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ECONOMIC ASPECTS OF ASSESSMENT AND MARKETING OF CARBON EMISSIONS BY ENTERPRISES BASED ON THE PRINCIPLES OF SUSTAINABLE DEVELOPMENT

Purpose. To analyze the economic aspects of carbon emissions by industry and conduct a marketing assessment of the emissions trading system (ETS). To develop recommendations for the introduction of market mechanisms for regulating emissions.

Methodology. Special and general methods of scientific knowledge are used: abstract-logical analysis to identify the predominant causes of greenhouse gas (GHG) generation; statistical methods of analysis to establish the correlation of capital investments and emissions; induction and deduction to identify complex management approaches to reducing harmful emissions; mathematical – for the formalization of the factors of the ETS market and their functional dependencies, necessary for the analysis of the market.

Findings. A correlation between capital investments and emissions has been established, which confirms the long-term trend of implementing a strategic policy of enterprises to reduce emissions. The presence of sectoral differences in correlation coefficients indicated the need for differentiation of institutional support for industries as a tool for changing the export structure. The effects of Carbon Border Adjustments Mechanism (CBAM) influence on the economy of Ukraine are indicated. Recommendations for harmonizing issues regarding Ukraine's obligations to reduce emissions are proposed. Measures to reduce risks for the economy during the introduction of the national ETS are proposed.

Originality. Factors of the ETS market and their functional dependencies that are necessary for market analysis are presented mathematically. An equivalence function is proposed for the assessment of individual specific indicators of enterprises. The factors that determine prices and the amount of demand at the ETS market are stratified. Principles of this market are formulated.

Practical value. It is proposed to introduce regional emission control laboratories and agree on the recognition of their certificates by Ukraine and the EU.

Keywords: *carbon emissions, emissions trading, carbon pricing, carbon tax, sustainable development*

Introduction. The importance of reducing the emission of greenhouse gases (GHG) to ensure sustainable development is indicated in a significant number of regulatory and legal acts of Ukraine, in particular: "Strategies for low-carbon development of Ukraine until 2050", "Strategies for environmental security and adaptation to climate change for the period until 2030", the ratified Paris Agreement and other international documents. The "Environmental Security Strategy" states that "insufficient attention to the challenges caused by the consequences of climate change... will threaten the prospects for achieving the Sustainable Development Goals". This determines the nature of the task of researching the economy of carbon emissions by industry. The task is complex in view of the need for systematic implementation of the Sustainable Development Goals (SDGs), namely: to ensure the achievement of economic goals while simultaneously solving environmental problems and increasing the quality of life of citizens.

This task is complicated to a great extent due to the effects of military aggression and the economic crisis, as well as the fact that plans and deadlines for the transition to carbon-free production are adopted without due consideration of external threats and internal risks. For example, it took thirty years for the European Union to reach the current level of greenhouse gas generation, and Ukraine committed to reach this level within only ten years. This leads to improper formation of strategic and tactical plans for adaptation of industrial enterprises and branches of industry to new market conditions, implementation of environmentally friendly technological processes.

According to the current regulatory and legislative acts, Ukraine is expected to reduce GHG emissions by 2030 by no less than 35 % of the volume of emissions in 1990, which is 3 % less than previously accepted commitments. It is planned to use emissions taxes and the formation of a market for GHG emission trading quotas as tools for the implementation of this task.

Literature review. Questions related to the marketing of carbon pollution, with the study on instruments of market influence to reduce the emission of hydrocarbons by industry are in the field of view of scientists. Thus, the article by Pollitt [1] examines the prospects for the introduction of a global market for carbon emissions and ways of integrating local markets for this. This found a certain response in the article by Zhu, et al. [2], where, using the difference-in-differences (DID) method, it was studied whether the regional pilot Emission Trading Scheme (ETS) could contribute to the acceleration of "anti-carbon" innovations at enterprises. Koval, et al. [3] raise the problem of strengthening the motivation of enterprise management, indicating the mechanism of the "voluntary carbon market" and the need to transfer knowledge among its participants. This problem is extremely relevant for Ukraine, since the high cost of know-how will slow down the process of updating technologies. A study by Wang and He [4] examines China's carbon trading scheme and whether it can achieve non-commercial but environmental goals from the point of view of "efficiency and fairness", which extends the issue of quota trading to the goals of sustainable development. The article by Wang, et al. [5] indicated the need for marketing research in adjacent markets using the differential game model in accordance with the regulation of restrictions and trading quotas with the receipt of a cost distribution scenario. The work by Zhang, et al. [6] is devoted to a comparison of the theory and practical results of the implemen-

tation of China's carbon trading policy. Li, et al. [7] indicate a certain peculiarity of the impact of ETS on the implementation of environmental technologies by enterprises, namely, their territorial unevenness. The reasons for this are: the unreliability of the regulatory role of the market, the lack of formation of a multi-level market, low market liquidity and insufficient government support. This should be taken into account when forming the Ukrainian ETS. Liu and Sun [8] point out that pilot implementations of ETSs for studying their dynamic effects should only increase financing of low-carbon technological innovations over time. The presence of a rebound effect upon the introduction of the ETS for certain provinces of China was confirmed in the works of Chen, et al. [9]. This is especially important for Ukraine, because the introduction of the carbon quota market may be accompanied by a delay in reducing emissions. This was taken into account when conducting the presented research. Lv and Bai [10], in the marketing of carbon trading in China from the perspective of corporate innovation, use patent statistics for anti-carbon technologies, considering both the quantity and quality of patents selected to evaluate the effectiveness of emission reduction policies. Unfortunately, such statistics are not collected in Ukraine. Marketing research by Feng, et al. [11] indicates the need to combine different tools for adjusting emission levels. In particular, an induction mechanism and optimization of trade in green certificates at the electricity market are proposed. The positive synergistic effect of the interaction of these market instruments is claimed. The need to take into account the synergy of market instruments is considered in this work. Bertini, et al. [12] indicate the importance for industrialists of planning production taking into account the future carbon footprint of products at all stages of the life cycle. Usually, the carbon footprint is understood as the specific amount of carbon oxides generated in the production process of a product unit. They also offer a compensatory mechanism to consider the importance of the manufacturing of each product "for the firm, the climate and society". Ukrainian manufacturers will also need compensatory mechanisms. Downar, et al. [13] indicate the importance of transparency of carbon emissions obligations and take into account the impact of this factor on the financial performance of enterprises in emissions marketing research. This is taken into account in this article. Moster [14] compares three carbon emission trading systems: the EU Emissions Trading System (ETS), the Korean ETS, and the Chinese ETS, and suggests changes to the emissions pricing model. Unfortunately, according to the authors, the analytical comparative part is insufficiently substantiated. Bayer, et al. [15] indicate that a carbon market can be efficient if it is a reliable institution whose policies are declared and predictable. Companies can then reduce emissions through efficient planning of their activities, even if market quota prices are relatively high.

Ukrainian scientists also pay attention to this issue. Thus, Drachuk, et al. [16] studied the effectiveness of marketing and management measures of the metallurgical sector in order to ensure climate balance. Bereznytska and Butrym [17] researched market-based carbon pricing instruments and compared the impact of a carbon tax and the introduction of GHG emissions trading on the market. Bilyk, et al. [18] studied the influence of environmental responsibility on the implementation of the principles of sustainable development and the peculiarities of the implementation of this global trend in Ukraine.

Purpose of the article. To analyze the state of the economy of carbon emissions by industry and conduct a marketing assessment of the emissions trading system (ETS). To develop recommendations for the introduction of market mechanisms for regulating emissions.

Methods. The research was carried out using general and special methods of cognition: the method of abstract logical analysis made it possible to establish the predominant causes of GHG generation in industry; the method of deduction and induction allowed establishing the differentiated impact of these causes of GHG generation for different industries; the method of statistical analysis allowed revealing a significant difference in capital investments and volumes and types of greenhouse gas emissions by types of economic activity of enterprises. The use of mathematical research methods made it possible to formalize the assessment of the level of significance of the carbon footprint; to form a representation of the price (or amount of demand) for carbon certificates from influencing factors; to propose an equivalence function to compare the importance of allocating free GHG emission permits to enterprises or the need to implement compensatory measures, etc. The methods of generalization and logical abstraction made it possible to conduct an analysis of export opportunities and changes in the domestic market of Ukraine by industry during the introduction of cross-border carbon regulation, its impact on the country's economy, and to generate conclusions.

Results. Using methods of analytical research, it was established that nowadays the predominant causes of GHG generation in industry are the burning of hydrocarbons (the main source of GHG is coal – 94.2 %) and the thermal processing of limestone. This has a differentiated meaning for different industries and determines their different planning of capital expenditures to reduce GHG emissions. Scientists discuss the level of awareness of the management of Ukrainian enterprises as for the need for capital expenditures to reduce GHG emissions [17, 18]. According to the analytical processing of data of the State Statistics Service [19], the formation of integrated arrays of data on emissions of all carbon oxides and all nitrogen oxides, it was established that capital investments in industry in recent years are correlated with the volume of emissions of harmful gases. In order to avoid changes in the exchange rate of the national currency over the years to impact the results of the analysis, capital investments in industry were attributed to GDP in constant prices of 2017. This did not lead to a change in the ratio of correlation coefficients by industry, but increased the value of correlation coefficients relative to the absolute values of capital expenditures by 1–2 %.

The values of the correlation coefficients found by applying statistical methods of data analysis indicate a significant difference by types of economic activity in the inverse dependence of capital investments and the volume of greenhouse gas emissions. Firstly, the establishment of the very existence of such dependence confirms the fact of the implementation of the strategic policy of Ukrainian enterprises regarding the financing of technologies to reduce the negative impact on the environment, which is evidence of the awareness of the management of enterprises of the inevitability of modernization to ensure carbon-free development. Secondly, such a correlation also indicates the establishment of a long-term trend in the management of industrial enterprises aimed at introducing technologies to reduce GHG emissions. Thirdly, the significant difference in the correlation coefficients of capital investments and GHG emission volumes by types of economic activity indicates uneven awareness of the need to reduce emissions by the management of enterprises in various industries. Evidence of this, for example, is a comparison of correlation coefficients for types of activities, the technologies of which are, to a large extent, similar: according to position 6 of Table 1 – correlation coefficient with the volume of emissions of carbon oxides – 0.64597, and according to position 7 – correlation coefficient – 0.43469. This should have a negative impact on the achievement of SDG No. 9 "Industry, Innovation and Infrastructure" and No. 13 "Climate Change Mitigation".

Also, using the methods of induction and deduction, it was established that for the most harmful industries, in view of the above-mentioned predominant causes of GHG generation, the focus of management is on reducing not only emissions of carbon oxides (in their entirety), but also, first of all, emissions of nitrogen oxides (correlation coefficients with capital investments are higher for them). This shows that the management is aware of the need for a comprehensive solution to the problem of environmental pollution.

Table 1

Correlation coefficients of relative (to GDP indicators in 2017 prices) capital investments by types of economic activity and volumes of emissions of carbon and nitrogen oxides

No.	By industry branch	By carbon oxides (CO_x)	By nitrogen oxides (NO_x)
1	Industry as a whole	–0.62282	–0.46620
2	Manufacture of coke, and refined petroleum products	–0.76343	–0.80753
3	Manufacture of chemicals and chemical products	–0.71646	–0.80124
4	Manufacture of food products, beverages and tobacco products	–0.38136	–0.49955
5	Manufacture of computer, electronic and optical products	–0.39145	–0.16954
6	Manufacture of machinery and equipment n.e.c.	–0.64597	–0.47562
7	Electricity, gas, steam and air-conditioning supply	–0.43469	–0.33481
8	Water supply, sewerage, waste management and remediation	–0.77868	–0.74278

It was also established that, as mentioned above, there is a group of industries for the technology of which GHG is generated to a relatively lesser extent. Targeted investments to reduce the carbon footprint in these industries will quickly lead to zero emission volumes, which simplifies the procedures for accessing their products to the markets of EU countries. That is, it is worth considering the priorities for differentiating the institutional support of industries as a tool for changing the export structure.

In order to assess the level of significance of the carbon footprint embedded in imports in the total volume of EU trade with a particular country and, accordingly, the level of significance for the specified countries of the EU-ETS certificate market, an index was introduced using mathematical methods, which is calculated as follows

$$k = D \cdot 100/S,$$

where k is the index of "dirty" imports, million tons/billion dollars, %; D is the volume of "dirty" imports, billion dollars; S is the total volume of imports, billion dollars.

The groups of factors that determine the price or amount of demand for carbon certificates are: factors influencing the current activity of enterprises using technologies that generate GHG (fluctuations in demand for their products, seasonal nature of production, etc.); factors that determine the amount of marginal costs for updating technologies (situation on the market, cost of borrowing, etc.); factors that determine exchange expectations and the choice of moment for buying quotas; long-term weather forecasts in the area where production is located; factors influencing the situation with related markets; factors affecting supply and demand in related types of economic activity.

This can be formulated mathematically as follows

$$var\, C \to \{f(x_1.x_2.x_3...)\gamma(y_1.y_2.y_3...)\varphi(z_1.z_2.z_3...)\},$$

where C is the price of ETS certificates; f is the demand function for certificates; γ is the offer function for ETS certificates; φ is the function of compensatory measures; $x_1.x_2.x_3...$ are a group of factors that determine the demand for certificates; $y_1.y_2.y_3...$ are a group of factors that determine the offer for ETS certificates; $z_1.z_2.z_3...$ are a group of factors that determine compensatory measures.

In order to determine the number of free emissions permits (or the need for compensatory measures) for the first, pilot, stage of the implementation of the national ETS, we propose to introduce an equivalence function for comparing industries that apply for such permits.

The equivalence function is needed to assess the individual specific indicators of enterprises to compare the importance of allocating free permits for GHG emissions to them, or the need to implement compensatory measures. Using mathematical methods, this function is presented as

$$\omega = \omega\left(\frac{S^i_{lc}}{averS_{lc}}; \frac{S^i_{capital}}{averS_{capital}}; \frac{V^i}{averV^i}\right),$$

under conditions

$$\left\{\frac{S^i_{lc}}{averS_{lc}}; \frac{S^i_{capital}}{averS_{capital}}; \frac{V^i}{averV^i}\right\} \le 1,$$

where ω is the equivalence function; S^i_{lc}, $S^i_{capital}$, V^i are respectively, costs of labor, capital, volumes of GHG emissions per unit of the i^{th} type of production of the enterprise; $averS_{lc}$, $averS_{capital}$, $averV^i$ are respectively, average values of specific labor costs, capital, emissions volumes for similar products of other Ukrainian or EU enterprises.

Conditions (4) are general, the specification of the equivalence function will be determined by the absolute values of the given ratios and the conditions for the introduction of the national ETS. At the same time, the rate of change in each of the above indicators over time, that is, their first derivatives, will be significant for comparison

$$\frac{\partial\omega}{\partial t} = \omega^*\left[\partial\left(\frac{S^i_{lc}}{averS_{lc}}\right)\Big/\partial t; \partial\left(\frac{S^i_{capital}}{averS_{capital}}\right)\Big/\partial t; \partial\left(\frac{V^i}{averV^i}\right)\Big/\partial t\right],$$

under conditions

$$\left\{\frac{\partial\left(\frac{S^i_{lc}}{averS_{lc}}\right)}{\partial t}; \frac{\partial\left(\frac{S^i_{capital}}{averS_{capital}}\right)}{\partial t}; \frac{\partial\left(\frac{V^i}{averV^i}\right)}{\partial t}\right\} < 0,$$

where $\frac{\partial\omega}{\partial t}$ is the first derivative of the equivalence function over time; ω^* is a functional representation of $\frac{\partial\omega}{\partial t}$.

This pace indicates the speed of change, which is necessary, for example, to determine the urgency of operational management influences.

The analysis of the data of the State Statistics Service [19] confirmed that the energy intensity of Ukrainian industry is significantly higher than that of neighboring countries and allowed to establish the level according to how much it is higher. In particular, when compared with the energy intensity of Poland's GDP, it is ~2.5 times more, compared with the energy intensity of Germany's GDP – ~3.3 times higher. It is the magnitude of the difference between these levels that forms the complexity of the transition to carbon-free development of Ukraine. According to the Ministry of Economy, this will cost the country ~1,500 million dollars per year. This level of energy intensity proportionally leads to an increase in the amount of GHG generated to produce a specific amount of electrical energy for the output of Ukrainian industry. This situation is also complicated by the fact that Ukraine uses a significant number of thermal power plants equipped with technologically outdated equipment for the production of electricity. CHP technologies, as it is known, are characterized by extremely high GHG emissions.

Various economic instruments are used to stimulate manufacturers to introduce environmental technologies in the EU. One of these tools is taxes on the emissions of carbon oxides. Some EU countries use the method of high values of such tax rates, which are much higher than the average in EU countries. In Sweden, for example, it is 140 €/ton, in Switzerland – 87 €/ton. Such taxes were not introduced in short periods of time but

grew year by year for 10–30 years. This facilitated the industry's adaptation to new environmental requirements. The consequence of this, for example, for the metallurgical industry of the European Community is reaching the level of emissions of 1.3 tons of CO_x/ton of steel, that is, their reduction during the implementation of the low-carbon policy was ~2 times. For the further planned reduction of GHG emissions over the decade by 95 % to the level of 1990, the industry will need ~1,000 billion €. Therefore, the EU is introducing a complex set of aid tools: cheap credit resources, compensation, grants, subsidies.

Institutional structures in Ukraine understand the importance of implementing a set of such tools. Thus, before the start of large-scale military operations, the National Investment Fund was created, the National Bank developed programs for "green" and sustainable financing; a pilot project for the transformation of coal regions was financed. But under the current Ukrainian realities, even after the end of large-scale military operations, the introduction of such tools will be extremely difficult. In conditions of damage to the infrastructure, destruction of fixed assets, reduction in sales volumes, management and owners of industrial enterprises of Ukraine will not have financial resources for technological support of reducing GHG emissions. The level of military threats and economic risks also significantly reduces opportunities for attracting foreign investment. In addition, there is a risk of restrictions on trade with EU countries due to a significant "carbon footprint" in export goods of Ukrainian production.

The change in export conditions to EU markets is associated with the introduction of new tools to reduce GHG emissions. Analysis of these tools in the context of this study is useful, as their implementation is declared, in particular, in government documents.

Thus, in order to achieve a reduction of greenhouse gas emissions by 55 % in 2030 from the level of 2019, and their reduction to zero in 2050, the European Union implemented the Emissions Trading System (EU ETS). Its implementation is carried out by limiting GHG emissions by the economic sector. A certain number of permits for GHG emission is put up for exchange trading. This led to the fact that GHG emissions began to have an exchange price, that is, to acquire the characteristics of a market product.

A consequence of this was that emissions trading contributed to the introduction of market principles to GHG. These principles can be formulated as: fairness (in particular, the more the polluter generates GHG, the more it should pay): competitive openness (the competitor will have predicted advantages when introducing low-carbon technologies); stability and predictability of the rules for trading emission certificates; transparency, which makes shadow schemes impossible. The implementation of these principles, in turn, leads to efficiency, economy and guaranteed achievement of the Sustainable Development Goals. And this, in particular, is evidence of ecological efficiency in reducing GHG emissions. Environmental efficiency is only one of the components of the SDGs. The provision of SDGs No. 1 "Poverty reduction" and No. 8 "Decent work and economic growth is more difficult due to the indirect connection of the implementation of the policy of carbon-free development". To clarify this connection, it is necessary to analyze the impact of the EU"s carbon policy on the economy of Ukraine.

The thesis, which would seem to contradict the achievement of SDGs Nos. 1 and 8, as according to the opponents [17, 18] it can complicate the economic activity of enterprises and entire industries, is that with the implementation of the ETS in Ukraine, the number of free GHG generation permits should decrease every year (as it happens in EU countries by 10 % every year). Opponents argue that at such a rate of reduction in the number of free GHG generation permits, it should be accompanied by a corresponding rate of capital investment in technological modification of production. Opponents claim that such pace of capital investment in renewal is beyond the power of domestic industry. But first of all, this only confirms that the rates of reduction in the number of free GHG generation permits must be substantiated in detail. Secondly, this requires a relevant assessment of the rates of capital investment required for technological modification of production. The results of such an analysis, shown in Table 1, indicate that capital investments in industry in recent years were aimed, in particular, at preventing the reduction of GHG emissions, and the rate determines the rate of reduction of greenhouse gases.

In order to neutralize the shock effect from the annual reduction of free permits when the ETS is introduced in Ukraine, approaches that are based on the above-mentioned principles of GHG emissions trading: stability, predictability of emission certificate trading rules, and fairness and transparency, are proposed. The application of the principles of justice and transparency, in our opinion, in this case consists in a differentiated policy of providing compensation for the implementation of carbon-free technologies. The differentiation of the compensation policy should consist of a financial scheme for compensating the capital expenditures of enterprises for environmental purposes, strictly regulated by regulatory and legal documents.

Starting in 2036, the EU plans to put the entire volume of permits up for auction. According to the analysis of the sectoral differentiated approach introduced by the European Union, energy companies should pay for 100 % of GHG emissions, and metallurgists, so far, for ~24 % of emissions. The differentiation of payments also applies to manufacturers of cement, chemical and other types of products, the technologies of which generate GHG, and the emissions are greater than the established norms. The cost of permits for GHG emissions in the EU is ~€ 59 per ton of carbon dioxide. In Ukraine, the tax on carbon dioxide emissions is ~10 hryvnias/ton. This puts the industry of the EU countries at a disadvantage in the global market. Therefore, the European Community introduced the Carbon Border Adjustments Mechanism (CBAM). In our opinion, the involvement of CBAM will contribute to the globalization of the environmental policy of the European Union. That is, CBAM becomes an accelerator of SDG implementation in the context of global climate policy. However, at present EU countries, which are importers of significant volumes of products of Ukrainian industry, are ahead of Ukraine on the way to achieving the goal of carbon-free production. As a result, in order to avoid the formation of "carbon offshores" – the transfer of harmful production by EU industrialists to third countries and to internationalize the practice of climate change prevention, it is proposed to use CBAM.

With the implementation of CBAM, an EU company importing products that produced GHGs must pay an amount equivalent to the cost of emission permits. This significantly changes the rules of the game on the market of the European Union countries and is a source of significant challenges for enterprises that export their products to the EU, in particular, for energy workers, metallurgists, chemists and other export industries of Ukraine.

The analysis of export opportunities and changes in the domestic market of Ukraine by industry in the introduction of CBAM is given in Table 2.

The analysis of the data presented in Table 2 also confirms that the implementation of CBAM has both direct and indirect effects on the economy of Ukraine.

This will lead to a decrease in export volumes, which, in turn, will result in a decrease in indicative indicators of Ukrainian industrial companies on international stock exchanges, and will also result in direct costs for exporters to pay the CBAM tariff in EU countries.

Far from all loss of sales volumes on foreign markets can be compensated by an increase in the supply of goods to the domestic market, as some scientists hope. A reduction in the production of export goods will lead to a decrease in the volume of production in related industries, which will create a synergistic effect on GDP in a negative way. The need for a quick technological update of production to avoid a carbon footprint in the products of Ukrainian industry becomes imperative.

Table 2

Analysis of export opportunities and changes in the domestic market of Ukraine by industry in the event of the introduction of CBAM

Branch	Foreign market	Domestic market
Energy	Ukraine's annual export of electricity (EE) to EU countries before the large-scale war was 0.003617–0.00534 TWh·h. Most of this EE (0.66) was produced at the TPP. For this, coal was burned, which is unacceptable for CBAM. With the implementation of CBAM, the share of EE produced at TPPs should not exceed 8 %, the rest is EE produced by nuclear power plants and renewable energy sources. Based on the estimated forecast value of the carbon dioxide emission price in 2030 of €61 per ton under the condition of integration of the Ukrainian power grid into the European Network of Transmission System Operators for Electricity (abbr. ENTSO-E), the net profit from the sale of EE can increase by 7 %	An increase for capital expenditures for updating TPP equipment. Increase in the cost of coal. Reduction in demand for coal. Closure of unprofitable mines
Metallurgy	The annual export of metallurgical products to EU countries before the large-scale war amounted to ~6.7 million tons. Approximate reduction by 10 % is predicted in the year 2030 due to introduction of CBAM of exports of mainly blast furnace products	Changes in the production structure of the metallurgical industry are possible. Refusal of blast furnace production, increase in the share of powder metallurgy
Chemical industry and production of fertilizers	Approximate reduction in export of mineral fertilizers and chemical compounds by 40 % is predicted	The reorientation of fertilizer manufacturers to the domestic market will be limited because agricultural products will have a carbon footprint
Production of building materials and structures	The volume of cement exports in 2030 will decrease by ~ 660 million tons, i. e. ~ 4.6 %	Probable reorientation to the domestic market and increased production of building structures

Table 3 shows the data that allow analyzing the significance of the introduction of the Cross-Border Carbon Regulation Mechanism for the import of EU goods from some countries of the world. For this, as an indicator, the index of "dirty" imports, the proposed mathematical representation of which is given above, was studied. The use of the indicator of "dirty" imports, the calculations of which are based on the processing of primary statistical data by the authors [20], are shown in Table 3, made it possible to establish that not only the volume of the carbon footprint in terms of its absolute values (which are usually used in analytical studies) in imports from one or another country will be important, but also the significance of this footprint (whose indicator is the index of "dirty" imports) in the total volume of trade with this country. The authors' calculations of the dirty footprint index are shown in Table 3.

From the analysis of the data presented in Table 3, it is also clear that a significant role in the EU trade policy will be played by the export structure of exporting countries and which share in this structure is provided by industries that use "dirty" technologies. Data analysis of Table 3 indicates that the countries that export hydrocarbons (Nigeria, Azerbaijan, Saudi Arabia, Libya), metals (Kazakhstan), and products of the chemical industry are the most vulnerable.

The indicator of "dirty" imports for Ukraine does not come close to the values of the indicators of the above-mentioned countries, but it is, for example, twice as large as that of Turkey. This country is included in the list of 20 countries that generate 75 % of the world's GHG emissions. The volume of emissions in Turkey grew by 3 % every year. Turkey implemented the first stage of ETS – the implementation of monitoring and verification of GHG emissions only in 2015, and received the first reports on GHG generation from enterprises in 2016, that is, in the not-so-distant past. The official institutions of Turkey have declared the introduction of ETS in two stages, which will last ~7 years. Turkey belongs to the group of industrialized countries. This should not only lead to setting a higher bar for reducing carbon pollution, but also establish obligations to provide assistance to less developed countries. Nevertheless, according to the results of the negotiations, only after the guarantee of financial support by France, Germany and the EBRD, the official structures of Turkey confirmed that their country will implement the requirements of the Paris Agreement "as a developing country" and is obliged to achieve a carbon-free level only in 2053.

This defense of one's own interests should become an example for neighboring states. For example, at the same time, the European Business Association (EBA) already in 2021 pointed out [21, 22] Ukraine's failure to fulfill its ambitious obligations under the "National Plan for Reducing Emissions from Large Combustion Plants". It threatened sanctions, including international isolation.

Reasons for non-implementation of the "National Emissions Reduction Plan": the above-mentioned insufficient substantiation of the plans; lack of legislative support for emission reduction financing mechanisms; war, crises in energy and economy of Ukraine. As a conclusion from this comparison, institutional structures need a more thorough scientific and analytical study before accepting international obligations for GHG emissions.

Therefore, following the example of Turkey, it is recommended with reference to unforeseen critical phenomena for the Ukrainian economy, to diplomatically achieve the following over the time of economic recovery:

- the introduction of preferential agreements that exempt Ukrainian importers (perhaps in a differentiated way: according to industries or the level of damage to the infrastructure of certain regions) from certain obligations, for example, certain conditions for the purchase of emission certificates or the payment of certain tariffs, the introduction of a separate formula for calculating tariffs;

Table 3

Comparison of pollution indicators – the carbon footprint in imports and the indicator of "dirty" imports

Country	Carbon footprint in imports, million tons	Import volume, billion U.S. dollars	Index of "dirty" importsk, *k*, %
USA	29	27264	10.6367
Saudi Arabia	18	2461	73.141
Nigeria	18	2076	86.7052
Kazakhstan	13	2048	63.4766
Libya	14	2097	66.762
China	13	55784	2.3304
Algeria	10	2259	44.2674
Azerbaijan	10	1379	72.5163
Turkey	8	9192	8.7032
Ukraine	5	2838	17.618
Japan	3	7345	4.0844
Taiwan	2	1777	11.2549

- the introduction of special, more loyal to Ukrainian manufacturers, conditions of CBAM;

- the use of dynamic adjustment of existing restrictions on exports to the EU as an additional compensatory mechanism for the adaptation of industrial enterprises of Ukraine to the EU's decarbonization policy;

- postponement of the introduction of the national ETS in accordance with EU Directive 87/2003 and the Association Agreement with the EU;

- postponement for Ukraine of the requirements of the EU Directives on decarbonization;

- on a bilateral basis with the EU countries and on a multilateral basis with the IMF, international financial organizations to form a fund for the decarbonization of Ukraine (for which to introduce amendments to draft law No. 4347). On the basis of this fund, develop and implement a system of financing mechanisms for the decarbonization of Ukrainian industry and achieving the Sustainable Development Goals, for which, in particular, introduce a list of enterprises whose technologies require modernization;

- providing preferential access to EU carbon-free technologies.

In connection with the unforeseen critical phenomena for the Ukrainian economy during the implementation of the national ETS, it is proposed:

- to introduce a differentiated approach, which should be specified in regulatory documents, to the distribution of quotas by regions of Ukraine, taking into account the level of damage and destruction of infrastructure;

- to introduce a differentiated approach, which should be specified in regulatory documents, to the allocation of the number of free permits for GHG emissions by regions, industries and individual enterprises in each of the regions;

- to introduce a differentiated approach, which should be specified in regulatory documents, to the annual change in the level of quotas and the number of free permits for GHG emissions by regions, industries and individual enterprises in each of the regions. This level can be lower or higher than the national one;

- to introduce a correlation of prices for GHG quotas of the national ETS with the EU ETS and prices for GHG quotas of world exchanges at the last stage of the implementation of the national market and with the condition that this stage must be preceded by the pilot launch of the national ETS.

Since the introduction of the carbon certificate market in Ukraine may not provide the required rate of emission reduction necessary to avoid the carbon tariffs of CBAM, which, in particular, is confirmed by research findings [8, 9], it is advisable to introduce regional laboratories for voluntary control of the level of emissions by Ukrainian enterprises [23, 24]. For this, it is necessary to agree on the recognition of their certificates not only by the Ukrainian side, but also by the EU countries.

The expediency of introducing EU-certified regional laboratories also lies in the fact that nowadays there is an unsettled issue of metrological monitoring of systems for measuring the content of carbon oxides in the emissions of Ukrainian enterprises and the unification of these systems is not standardized. This creates risks of non-compliance with the provision of reporting information in accordance with the Law of Ukraine "On the Principles of Monitoring, Reporting and Verification of Greenhouse Gas Emissions" and the Order of the Ministry of Environmental Protection and Natural Resources "On Approval of Standard Forms of Documents in the Field of Monitoring, Reporting and Verification of Greenhouse Gas Emissions and Requirements for their filling".

Conclusion. The inverse correlation dependence of capital investments and GHG emission volumes for industry and the significant difference of this correlation by types of economic activity have been established. The existence of a correlation confirms the fact that the management is implementing a strategic policy regarding the financing of emission reduction technologies. It also indicates the establishment of a long-term trend of greening production. A significant difference in correlation coefficients for enterprises of various types of activity indicates the unevenness of management's sectoral awareness of the need to reduce emissions. This will have a negative impact on the implementation of the SDGs. The presence of a difference in the correlation coefficients for enterprises of different types of activity also indicates the different paces necessary for their adaptation to the tariff obstacles of the CBAM and, accordingly, the need for differentiation of institutional support for industries as a tool for a substantiated change in the structure of exports.

Mathematically presented factors of the ETS market and their functional dependencies are necessary for market analysis. In particular, the equivalence function is presented, which is required for the assessment of individual specific indicators of enterprises to compare the importance of allocating them free permits for GHG emissions. The factors that determine the prices and the amount of demand for carbon certificates are stratified by groups: factors influencing the current activity of enterprises that use technologies that generate GHG; factors that determine the amount of marginal costs for updating technologies; factors that determine exchange expectations and the choice of moment for buying quotas; long-term weather forecasts; factors influencing the situation with related markets; factors affecting the supply and demand of neighbors. This allows for a more reasonable economic analysis of emissions.

The formation of the market of certificates created a new type of product "the right to GHG emissions". Trade in this product provided an opportunity to apply market principles to GHG. The following formulation of these principles is proposed: fairness (the more GHG the polluter generates, the more they must pay): competitive openness (the competitor will have predicted advantages when introducing low-carbon technologies); stability and predictability of the rules for trading emission certificates; transparency, which makes shadow schemes impossible. The implementation of these principles, in turn, leads to efficiency, economy and guaranteed achievement of the SDGs. Approaches to neutralize the shock effect of the annual reduction of free permits upon the introduction of the ETS have been proposed.

The analysis of export opportunities and changes in the domestic market of Ukraine by industry sectors with the introduction of the CBAM was carried out, and the effects of the implementation of the CBAM on the country's economy were indicated.

The specified reasons for Ukraine's non-fulfillment of its obligations to reduce emissions are: insufficient substantiation of plans; lack of legislative support for emission reduction financing mechanisms; war, crises in energy and economy of Ukraine. With this in mind, recommendations are offered.

In connection with the critical situation, it is also proposed when introducing the national ETS: to introduce a differentiated approach to the distribution of quotas by regions of Ukraine, taking into account the level of damage and destruction of infrastructure; to introduce a differentiated approach in the documents to the allocation of the number of free permits for GHG emissions by regions, industries and individual enterprises in each of the regions; to introduce a differentiated approach to the annual change in quotas and the number of free permits for GHG emissions by regions, industries and individual enterprises in each of the regions; to introduce a correlation of the prices for GHG quotas of the national ETS with the EU ETS and the prices for GHG quotas of the world exchanges at the last stage of the implementation of the national market and necessary preceding of the pilot launch of the national ETS to this stage.

Since there is an unsettled issue of metrological monitoring of systems for measuring the content of carbon oxides in emissions and their unification, it is proposed to introduce regional laboratories for voluntary control of the level of emissions. For this, it is necessary to agree on the recognition of their certificates not only by the Ukrainian side, but also by the EU countries.

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Економічні аспекти оцінки та маркетинг викидів вуглецю підприємствами на принципах стійкого розвитку

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Мета. Проаналізувати економічні аспекти викидів вуглецю промисловістю та провести маркетингову оцінку системи торгівлі викидами (СТВ). Розробити рекомендації щодо запровадження ринкових механізмів регулювання викидів.

Методика. Використані спеціальні й загальні методи наукового пізнання: абстрактно-логічного аналізу для виявлення переважаючих причин генерації парникових газів (ПГ); статистичні методи аналізу для встановлення кореляції капітальних інвестицій та обсягів викидів; індукції та дедукції для виявлення комплексних підходів менеджменту до скорочення шкідливих викидів; математичні – для формалізації чинників ринку СТВ і їх функціональних залежностей, необхідних для аналізу ринку.

Результати. Встановлена кореляція капітальних інвестицій і обсягів викидів, що підтверджує довгостроковий тренд упровадження стратегічної політики підприємств для зменшення викидів. Наявність галузевої різниці коефіцієнтів кореляції вказала на необхідність диференціації інституційної підтримки галузей як інструменту зміни структури експорту. Указані ефекти впливу «Механізму транскордонного вуглецевого регулювання» (Carbon Border Adjustments Mechanism) на економіку України. Запропоновані рекомендації для узгодження питань щодо зобов'язань України по скороченню викидів. Запропоновані заходи зменшення ризиків для економіки при запровадженні національної СТВ.

Наукова новизна. Математичним чином представлені чинники ринку СТВ і їх функціональні залежності, необхідні для аналізу ринку. Для оцінки індивідуальних питомих показників підприємств запропонована функція еквівалентності. Стратифіковані чинники, що визначають ціни й величину попиту на ринку СТВ. Сформульовані принципи цього ринку.

Практична значимість. Запропоновано запровадити регіональні лабораторії контролю рівню викидів і узгодити визнання їх сертифікатів Україною та ЄС.

Ключові слова: *викиди вуглецю, торгівля викидами, ціноутворення на вуглець, податок на вуглець, сталий розвиток*

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