three ETSs, there is a general trend towards greenhouse gas emission prices, which, along with quota limits, act as levers used to influence economic sectors in order to support or hinder their development through quota allocation. Considering the possibility of shifting the purchase price of quotas to consumers, the issue of fairness in using this tool depends on the ultimate goal of implementing ETSs. If reducing emissions is not the primary goal, but rather a secondary benefit, and priority is placed on accumulating

Table 1

Main Determinants of Setting and Changing the Price of a Carbon Unit

Determinants	Description
Government policy	The government regulates the price by changing the number of carbon allowances and offsets, introducing a carbon reserve, pricing mechanism and allowing the borrowing of quotas. By such actions, the government influences supply, thereby changing prices. The price of emissions in the international carbon market is determined by supply and demand
Total emission quotas	The market price of emission allowances reflects their excess or deficit. Before 2007, this was obvious in the EU quota trading system: the more quotas there are on the market, the lower their price. Conversely, a shortage of quotas leads to an increase in their cost. The same logic applies to the volume of quotas distributed for free
The number of free quotas distributed	Increasing the share of free quotas can reduce the total number of emission quotas available for sale on the market, while maintaining the same total volume of quotas. In a scenario with a large number of free quotas, the amount of paid quotas will be significantly less. With a stable supply–demand ratio, this will lead to higher prices for emissions
The number of industries affected by the ETS	The more industries involved in the ETS, the lower the price of a carbon unit will be. The existence of industries with lower GHG emissions, or with greater opportunities to reduce them, brings quota suppliers to the market — and the supply of available quotas is growing. As a result, prices for emission quotas are reduced, and the accumulated quotas can be used in the future
Energy prices (crude oil, gas, coal, gasoline)	The relative price of energy can directly affect firms' demand for CO2emissions. Changes in energy prices may force companies to change the structure of their energy consumption
Shocks causing recessions (COVID-19 pandemic, global financial crises, etc.)	The reduction in production in many industries causes a general economic downturn and a decrease in demand in the carbon units' market, which leads to lower prices for emission quotas
Economic activity	An increase in economic activity implies an increase in demand for fossil fuels and, as a result, for the right to emit GHGs. Economic activity has always been one of the main drivers of fluctuations in carbon prices. However, the importance of this factor decreases as alternative forms of energy are introduced into the production process

Source: compiled by the authors based on data from [5–8, 17, 18].

funds for public goods or compensating for societal losses, then, since each potential consumer (individuals and legal entities) benefits from the good and creates demand for it, it is fair to contribute money to the budget. If there is a lack of funds, the state budget may need to limit the implementation of important government programs, including those related to decarbonization. At the same time, if the financial aspect of these payments is a priority, then it does not matter who makes the payments as long as they are directed towards achieving the final goal, provided that they are targeted [16, p. 226–227].

In this regard, government policies, the amount of free quotas, and the number and proportion of total emissions from industries involved in the Clean Development Mechanism (CDM) can be considered the main factors determining the setting and change of prices in the carbon market. This list of factors affecting the pricing of carbon units is not comprehensive and can be expanded (*Table 1*).

For example, A. Maydybura and B. Andrew (2018) developed a model to study the relationship between the price of carbon and several factors, including prices for coal, oil, and natural gas, as well as GDP growth and ambient temperature. To correct for positive skewness and obtain a more normal distribution, they logarithmized all variables in the model (except for GDP growth) to arrive at the following equation:

$$ln\left(P_{Carbon}\right)=ln(P_{Oil})+ln\left(P_{Coal}\right)+ \\ +ln(P_{Gas})+ln\left(T\right)+\Delta GDP\%, \quad (1)$$

where P_{Carbon} — the price of coal; P_{Coal} — the price of oil; P_{Oil} — the price of gas; P_{Gas} — цена газа; T — the average temperature in the region; $\Delta GDP\%$ — the percentage of GDP growth.

In order to increase accuracy and verify the impact of free carbon quotas on carbon prices, we will modify this model. We will remove the average temperature from the model due to its high variability. Instead of using natural logarithms, which can create false connections in time series data, we will use percentage growth rates for variables. This will help eliminate non-stationary observations. The futures prices of Brent crude oil, Natural Gas (NG) and Australian thermal coal have been selected as representative prices for oil, gas, and coal.

The large volume of free quotas distributed in the early stages of the quota trading system may lead companies to minimize their quota purchases in the initial trading periods. This can reduce real costs and provide an incentive to reduce emissions. In other words, an overestimation of the quota allocation level can lead to a potential reduction in prices and their retention at a lower level. This is a common situation in many national trading systems, so including free quotas in the model seems reasonable and logical.

$$D\left(P_{Carbon}\right)=D\left(P_{Oil}\right)+D\left(P_{Coal}\right)+ \\ +D\left(P_{Gas}\right)+D\left(T\right)+\Delta GDP\%, \quad (2)$$

where D denotes the difference between observations.

The results of multiple regression models for assessing the impact of the determinants included in formula 2 on quota prices and evaluating the quality of regression models (R^2 and *F*-value) are presented in *Table 2*.

Judging by the values of R^2 and the *F*-value, the obtained multifactorial regression models are significant, but they are characterized by weak predictive power. However, coefficients for variables can provide additional information about dependencies and changes. For New Zealand and South Korea, there is a negative relationship between the number of free-of-charge quotas and the price of carbon quotas. On the other hand, this relationship is not observed for the EU, although excessive distribution levels during the first stage of the development of the ETS led to a significant underestimation of prices.

When assessing the regression, it is also important to note that after a sharp almost

Table 2

Estimation of Multivariate Regression Models for EUA, KETS, NZUs Prices

Region	Const	OIL	COAL	GAS	GDP	ALLOC	R^2	F-value
EU	7.09	−0.22	0.10	6.91	−2.33	0.019	0.54	2.33
New Zealand	5.80	0.00	0.04	3.59	185.23	−4.02	0.73	3.84
North Korea	0.01	1.34	−0.18	−0.02	7.87	−6.87	0.61	0.64

Source: Compiled by the authors on the basis of data: EU Emissions Trading System (ETS) data viewer: European Environment Agency; Brent oil futures. Analytical platform Investing; Natural gas futures. Analytical platform Investing; Coal (Australian). IndexMundi: world statistical database; NZU price data. Hosting of financial projects; Korea Emissions Trading Scheme. International Carbon Action Partnership (ICAP). URL: https://www.eea.europa.eu/en/analysis/maps-and-charts/emissions-trading-viewer-1-dashboards; https://ru.investing.com/commodities/brent-oil; https://www.investing.com/commodities/natural-gas; https://www.indexmundi.com/commodities/?commodity=coal-australian&months=120; https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv; https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-47.pdf https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv; https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-47.pdf (accessed on 22.10.2024).

twofold reduction in emission quotas in 2014 within the framework of the EU ETS, a comparable price increase followed only 4 years later — in 2018 (*Fig. 1*). This makes the relationship between variables less obvious. Thus, any government measures (including the number of quotas allocated) may have a time-delayed effect. As noted earlier, companies in the EU were able to accumulate a large surplus of emission permits in 2005–2008. It follows from this that reducing the allocation of quotas directly affects their surplus, which decreases over time. Companies turn to secondary markets to purchase quotas during a period of declining value. Over time, the surplus is depleted, and prices rise. The trend towards reducing free permits supports further price increases.

Another reason for the low quality of the models and, in particular, a number of coefficients is missing, unidentified variables that influence the change in prices of carbon units. Unlike the Australian ETS, there is no fixed price period in KETS, and it is relatively difficult for market participants to inform about the price in advance. Therefore, the Korean ETS Law provides for various cost containment measures. The list of market stabilization measures includes monitoring the formation of reserves, setting maximum and minimum retention levels, limiting borrowing between compliance periods, regulating offsetting loans, and setting a price ceiling or lower limit. It is expected that the quota reserve in KETS will become a crucial factor in stabilizing the domestic carbon market by providing additional quotas (up to 25% of the total reserve) in case of rapid price changes.

The mechanism of cost containment measures and the establishment of a minimum price (reserve auction price) operating in the New Zealand market is as follows: if a pre-set starting price is reached at the auction (updated annually), then a certain number of discounts are additionally allocated for the sale of quotas. Other parameters of the auction offer may also change. The minimum price is formed from the reserve price and the minimum bid accepted at the auction. In addition to the minimum price set at the auction, the government has introduced a confidential reserve price. It is set based on secondary market prices and uses a confidential methodology to determine the reserve price below which quotas cannot be sold. If it is set higher than the fixed reserve price of the auction, it becomes the new minimum value of the reserve price for this auction.[9]

Thus, there is reason to believe that the influence of the state on the price of a carbon unit cannot be described by a single variable, but by a number of dependent variables characterizing the bidding policy and the general rules of operation of a particular ETS. Based on the available information for analysis, we can assume that these factors include the number of participants in the market, the number of free-of-charge units, the auction reserve price (ARP), and the proportion of free-of-charge quotas compared to paid quotas.

Formula 3 represents a multifactor regression model that takes into account the complex interaction between these factors and government policies to predict the price of carbon units. This model can help us understand the impact of different policies and make informed decisions about how to best manage the carbon market:

$$D(P_{carbon}) = D(PART) + D(ALLOC) + \\ + D(ARP) + D(SHARE) + D_{2020}, \quad (3)$$

where *PART* is the number of participants in the carbon quota trading system;

ALLOC — the number of quotas distributed for free;

ARP — reserve auction price;

SHARE — the share of free-of-charge quotas in the total number of quotas to pay off the carbon footprint of enterprises;

D_{2020} –– a dummy variable (before 2020–0, after — 1).

The specification of this model uses the first variable difference to avoid false regression and time series instability. A temporary dummy variable can have a significant impact on the model, because since June 22, 2020, the state has been provided with a wide range of compliance tools that help manage and maintain the integrity of the JTC and ensure that the ETS achieves its goal[10] (*Table 3*).

The results of the model evaluation (*Table 3*) indicate that the model has an *F*-value of 6.00 (with a *p*-value around 0.018) and an R^2 of 0.81. In addition to the satisfactory performance of the model itself, the coefficients for variables also show significance (*Const, PART*, D_{2020} — at 5%, and the rest — 10%).

The government impact model could potentially have more variables. In order to avoid multicollinearity and wide confidence intervals, methods can potentially be used to reduce the dimensionality of the data (for example, the PCA principal component method).

MODELING THE VOLATILITY OF THE CARBON UNIT PRICE

Based on the possibility of determining the determinants affecting prices within the framework of the ETS, it is possible to determine the causes and consequences of price changes for greenhouse gas emission quotas in the market.

Descriptive statistics on the daily variability of the price of carbon units in the national markets of the European Union, South Korea

[9] New Zealand: Emissions trading system. International Carbon Action Partnership. URL: https://icapcarbonaction.com/en/ets/new-zealand-emissions-trading-scheme (accessed on 25.10.2024).

[10] Participation in the Emissions Trading System (ETS). EPA. URL: https://www.epa.govt.nz/industry-areas/emissions-trading-scheme/participating-in-the-ets / (accessed on 23.10.2024).

Table 3

Estimation of 'Public Policy'multivariate Regression Models for the Price of NZUs

Indicator	Coefficient	Standard Error	*t*-statistics	*p*-value
Const	13.61	3.63	3.74	0.0072
PART	−0.01	0.002	−4.26	0.0037
ALLOC	−5.67	2.70	−2.10	0.0742
ARP	−0.48	0.24	−1.97	0.0893
SHARE	77.80	38.83	2.00	0.0852
D 2020	16.81	6.54	2.57	0.0370

Source: Compiled by the authors on the basis of data: NZU price data. Hosting of financial projects; Participation in the Emissions Trading System (ETS). EPA; Decisions on allocation of allowances under the Emissions Trading Scheme. Ministry of Environment of New Zealand. URL: https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv; https://www.epa.govt.nz/industry-areas/emissions-trading-scheme/participating-in-the-ets/; https://www.epa.govt.nz/industry-areas/emissions-trading-scheme/industrial-allocations/decisions/ (accessed on 10.10.2024).

Table 4

Descriptive Statistics of EUA, KETS, NZUs Yields

Indicator	EUA	KETS	NZUs
Observations	4311	2339	1461
Average	0.07%	0.03%	−0.09%
Minimum	−35.26%	−13.90%	−29.40%
First quartile	−1.41%	−0.57%	−0.62%
Median	0.04%	0.06%	−0.04%
Third quartile	1.61%	0.01%	0.48%
Maximum	27,19%	12,03%	22.08%
Standard deviation	2.99%	2.61%	2.02%
Start of the period	02.01.2008	12.01.2015	22.01.2018
End of the period	02.08.2024	12.07.2024	18.10.2024

Source: Compiled by the authors on the basis of sources data: EU carbon emission permits; NZU price data. Hosting of financial projects; Allowance Price Explorer. International Carbon Action Partnership. URL: https://tradingeconomics.com/commodity/carbon; https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv; https://icapcarbonaction.com/en/ets-prices (accessed on 21.10.2024).

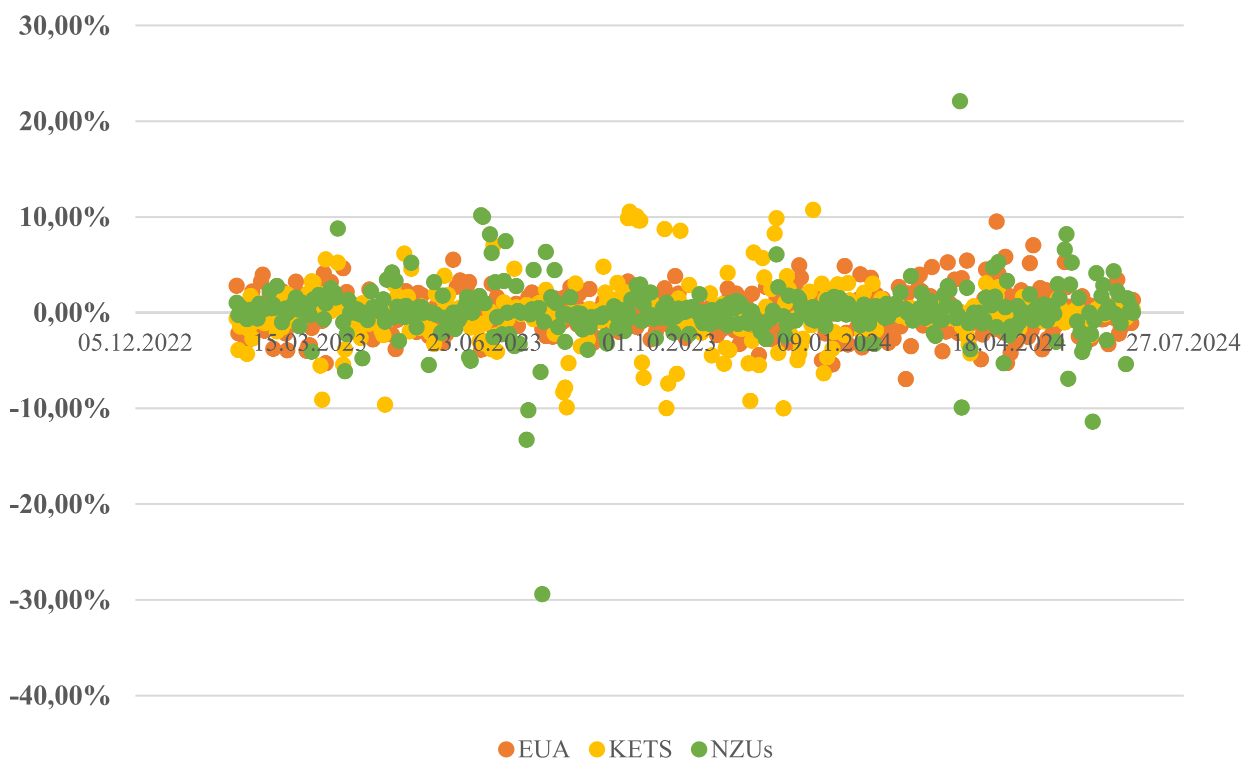

Fig. 2. **Daily Percentage Deviation of Carbon Unit Prices in the European, South Korean and New Zealand Markets from December 2022 to July 2024**

Source: Compiled by the authors on the basis of sources data: EU carbon emission permits; NZU price data. Hosting of financial projects; Allowance Price Explorer. International Carbon Action Partnership. URL: https://tradingeconomics.com/commodity/carbon; https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv; https://icapcarbonaction.com/en/ets-prices (accessed on 21.10.2024).

and New Zealand (*Table 4*) demonstrates that the average and median values in all systems tend to zero.

European prices show the greatest variability in the widest range: they ranged from minus 35.26% to 27.19%, and the standard deviation was almost 3%, which is significantly higher than the prices of the South Korean market (by 14.56%) and the prices of the New Zealand market (by 48.02%). The Korean and New Zealand systems have a much shorter history of existence. In addition, there is less volatility in the range of variability and in the standard deviation indicator for these ETSs (*Fig. 2*).

In the case of New Zealand's carbon unit prices, the average daily change σ ≈ is approximately 2%, but the range over the period is 51.48%. By comparison, the South Korean market had a range of 25.93% over the same period, which is almost half as much.

The idea of increasing the price of emissions permits as a significant incentive for reducing greenhouse gas emissions is currently a given. However, as carbon prices rise, so do the operating costs for companies, which can create barriers to the sustainable growth of individual businesses and entire industries [19, p. 193]. The market mechanism causes fluctuations in quota prices, which affect both economic decision-making and the pricing of financial instruments used in the emissions trading system. Volatility in prices is a crucial factor in derivative pricing, which companies can use to hedge risks.

It can be seen from the graphs (*Fig. 3*) that in the European market, during

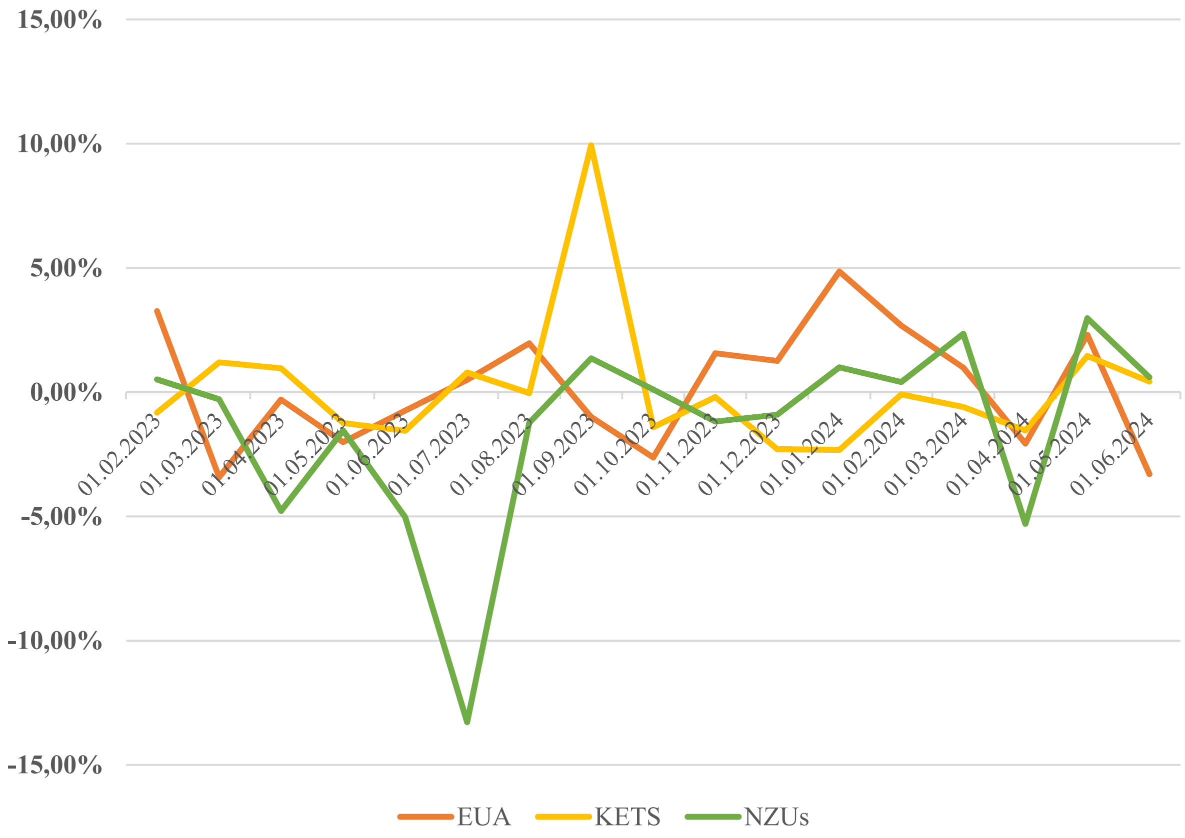

Fig. 3. **Carbon Unit Price Volatility in the European, South Korean and New Zealand Markets from December 2022 to July 2024**

Source: Compiled by the authors on the basis of sources data: EU carbon emission permits; NZU price data. Hosting of financial projects; Allowance Price Explorer. International Carbon Action Partnership. URL: https://tradingeconomics.com/commodity/carbon; https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv; https://icapcarbonaction.com/en/ets-prices (accessed on 21.10.2024).

the first half of the period, prices were characterized by lower volatility. However, there were observations with the highest intensity of daily changes concentrated on 19.04.2024. This corresponds to the typical behavior modeled using ARCH and GARCH models. According to their logic, days with low volatility are likely to be followed by days with similar volatility parameters. Interestingly, the prices in the Korean and New Zealand markets had a lower intensity and amplitude of variability. Before 12.01.2024, KETS had greater volatility than after that date. Meanwhile, NZUS did not show as much volatility as in previous cases. Nevertheless, clusters of volatility can be identified in all three markets. This indicates the possibility of using ARCH or GARCH models to model the conditional variance of carbon prices.

A wide sample of observations should be used to build combined time series models. The study used data on the price change for greenhouse gas emission quotas in the European market from 2008 to 2024, from 2015 to 2024 in the South Korean market, and from 2018 to 2024 in the New Zealand market. This resulted in 4,999, 2,339, and 1,461 observations, respectively, which was enough to create ARCH and GARCH models. According to these models, conditional volatility (the variance of a random variable considering the values of one or more other variables) can be expressed as [20]:

Table 5

Estimation of ARCH and GARCH Models with Different Specification for EUA

Indicator	α_0	α_1	α_2	β_1	β_2	AIC
ARCH (1)	0.00065*** (11.84)	0.29066*** (11.55)	–	–	–	−18 398
ARCH (2)	0.00047*** (17.38)	0.26761*** (5.91)	0.24911*** (4.96)	–	–	−18 696
GARCH (1,1)	0.00001*** (2.73)	0.10388*** (6.24)	–	0.88762*** (49.22)	–	−19 227
GARCH (2,1)	0.00001** (2.33)	0.096*** (4.38)	0.01222 (0.34)	0.88299*** (32.46)	–	−19 225
GARCH (2,2)	0.00002** (2.49)	0.09531*** (4.88)	0.07875 (1.59)	0.25965 (0.53)	0.552 (1.25)	−19 224

Source: Compiled by the authors on the basis of data: EU carbon emission permits. URL: https://tradingeconomics.com/commodity/carbon (accessed on 14.10.2024).

Note: (z-values are shown in parentheses); *significance level by 10%, **significance level by 5%, ***significance level by 1%.

Table 6

Estimation of ARCH and GARCH Models with Different Specification for KETS

Indicator	α_0	α_1	α_2	β_1	β_2	AIC
ARCH (1)	0.00037*** (9.45)	0.60727*** (6.08)	–	–	–	−10 351
ARCH (2)	0.00027*** (7.21)	0.43845*** (5.77)	0.34122*** (3.28)	–	–	−10 570
GARCH (1,1)	0.00002** (1.93)	0.22609*** (4.15)	–	0.78849*** (15.83)	–	−10 873
GARCH (2,1)	0.00001** (2.25)	0.44387*** (3.78)	−0.27754** (−2.46)	0.84746*** (24.23)	–	−10 913
GARCH (2,2)	0.00001 (1.49)	0.43737*** (3.74)	−0.29519** (−2.38)	0.95314*** (2.72)	−0.0839 (−0.3034)	−10 912

Source: Compiled by the authors on the basis of data: Allowance Price Explorer. International Carbon Action Partnership. URL: https://icapcarbonaction.com/en/ets-prices (accessed on 21.10.2024).

Note: (z–values are shown in parentheses); * significance level by 10%; ** significance level by 5%; *** significance level by 1%.

Table 7

Estimation of ARCH and GARCH Models with Different Specification for NZUs

Indicator	α_0	α_1	α_2	β_1	β_2	AIC
ARCH (1)	0,00025*** (4,28)	0,51256*** (2,63)	–	–	–	–7583,7
ARCH (2)	0,00022*** (3,28)	0,46330*** (2,65)	0,14978*** (1,14)	–	–	–7624,6
GARCH (1,1)	0,00004** (1,99)	0,20097*** (3,02)	–	0,73047*** (10,81)	–	–7689,6
GARCH (2,1)	0,00004** (2,50)	0,19244* (1,66)	1,05E-12 (0,00)	0,73908*** (15,2)	–	–7687,5
GARCH (2,2)	–	–	–	–	–	–

Source: Compiled by the authors on the basis of data: NZU price data. Hosting of financial projects. URL: https://github.com/theecanmole/nzu/blob/master/nzu-edited-raw-prices-data.csv (accessed on 23.10.2024).

Note: (z–values are shown in parentheses); * significance level by 10%; ** significance level by 5%; *** significance level by 1%..

$$ARCH(p): \sigma_n^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i u_{n-i}^2, \quad (4)$$

$$GARCH(p,q): \sigma_n^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i u_{n-i}^2 + \sum_{i=1}^{q} \beta_i \sigma_{n-i}^2, \quad (5)$$

where σ_n is the conditional standard deviation in the n period; σ_{n-i} is the conditional standard deviation in the *n-i* period; u_{n-i} is the profitability indicator in the *n-i* period; α, β are the estimated parameters.

The constant parameter $\alpha_0 > 0$, since volatility theoretically cannot be negative. In addition, there are certain restrictions on $\alpha_1 > 0$, $\beta_1 > 0$ and $\alpha_1 + \beta_1 < 1$ [21, c. 61–62]. The criterion of agreement is the Akaike information criterion, that is, the smaller the AIC, the better the model.

From the presented results (*Table 5*) it is possible to judge the significance of the coefficients of models with different parameters, which indicates the existence of volatility clusters due to the lag dependence of the conditional variance. Moreover, for the GARCH model of the South Korean market (*Table 6*), despite their statistical significance, the necessary inequalities are not fulfilled, which is why it is worth paying attention to ARCH (2). For the European market, judging by the Akaike criterion, the best model specification is GARCH (1, 1), since AIC is the smallest in this case. Moreover, all coefficients are significant at the 1% significance level, $\alpha_1 \approx 10\%$, $\beta_1 \approx 90\%$, which indicates the consistency of the model.

For the indicators of the New Zealand greenhouse gas emissions quota market (*Table 7*) GARCH (1, 1) also shows good results, combined with the ease of interpretation, the choice falls on GARCH (1, 1).

The evaluation of the models led to the conclusion that there are clusters of volatility in the carbon unit markets.

A distinctive feature of the models used is that they are based on the assumption of volatility variability. Over certain time intervals, the volatility of a particular indicator may be relatively weak, or relatively strong in other periods, which allows you to track changes in the values of variability over time.

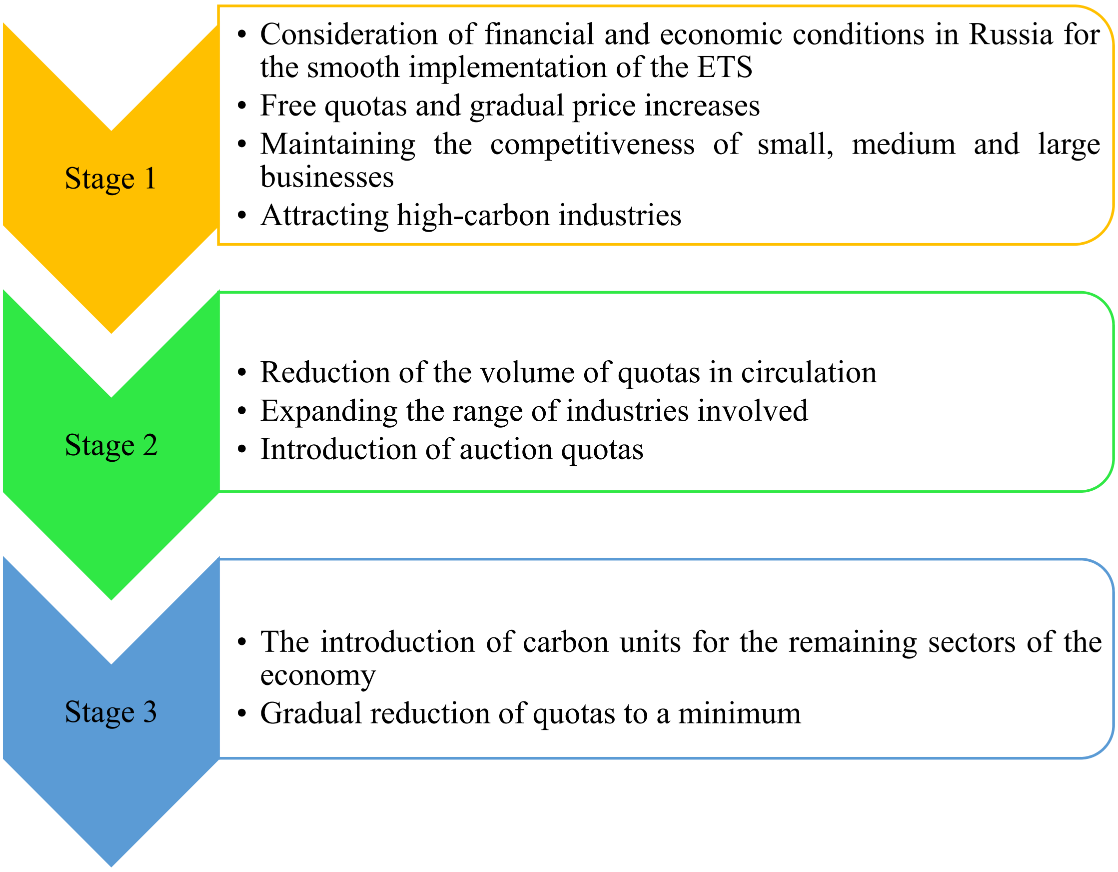

Fig. 4. **Stages of Carbon Unit Price Formation and Their Characteristics**

Source: Compiled by the authors.

Let's present the GARCH (1,1) specification:

$$GARCH(1,1): \sigma_n^2 = \gamma V_L + \alpha u_{n-1}^2 + \beta \sigma_{n-1}^2, \quad (6)$$

where *VL* is the long–term variance; γ, α, β are the estimated parameters, with γ + α + β = 1.

In practice, the variance values tend to be average. The GARCH model (1, 1) includes this effect, which determines the attractiveness of models of this type. The long-term variance can be calculated as a fraction $\frac{\alpha_0}{1-\alpha-\beta}$. In this study, the long-term average daily variance of the European carbon quota market, estimated using the GARCH model (1, 1), was 0.001383. It corresponds to a standard deviation of 0.037188, or 3.7188% per day. In the case of New Zealand, these figures are 0.00639% and 2.05075%. Such outbreaks of carbon market volatility can be caused by international climate and energy conferences, abnormal price changes for traditional energy sources (especially oil), and public health emergencies worldwide. A number of dramatic events affecting the energy sector of countries are causing certain shocks in the greenhouse gas emissions trading market. Moreover, the impact of negative news on the volatility of the carbon market is stronger than positive news [22].

RECOMMENDATIONS FOR THE CREATION OF A RUSSIAN NATIONAL QUOTA TRADING SYSTEM BASED ON FOREIGN EXPERIENCE

An analysis of foreign experience in launching quota trading systems and price determinants allows us to develop recommendations on the formation and regulation of quota prices (*Fig. 4*). This, in turn, will reduce greenhouse gas emissions in Russia.

At the initial stage, it is necessary to analyze the specifics of the Russian manufacturing sector and take into account the current economic conditions for a smoother implementation of restrictions. This will help to avoid financial instability of companies. To prevent a sharp increase in production costs of enterprises, free quotas should be provided at the initial stage of the program implementation. In the future, it is advisable to maintain a moderate level of prices for carbon units.

The degree of influence of pricing policy on enterprises of various sizes should be taken into account: the impact of additional costs on medium and small businesses will differ significantly from the effect of introducing carbon units for large businesses. In this regard, it is necessary to carefully calculate the amount of free quotas allocated for medium and small businesses to support their competitiveness.

According to Rosstat,[11] about 78% of greenhouse gas emissions in Russia in 2020 were related to the activities of the energy sector, which means that this sector needs to be included in the ETS at the initial stage in order to achieve carbon neutrality.

The intermediate stage includes the expansion of the industries involved and the tightening of conditions by reducing the number of allocated quotas, which will lead to an increase in their cost.

It is important to develop a strategy to contain the excess volume of quotas in the general access, which may lead to their devaluation [23]. This strategy may include:

- Mandatory use of existing quotas;
- A reservation system for the temporary withdrawal of quotas by the State;
- Limit on the total number of quotas;
- Auction trading.

Emphasizing the importance of adapting the financial system to climate change, it can be said that various aspects of the transition to a more sustainable economy demonstrate the need to introduce specific tools for financing and implementing "green" projects both in policy decisions and in practical financing mechanisms, which is confirmed by previous research conducted both for Russia and for other countries [24, 25].

The use of auction trading in the ETS system can be considered as a tool to compensate and adjust the impact on the free market, ensuring a more sustainable and balanced development.

The final stage involves the full-scale use of the ETS for the entire economy, as well as for making changes to the system based on the data received and feedback from participants. This will improve the efficiency of the system and achieve the goals of reducing greenhouse gas emissions in Russia.

CONCLUSIONS

During the study, the following results were obtained:

- The selection of best practices and methods for regulating emission volumes implemented by foreign countries, using the example of European, New Zealand, and Korean ETSs, with the most effective and highly developed models of emission trading.
- Using ARCH and GARCH models, as well as correlation and regression analysis, we investigated the relationship between greenhouse gas emissions price dynamics and the overall effectiveness of existing ETSs.
- We identified key determinants of carbon quota price volatility and the factors contributing to its growth, in order to understand the mechanisms of price formation. These factors include the price of crude oil, gas, and coal; shocks causing recessions; total carbon emission quotas; the amount of free quotas; the number of industries covered by ETS; economic activity; and public policy.
- We proposed steps for pricing carbon emissions to reduce greenhouse gas emissions in Russia.

[11] Environmental protection in Russia. 2022: Statistical collection of Rosstat. Moscow: Rosstat; 2022. 115 p.

In conclusion, it should be noted that, since in most countries of the world, the formation of a carbon market is part of official national and sectoral development strategies, we can expect that the development of carbon trading systems (ETSs) will continue at an increasing pace, and investment in them will also increase. Therefore, the creation of a national ETS in Russia seems inevitable.

The results of the study on the variability of carbon pricing (prices for greenhouse gas emissions in the European, South Korean, and New Zealand markets) are highly relevant for the development and implementation of a national carbon trading system (ETS) in Russia. It is believed that carbon pricing is the most significant factor influencing the attainment of carbon neutrality goals and the generation of new revenue streams for the Russian consolidated budget. Daily high volatility and sudden price fluctuations can have a detrimental impact on both individual sectors of the economy and the overall effectiveness of the ETS.

As a result of studying the carbon markets of the selected countries, we have found that there are clusters of volatility in their markets. This suggests that ARCH or GARCH models may be suitable for these markets. To avoid the formation of volatility clusters in the Russian market, we need a wide range of tools to influence carbon prices and ensure their gradual growth. Energy prices can significantly affect the pricing of carbon, and shocks in oil, gas, and coal markets can have a negative impact. Measures to stabilize prices can help level them out. It would be beneficial for Russia to implement lower and upper limits for carbon prices, provide additional quotas, and limit the number of allocations during times of unfavorable market conditions.

Many foreign ETSs have gone through several stages of development. These stages are characterized by the inclusion of an increasing number of companies in ETSs and the expansion of industry coverage. At the same time, there has been a decrease in the number of free-of-charge quotas in order to prevent the burden of payments from shifting to end users and dependent counterparts.

However, if there is an excess of quotas, measures should be taken to reduce them. This could be done by changing the auction system or other central measures. Excessively lenient policies at the initial stage of development can lead to long-term price stagnation and the formation of excess quotas.

The results of the study, which took into account global technological trends and the needs of the Russian economy and society, have made it possible to develop high-tech solutions that meet Russia's national interests. These solutions will help improve citizens' quality of life by reducing greenhouse gas emissions through the use of financial management tools such as prices for emission quotas.

The materials of the article contribute to the development of Russian science by providing a basis for further research. This research will focus on organizational and economic issues related to the functioning of the market for carbon units, including the exchange trading of carbon quotas. To solve the problem of forming and developing the Russian carbon market, significant scientific results are expected in the future. These results will provide an assessment of the effectiveness of financial measures and tools and an analysis of the challenges, threats, and opportunities that will help identify the main areas for improvement in the development of the market.

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N.R. Denisenko — literature review, data collection and analysis, creation of the text.

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