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INCREASING AMBITION TO REDUCE THE CARBON TRACE OF MULTIMODAL TRANSPORTATION IN THE CONDITIONS OF UKRAINE'S ECONOMY TRANSFORMATION TOWARDS CLIMATE NEUTRALITY

Introduction. *It has been stated that the strategic guideline for the transformation of Ukraine's economy towards climate neutrality is to increase the ambition to reduce the carbon trace of multimodal transportation through the use of an arsenal of effective regulatory and fiscal measures.*

Problem Statement. *The challenge is to find ways to increase the ambition to reduce the carbon footprint of multimodal transportation in the context of transforming Ukraine's economy to climate neutrality.*

Purpose. *The purpose of this research is to develop scenarios for reducing the carbon footprint of multimodal transportation to ensure the environment preservation and well-being of the future generations.*

Materials and Methods. *The following methods have been used: economic and mathematical modelling on the basis of correlation-regressive analysis, for determining the dependence of greenhouse gas emissions on fuel consumption in the transport sector, cargo and passenger turnover, GDP, the number of permanent population; decoupling analysis, for estimating the impact of transport on the environment; comparative analysis, for studying the elasticity of greenhouse gas emissions with GDP changes in countries with the length of transport routes close*

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to Ukraine; strategic analysis, for assessing the realism of NDCs2; scenario forecasting, for identifying alternative scenarios of changes in greenhouse gas emissions, provided that the traffic flows increase.

Results. *For the first time, a mechanism for paying a carbon tax on fuel, which ensures a fair attitude towards environmental pollutants and a reasonable formation of the investment potential of the Decarbonisation Fund. has been proposed.*

Conclusions. *Having chosen the transformation of Ukraine's economy towards climate neutrality as a strategic guideline, the government shall decide to increase the ambition to reduce the carbon footprint of multimodal transportation through the use of an arsenal of effective fiscal measures.*

Keywords: anti-carbon policy, carbon emissions, carbon tax on fuel, decoupling, multimodal transport, and climate neutrality.

The UNFCCC global campaign to unite politicians and businesses, states, regions and cities, foundations and investors to ensure climate neutrality (carbon neutrality) and the adoption of the first international agreement to reduce greenhouse gas emissions, the Kyoto Protocol to the United Nations Framework Convention on Climate Change [1] valid for the period 2008—2012 and, in numerous negotiations, extended by the Doha Amendment [2] up to 2020 are landmark events at the beginning of the 21st century.

Instead, the main purpose of the Doha Amendment was to radically revise the Kyoto Protocol rather than to amend its content, namely, to eliminate the possibility of international trade in quotas and to impose on member states more burdensome obligations to reduce greenhouse gas emissions, which has led to adverse consequences. namely, Canada's withdrawal from the members, the refusal of the Amendment ratification by the United States and China, and the refusal of Russia and Japan to take part in its second period.

The refusal of the states to take part in the global initiatives for combating climate change, which account for the largest amounts of carbon emissions, has in fact devalued the mechanisms of the Kyoto Protocol. Therefore, it is necessary to find new approaches that would ensure the accession to the UNFCCC of those countries that account for the largest volumes of greenhouse gas emissions [3, 37].

Therefore, to replace the Kyoto Protocol at the UNFCCC Conference of Parties held in Paris on 12.12.2015, a global agreement on combating climate change for 2021—2030 was adopted, ratified by Ukraine under the Law on the Ratification of the Paris Agreement No. 1469-VIII of 14.07.2016 [4].

Unlike the Kyoto Protocol, the Paris Agreement changed the basic top-down approach (setting commitments for advanced and transition economies to reduce greenhouse gas emissions and combat climate change) to a bottom-up approach. According to it, global international obligations are formed by the participating countries independently in the form of nationally determined contributions (hereinafter — NDC), depending on the combination of their national ambitious goals, financial and economic situation and historical responsibility for the consequences of long-term greenhouse gas emissions.

Exactly introduction of the UNFCCC format of the NDCS has helped to resolve political controversies over international legal obligations in the field of combating climate change and accession to the Paris Global Compact, in particular, such leading countries in terms of air pollution as China, the United States and others that allows expanding the coverage of the Paris Agreement to 97.1% of global greenhouse gas emissions against 15% provided by the Kyoto Protocol after the refusal of several countries to participate in it [3, 38].

Instead, the reason for the expansion of coverage under the Paris Agreement was not only the accession of leading countries in air pollution, but also developing countries, least developed countries and island nations. It will be recalled that under the Kyoto Protocol, commitments to reduce greenhouse gas emissions applied only to developed countries and countries with economies in transition.

However, over time, rising greenhouse gas emissions have ceased to be associated exclusively with developed countries, as developing countries have intercepted the flag of superiority in CO_2 emissions — mainly due to low energy efficiency of production and use of carbon-intensive fossil fuels, active oil and gas production, which, in the absence of clean technologies, has led to a significant increase in their "contribution" to global greenhouse gas emissions. With the adoption of the Paris Agreement, the obligation to limit carbon emissions has been extended to a wide group of countries, which has made the system of obligations to limit anthropogenic emissions truly global [3, 36].

At the same time, the Paris Agreement is not without its shortcomings and needs a more detailed international legal framework to launch all the outlined mechanisms and measures provided for in it. As a result, in 2019 the EU approved a new large-scale *European Green Deal* program for economic transformation until 2050, which provides for the complete abandonment of fossil fuels and the exclusion from the economy of industries that generate harmful emissions. This initiative was joined by a number of other countries, such as China, Japan, South Korea, South Africa, Canada, etc., the association of which was tentatively called "Climate Neutrality" [5].

Ukraine is not left out either. Together with the whole civilized world, it has committed itself to significantly reduce greenhouse gas emissions by 2030, which is quite possible, in our opinion, with active structural and technological renewal of the country's economy based on the latest world standards, and therefore, provided a balanced not only a comprehensive strategy, but also sectoral strategies, among which we consider extremely important strategy of low-carbon multimodal transportation, formed with the participation of public authorities, business structures, public organizations, research institutes and independent experts [3, 34].

However, developing a strategy alone to achieve ambitious low-carbon development goals is not enough. Significant investment is needed to achieve the intended goal. Currently, the *Green Climate Fund* has been created, which aimed to attract up to USD 100 billion by 2020. However, unfortunately, the expected result has not been achieved [6]. Therefore, the negative environmental consequences of economic growth remain global, and the problems of financing carbon reduction measures remain national.

Of course, today in Ukraine there are many different funds, banks, insurance companies and other institutions that have large amounts of capital. However, their participation in investing in low-carbon development is very small, which is primarily due to the lack of an effective system of their motivation to invest in this area [7, 22]. There is also no motivation for vehicle owners and businesses to reduce greenhouse gas emissions.

Therefore, to achieve the ambitious goals of mitigating the carbon trace of vehicles, first of all, we need a national system of motivation for sustainable low-carbon development, based on an effective mechanism for paying tax on carbon dioxide emissions under paragraph 4 of Article 242 of the Tax Code of Ukraine [8] (hereinafter — TCU) and the formation of the Decarbonisation Fund. Thus, the issue of reducing the carbon trace of multimodal transportation does not lose its relevance, but with the adoption of anti-carbon policy, generally determined by the mainstream transformation of the economy to climate neutrality.

For many years now, a significant cohort of both foreign and domestic politicians, scientists and practitioners has been actively working on reducing the carbon trace of multimodal transportation. In particular, UN Secretary-General Antonio Guterres emphasizes that existing climate threats, biodiversity crises and environmental pollution require humanity to reflect on the true value of nature. It is worth to admit that humanity will ensure the well-being of the planet only by understanding its value and directing ingenuity to the transition to low-carbon production, and hence the well-being of present and future generations [9].

David Bannister, Honoured Professor of Transport Studies at SoGE (Oxford), participant in VIBAT-London projects: vision and retrospective analysis of London transport until 2050, HEFCE and DIUS, EEA, OMS and others emphasizes in its numerous works, and in particular in its work *Transport Policy and the Environment* [10], its serious concern about the growing demand for transport and related air pollution.

The author for the first time proposed a method of quantitative assessment of the pressure of transport on the environment, which is generally recognized as the main contribution of British research in studying the impact of transport on the environment. Banister D. has repeatedly emphasized that the way to address greenhouse gas emission reductions is to unite countries, regions and cities in finding political, economic and innovative solutions.

Robin Hinkman, the follower of Banister's ideas in research *Looking to the future: transport and reducing CO_2 emissions in the UK by 2030* [11] reports that he has completed a study of possible options to achieve a 60% reduction in CO_2 emissions in transport sector of Great Britain by 2030. The author comments on the scenarios proposed by Banister D. and makes minor clarifications and adjustments related to changes in demand for transportation in conditions of uncertainty.

Petri Tapio, in his work *Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001* [12] emphasizes that the transition to low-carbon multimodal transport and achieving neutral greenhouse gas emissions is vital important and is a fundamental basis in solving the climate problem, both the country and the planet as a whole. According to statistics from the EU-15 for the period 1970—2000, the author determined the elasticity of both freight and passenger traffic in terms of GDP.

The researcher emphasizes that among the studied countries, only in the United Kingdom, Sweden and Finland in some years during the period under study, there is an accompaniment to the growth of traffic by the phenomenon of decoupling. On the example of Finland, the scientist describes in great detail the dependence of changes in carbon emissions on increasing traffic and proves the need to take measures to reduce them.

M. Z. Acutt and J. S. Dodgson in research publication *Transport and Global Warming: Modelling the Consequences of Alternative Policies* [13], try to convey to the government, business and citizens the need for the fastest possible mobilization to achieve carbon neutrality in the field of transportation. The authors emphasize the pressure of transport on the environment and discuss the economic models they have developed for forecasting greenhouse gas emissions in line with alternative UK policy scenarios.

Given the fact that the UK government has rejected the European Commission's (EC) proposals for a carbon tax and decided to expand the value added tax (VAT) base on domestic fuel and increase the duty on motor fuel, the authors have proposed three alternative scenarios of the state policy on reduction of greenhouse gas emissions by vehicles: the baseline scenario with keeping fuel prices at the level at the beginning of 1996; the next scenario — with an annual increase in the fuel duties by at least 5%; and the last scenario, with doubled prices for motor fuel.

M. Z. Acutt and J.S. Dodgson stressed that due to the deepening climate crisis, the government has no right to waste time and should immediately take decisive decisions to mitigate the impact of transport on the environment [13].

I. P. Haidutskyi in his article *Low-Carbon Development: Global Tools of Motivation* [7] argues the need for a global and national system of motivation for sustainable low-carbon development of the economy as a whole and its individual industries. The author emphasizes that achieving ambitious goals requires large amounts of investment. But the formation of such investment potential is complicated by contradictions in the global anti-carbon policy, when the negative environmental consequences are global, and the financing of measures to reduce greenhouse gas emissions is national.

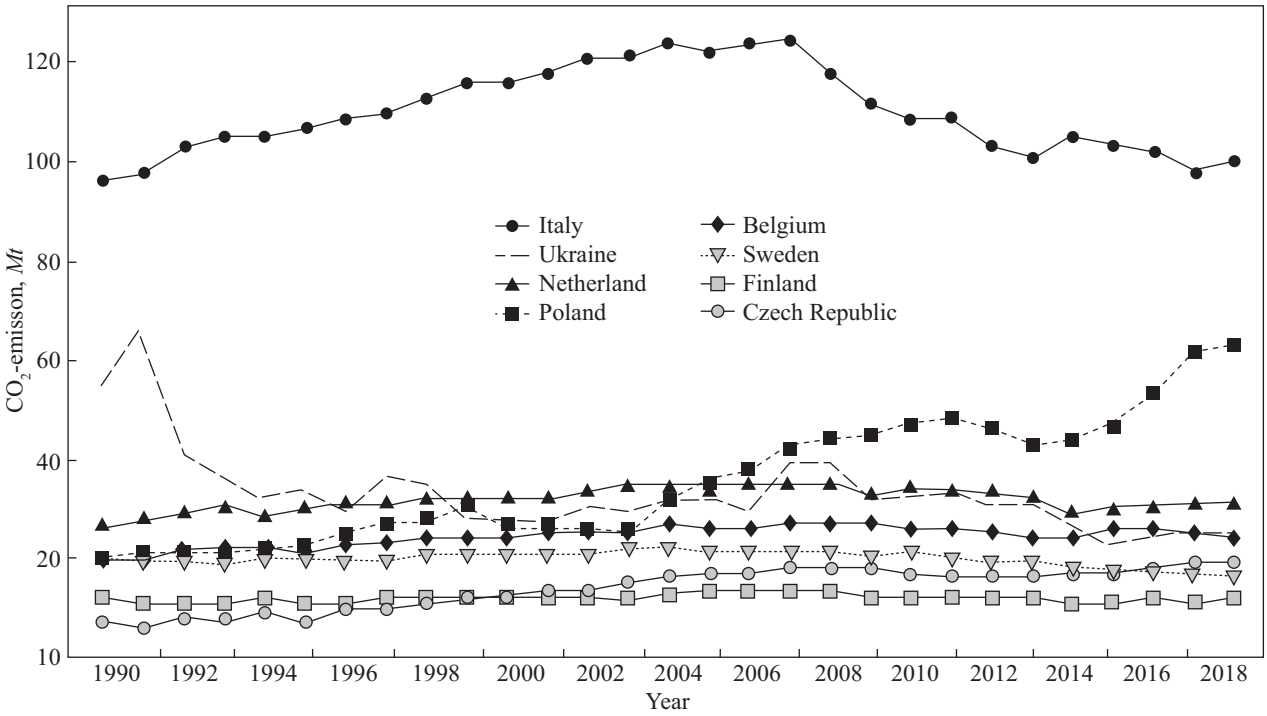

Fig. 1. Carbon trace of the member states of the Paris Agreement, close to Ukraine in the length of transport routes

The researcher substantiates the expediency of establishing the Global Anti-Carbon Fund as the main source of funding for sustainable low-carbon development, which should be formed on the basis of: participation of countries in the fund adequate to the amount of carbon emissions; payment of global anti-carbon tax; ensuring a faster reduction in carbon emissions against GDP growth; responsibilities for countries that refuse to participate in the fund through the introduction of international anti-carbon sanctions; optimal balancing of income and expenditure of the fund by country, etc. [7, 24].

We partially support I.P. Haidutsky, but numerous negotiations on the creation of the Global Anti-Carbon Fund, which may take years, will lead to the loss of precious time. Countries with the right to self-determine NDCs should take decisive regulatory and fiscal decisions today to reduce greenhouse gas emissions.

Hence, the purpose of this study is to study the possibility of reducing the carbon trace of multimodal transportation in the transformation of Ukraine's economy to climate neutrality through the introduction of a mechanism for paying carbon tax on fuel that will ensure fair treatment of environmental pollutants and reasonable formation of investment potential of the Decarbonisation Fund.

In the course of the research the following methods were used: economic and mathematical modelling — in determining the dependence of greenhouse gas emissions on GDP (at constant 2010 prices) and the number of permanent population, freight and passenger turnover, as well as fuel consumption in the transport sector; decoupling analysis — when assessing the impact of transport on the environment; comparative analysis — when studying the elasticity of greenhouse gas emissions with changes in GDP in countries with the length of transport routes close to Ukraine; strategic analysis — when assessing the realism of NDCs2; ,GAP-analysis — in finding ways to achieve the ambitious goals to reduce the carbon trace

of transport; forecasting — when determining the volume of greenhouse gas emissions under the condition of increasing the volume of transport; abstract and logical — in generalizing the results of the study and formulating conclusions [14].

Undoubtedly, these prerequisites have a significant impact on increasing the volume of multimodal traffic, but the decisive role in their change still plays the volume of GDP. With its growth, the volume of traffic increases, and accordingly their carbon trace, that is catastrophically dangerous for the environment. In order to convince the correctness of this statement, according to the International Energy Agency (IEA) [15], we will perform a comparative analysis of the dependence of greenhouse gas emissions on GDP in the member states of the Paris Agreement, which are close to Ukraine in terms of transport routes.

Given that the requirements of the Paris Agreement provides for the definition of NVV in comparison with 1990, so, according to Fig. 1, consider the current trends in reducing carbon emissions for the period from 1990 to the present in countries such as Italy, Sweden, Belgium, Finland and others (Fig. 1 and Fig. 2).

Among the countries presented in Fig. 1 during the period studied in terms of greenhouse gas emissions, Italy is in the lead, which before the global economic crisis in 2008 aggressively increased GDP. However, with its onset, the situation changed to the opposite (which is natural). Therefore, in the following years there was a clear downward trend in both GDP and CO_2 emissions.

In recent years, Poland has been characterized by gradual economic growth and a steady increase in greenhouse gas emissions.

Even with the ratification of the Kyoto Protocol in 2008, CO_2 emissions gradually increased over the next two years. However, with the decline in production volumes, the weakening of the national currency and a significant increase in government debt due to the global financial crisis during 2010—2012, we observe a decline in the carbon emission curve. Instead, supporting Polish exports allowed recovering the Polish economy in the post-crisis years. Consequently, there is a sharp increase in greenhouse gas emissions in 2014—2017.

Therefore, only with the ratification of the Paris Agreement in Poland on greenhouse gas emissions is there some stabilization, which is associated with the adoption of an anti-carbon policy and the definition of commitments to reduce CO_2 emissions.

Regarding Ukraine, it should be noted that during the period under study, the most significant decline in greenhouse gas emissions in the country was observed during 1990—2000, which was unfortunately not based on modernization of production and implementation of innovative projects, but by the impressive decline of the Ukrainian economy.

Indeed, the results of the last inspection experts of UNFCCC Secretariat National inventories of anthropogenic emissions undertaken in accordance with decision 20 / SR.21 and 10 / SMR.11 Conferences of the Parties to the UNFCCC and the Paris agreement established that Ukraine in recent years has demonstrated full compliance obligations for NDCS1 to the Paris Agreement. However, we emphasize once again that the basis for such changes was not the modernization of production and the introduction of clean technologies, but the reduction of GDP. Greenhouse gas emissions in other countries, shown in Fig. 1, are characterized by moderate fluctuations throughout the period under consideration.

The situation with Ukraine proves that studying only the dynamics of changes in greenhouse gas emissions and GDP is insufficient to assess the effectiveness of anti-carbon policies of countries and the real state of their transformation into a low-carbon economy. We consider it possible to have a realistic assessment of the situation if we study the accompaniment of an increase in GDP by the effect of decoupling.

The concept of decoupling in domestic practice has not yet been widely used. Interpretations of its substantive component are mainly based on the etymology of the borrowed English term [16].

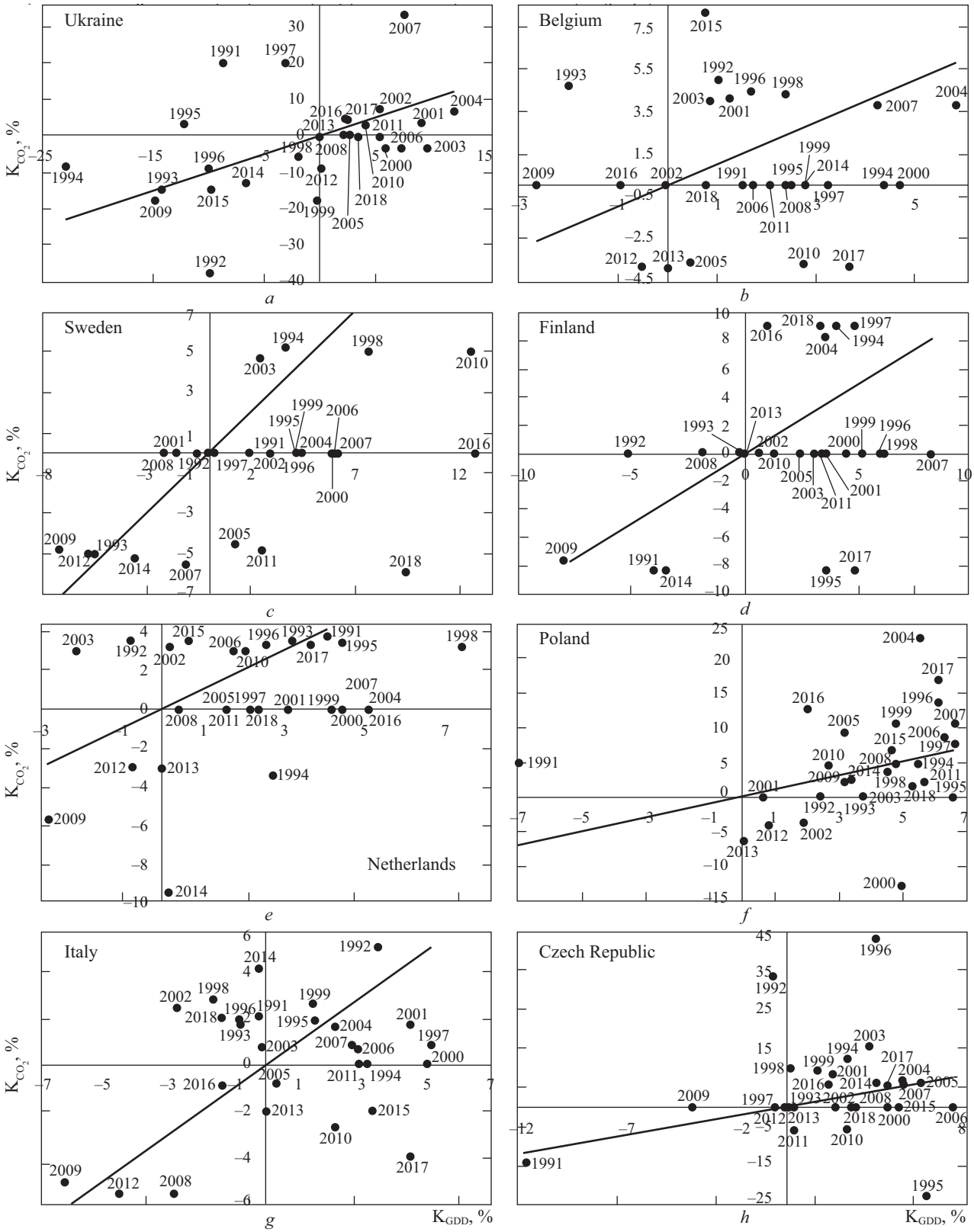

Fig. 2. Dynamics of greenhouse gas emissions dependence on GDP in Ukraine and in the parties to the Paris Agreement, which are close to Ukraine in terms of the length of transport routes

In particular, in the presentation of its content in the Millennium Declaration, approved by the UN General Assembly Resolution of 08.09.2000 on No. 55 / 2 [16], where decoupling is seen as a break between the negative environmental impact and economic benefits.

Instead, with the formation of the Assessment of resource efficiency indicators and targets (Final report 2012) and with the beginning of laying UNEP report *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*, the concept of decoupling has become more broadly interpreted, namely as a key principle related processes of economic growth, the amount of natural resources consumed and environmental pollution, which provides for the growing needs of society while minimizing the impact of nature load [17].

The effect of decoupling is manifested when the positive dynamics of economic growth indicators of negative impact on the environment remain stable or show a downward trend over the same period [12].

According to the OECD methodology, the effect of decoupling is evaluated by the decoupling index *(DecInd)* and the decoupling factor *(DecFact)* and is defined [18] as follow:

$$DecInd = \frac{(EP/DF)_{ending}}{(EP/DF)_{begining}} = \frac{K_{EPending}}{K_{DFbegining}}, \quad (1)$$

$$DecFact = 1 - DecInd, \quad (2)$$

where *EP* is environmental pressure, indicator of anthropogenic pressure on the environment, natural units; *DF* is driving force, an indicator of economic growth through gross domestic product, natural units; K_{EP}, K_{DF} are growth rates of relevant indicators.

We introduce the following notation: K_{CO2} is chain growth rates to the previous year of CO_2 emissions from fuel combustion of transport of the country, %. K_{GDP} is chain growth rate to the previous year of the country's GDP, %.

To calculate the values of indicators are taken in the final (ending) and base (beginning) periods of the study (years).

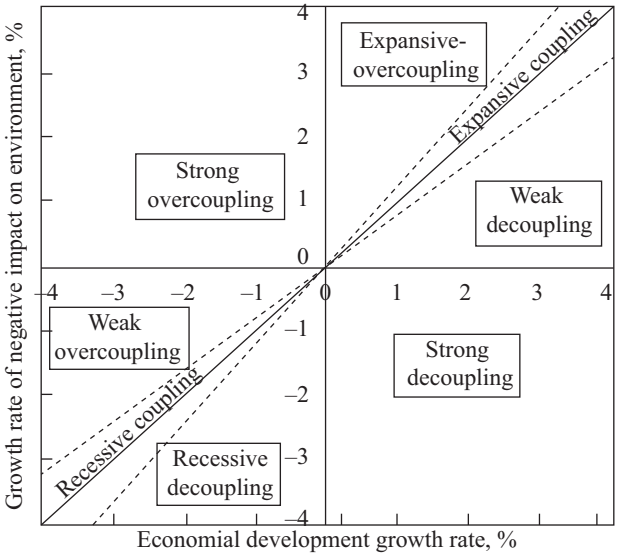

Fig. 3. Classification of types of decoupling effect

To describe the effect of decoupling, we use the classification of types of the effect of decoupling according to P. Tapio [12], given in Fig. 3.

Guided by the classification of types of decoupling effect by P. Tapio, we note that during the period studied the decoupling effect is characterized in the countries-parties to the Paris Agreement, which are close to Ukraine in terms of the length of transport, as follows:

- in particular, in Ukraine, in the 1990s, the decline in GDP was accompanied by an increase in CO_2 emissions and, consequently, a strong overcoupling effect, i.e. when *DecInd* is in the range *DecInd* <0. At the beginning of the 21st century, the situation is gradually changing, but rather sluggishly. During the first decade, GDP growth was accompanied by a simultaneous increase in greenhouse gas emissions with a slight excess of the rate of change of the latter. Thus, with the growth of GDP in the country there is an *expansive overcoupling-effect* (i.e. when *DecInd* is in the range *DecInd*> 1.2) [19], which in the early second decade is gradually transformed into a *strong decoupling-effect*, in which economic growth is accompanied by simultaneous reduction of carbon emissions, i.e. when *DecInd* is in the range of *DecInd* <0;

- the situation in Finland, Belgium, and the Netherlands is practically opposite to Ukraine. Since the late 1990s, the country's economic growth has been accompanied by a decline in greenhouse gas emissions and, consequently, accompanied by *expansive overcoupling*- and *strong decoupling-effects*;
- for Italy, in the pre-crisis years (until 2008), it is accompanied with *expansive overcoupling-effect*, but with the crisis of 2008—2009, the situation changed dramatically. The fall in GDP has led to *a recessive decoupling effect*, in which CO_2 emissions decrease with a simultaneous decline in economic growth, but at a faster pace, i.e. when *DecInd* is in the range of *DecInd*> 1.2.

This is explained by Italy's ratification of the Kyoto Protocol and its commitment to reduce greenhouse gas emissions. The full implementation of the Kyoto Protocol's obligations in both the first and second periods of its validity, as well as Italy's ratification of the Paris Agreement, contributed to a change in the type of decoupling effect in the following years. Since the rate of economic growth is characterized by a simulta-

Table 1. **Dynamics of Indicators in the Transport Sector of Ukraine [20—23]**

Years	Permanent population, thousand people	GDP, UAH million (at constant 2010 prices)	Cargo turnover, billion tons km	Passenger turnover, billion pass. km	Fuel consumption in the transport sector, million tons	CO_2 emissions from Transport sector, Mt
1990	51 556.5	991960.7	688.2029	199.3496	17.587	55
1991	51 623.5	905660.1	680.9651	198.2304	19.19	66
1992	51 708.2	815999.8	543.2332	163.1956	10.958	41
1993	51 870.4	700127.8	496.0737	153.8127	9.138	35
1994	51 715.4	539798.5	465.6349	129.0364	8.051	32
1995	51 300.4	473943.1	471.0687	128.3214	8.24	33
1996	50 874.1	426548.8	440.1246	98.2589	7.193	30
1997	50 400.0	413752.3	497.1041	137.2831	9.176	36
1998	49 973.5	405891	472.3247	120.8751	8.284	34
1999	49 544.8	405079.3	390.1214	82.3145	6.656	28
2000	49 115.0	428978.9	380.7281	81.2291	6.499	27
2001	48 663.6	468445	384.5037	84.1463	6.942	28
2002	48 240.9	493036	398.1241	89.1365	7.39	30
2003	47 823.1	539953	450.7344	95.8034	7.067	29
2004	47 442.1	605335	469.4001	104.7191	7.432	31
2005	47 100.5	623479	460.6401	111.4239	7.371	31
2006	46 749.2	669865	477.2375	116.3022	7.551	30
2007	46 465.7	720731	496.4509	144.4230	9.179	40
2008	46 192.3	737336	491.7461	147.2652	9.134	40
2009	45 963.4	628516	380.0035	130.1068	8.293	33
2010	45 782.6	1079346	404.5729	129.8153	8.459	34
2011	45 598.2	1138338	426.4277	134.2541	8.38	34
2012	45 453.3	1141055	394.6481	132.4797	8.578	31
2013	45 372.7	1140750	379.045	128.5082	8.403	31
2014	45 245.9	1066001	335.1517	106.1478	7.022	27
2015	42 759.7	961821	315.3418	97.2807	6.302	23
2016	42 590.9	985299	323.4739	102.2394	6.85	24
2017	42 414.9	1009597	343.0571	99.2777	7.047	25
2018	42 216.8	1043977	331.8562	96.1408	7.084	25

neous decrease in the rate of greenhouse gas emissions, we have reason to believe that GDP growth in the country is accompanied by *a strong decoupling effect*);

- in Poland and the Czech Republic, in contrast to the countries previously considered, during the period under study, economic growth is accompanied only by *an expansive overcoupling effect*, which is gradually transformed into *a strong decoupling effect*. Only 2008 (the beginning of the global financial crisis) became for the Czech Republic a year of accompanying changes in GDP of *recessive decoupling-effect*.

Thus, we come to the conclusion that a real assessment of the transformation of countries to a low-carbon economy can be obtained only if a clear understanding of the type of decoupling effect, which is transformed into one or another type with a change in GDP.

To establish for the next decade changes in CO_2 emissions in Ukraine from changes in traffic and, accordingly, fuel combustion, with the same engine design and fuel type used, based on the impact of cargo, passenger and gross output, given in Table. 1, the authors based on the conducted results of the correlation and regression analysis propose the regression functional dependences, which reflect the existing relationship between the obtained result and the combination of influencing factors.

According to Table 1, it is obvious that the growth of cargo turnover, passenger turnover and GDP causes an increase in CO_2 emissions. Based on the assumption that the main factor influencing CO_2 emissions in the transport sector is fuel combustion, which is generally characterized by traffic volumes, which in turn have basic factors influencing economic growth and demographics, the authors proposed the following system of simultaneous nonlinear regressions:

$$PTV = -1794.7488 + 75.6741 \cdot \ln(GDP) + 4.1189 \cdot \sqrt{POP}, \quad (1)$$

$$CTV = -6867.6739 + 123.7834 \cdot \ln(GDP) + 382.0944 \cdot \sqrt[4]{POP} \quad (2)$$

$$OCT = 3.3388 + (0.0046 \cdot CTV)^2 + (0{,}4895 \cdot PTV)^{0.5} \quad (3)$$

$$E_{CO2} = -39.0359 + 34.1657 \cdot \ln(OCT), \quad (4)$$

where: *GDP* is GDP of Ukraine (at constant prices of 2010), UAH million; *POP* is permanent population, thousand people; *CTV* is cargo turnover, billion tons, km; *PTV* is passenger turnover, billion pass. km; *OCT* is fuel consumption in the transport sector of Ukraine, million tons; E_{CO2} is volume of CO_2 emissions from fuel combustion in the transport sector of Ukraine, million tons.

The coefficients of multifactor nonlinear regression (1)—(3) after the initial linearization by logarithm were found by the generalized least squares method (LSM) in matrix form, and the model (4) — by ordinary LSM [24]. The form of nonlinear models was chosen by the method of directed search of power and logarithmic dependences. The criterion for the best fit of the model to reality was the closest value of the coefficient of determination R^2 to unity (Table 2). This coefficient determines the fraction of variation of one of the variables, which is explained by the variation of other variables, i.e. measures the fraction of the scatter relative to the average value, which is explained by the constructed regression. Fisher's test, $F > F_{cr}$, showed that with a reliability of 95% (significance level $\alpha = 0.05$) we can assume that the corresponding R^2 is statistically significant and the proposed mathematical models are adequate to the statistical data and on the basis of the accepted system of simultaneous regressions it is possible to carry out the researches.

Table 2. **Coefficients for the Analysis of the Adequacy of the Proposed Mathematical Model**

№ regression equation	R^2	F	F_{cr} ($\alpha = 0.05$)
1	0.7137	32.4157	
2	0.6709	26.5015	3.37 ($k_1 = 2, k_2 = 26$)
3	0.8690	86.2652	
4	0.9443	458.2549	4.21 ($k_1 = 1, k_2 = 27$)

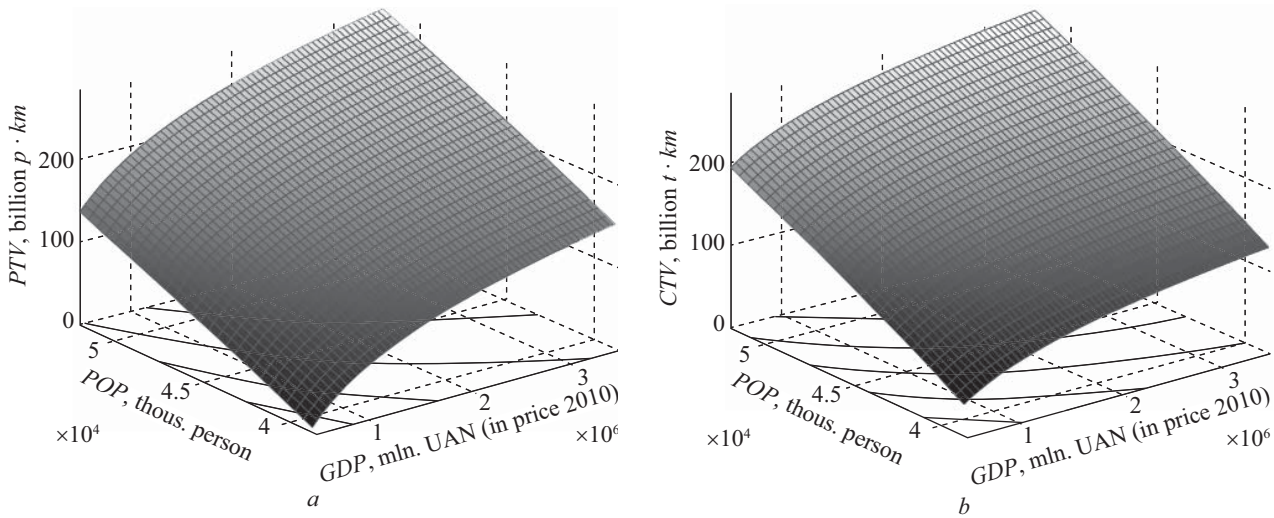

Fig.4. Surface of regression of passenger (*a*) and cargo (*b*) turnover

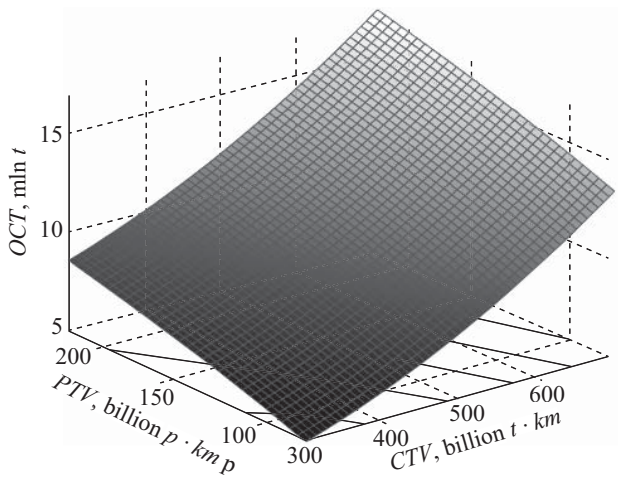

Fig. 5. Surface of regression of fuel consumption in the transport sector of Ukraine

Analysing the regression equations (1) and (2), we observe their rather similar character (Fig.4). Both surfaces have a convex shape. Both factors *GDP* and *POP* contribute to the growth of indicators *CTV*and *PTV*, however, the factor *POP* causes a faster change in the indicator *CTV* in formula (2) than the indicator *PTV* in formula (1).

Both factors *PTV* and *CTV* in regression (3) also cause an increase in the indicator *OCT* (Fig. 5). The nature of this dependence is different — the surface has a convexity to the bottom in contrast to the previous two.

In Fig. 6 solid line shows the regression equation (4), the round markers show the initial statistics for 1990—2018 with Table 1, the squares indicate the predicted values.

According to the State Statistics Service of Ukraine [25], the population as of January 2020 amounted to 41,401.96 thousand people. Instead, according to the Modelling Report prepared by the Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine (IEF) for the Government of Ukraine [26], it was established that the population of Ukraine in 2030 will be 40.6 million people, and in 2050 39.7 million people.

Economic growth is also expected in Ukraine. According to [27] starting from 2019, GDP is projected to grow on average by 4.2% over the year, and after 2030 by 3.2. However, according to the State Statistics Service of Ukraine [28], in 2019 GDP grew by only 3.2%, and in 2020 due to the COVID-19 pandemic, there is even a decline.

In fact, the pace of economic growth in Ukraine will be determined by the success of structural reforms, product and geographical diversification of exports and, in particular, the warming of the domestic market. To do this, starting from 2020, it is necessary to conduct a large-scale investment campaign, the growth rate of gross fixed capital formation should reach at least 8—14%,

2020—2025, and 15—18%, 2021—2050. In this case, the rate of accumulation of fixed capital to GDP should reach 20—24%, which is the initial condition for accelerating economic growth [29].

Among other important factors that should ensure economic growth in Ukraine is the achievement of a general political consensus. Then the economy will receive a strong impetus for the development of individual industries and for the economy as a whole.

Therefore, we consider it reasonable to choose an average growth rate of 3% per year until 2050 under scenario 1, 3.5% under scenario 2 and 3.7% under scenario 3 [26]. Having determined the forecast volumes of GDP for the medium and long term and guided by formulas (1)—(4), the calculation of the forecast values of the relevant indicators is carried out. The forecast values are summarized in Table. 3.

According to Table 3, the limited pace of implementation of national and municipal policies (climate, energy efficiency, etc.) observed in previous years and the maintenance of which is envisaged in Scenario 1 will still have an impact on overall greenhouse gas emissions in some sectors of Ukraine, however, without a new climate policy in transport or an updated National Transport Policy, greenhouse gas emissions will increase very rapidly, as we can see from Table 3 and Fig. 6.

This necessitates the introduction of key measures to reduce carbon emissions under Scenario 2: upgrading the rolling stock of private and public transport to improve energy efficiency; continuing to stimulate the transition to the use of electric vehicles in passenger traffic; continuing to stimulate the use of liquefied natural gas (cheaper, less greenhouse gas emissions and harmful substances); growth of the share of biofuel consumption in the next 10—20 years; optimization of the structure of passenger and freight traffic in cities. Due to such measures, the estimated value of fuel consumption is expected to decrease in accordance with NDCs2.

Projected values of CO_2 emissions according to the three scenarios are indicated by squares

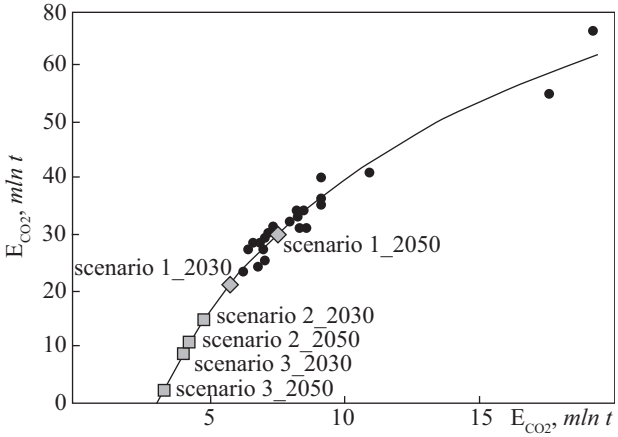

Fig. 6. Graph of CO_2 emissions by vehicles depending on fuel combustion volumes

in Fig. 6. As we can see in the first scenario, CO_2 emissions increase to the level of 2009. Based on the results of modelling of Scenario 3, greenhouse gas emissions in 2030 will be reduced by 53.6% compared to the reference year in transport, in 2050, CO_2 emissions will be reduced by 90.1%, which will be consistent with the Strategy of low-carbon development of Ukraine until 2050 year, where the respective percentages of reduction are 60 and 90% [27].

The results of the conducted decoupling- analysis show that the implementation of Scenarios 2 and 3 will contribute to the support of economic growth of *strong decoupling-effect* in the country, in which, as noted earlier, economic growth is prone to growth and negative impact on the environment, on the contrary, is prone to decline. If the government chooses Scenario 1 in 2050, we can expect only *a weak decoupling-effect*, in which economic growth rates, along with CO_2 emissions, tend to increase, but the growth rates of the former are higher than the growth rates of the latter.

The success of any of these projects, first of all, will be determined by the conditions of effective financial support. In many countries where such support is available (particularly in the EU), there have been significant advances in the movement of transport sector on a low-carbon trajectory. However, in many countries such subsidies

are at a very low level, due to which there is still a high intensity of carbon emissions.

A generally accepted effective way to mobilize financial resources is a tax mechanism. However, the environmental taxes provided by the Tax Code of Ukraine (hereinafter — TCU) are far from fulfilling this task. Their share in GDP and tax payments is very low and inadequate to the nature of the economy. Unfortunately, the tax base is not related to environmental pressures.

Therefore, the current environmental taxes do not affect the intensity of carbon reduction. We need a new paradigm for building such a tax mechanism, which would be an effective tool for a global system of motivation for sustainable low-carbon development, both the economy as a whole and its individual sectors [7, p. 323].

For this purpose, we propose to introduce a mechanism for owners of vehicles to pay an environmental tax on greenhouse gas emissions and other pollutants from fuel combustion during in transport implementation, the so-called carbon tax on fuel (Fig. 7), and, consequently, to amend the following legislative acts of Ukraine, in particular the Tax Code of Ukraine, the Budget Code of Ukraine and the Draft Law of Ukraine *on Amendments to the Budget Code of Ukraine in terms of the Introduction of the State Decarbonisation Fund*.

Thus, the results of the present study states that according to the National Inventory of Anthropogenic Emissions [30], more than 10% of total greenhouse gas emissions are emissions from transport, the amount of which depends on changes in GDP, population and other factors.

Table 3. **The Results of Modelling the Forecast Indicators of Ukraine's Economic Growth and the Carbon Trace of Transportation**

Indicators	2030			2050		
	scenario	scenario	scenario	scenario	scenario	scenario
The permanent population of Ukraine, *POP*, million people	40.6			39.7		
GDP of Ukraine *GDP*, % (at constant prices in 2010), UAH mln. (with an average annual growth, %)	1389997.8 (3%)	1458966.6 (3.5%)	1487406.6 (3.7%)	2510490.6 (3%)	2903035.6 (3.5%)	3076129.1 (3.7%)
Passenger turnover, *PTV*, billion pass. km	815999.8	543.2332	163.1956	10.958	41	41
Cargo turnover, *CTV*, billion tons km	307.0002	312.9946	315.3842	349.8669	367.8500	375.0189
Fuel consumption in the transport sector of Ukraine, *OCT*, million tons without taking into account the transition to other fuels and the use of more economical engines	5.8358	6.0378	6.1182	7.5498	8.1395	8.3751
Volume of CO_2 emissions from fuel combustion in the transport sector of Ukraine, E_{CO2}, million tons, without taking into account the transition to other fuels and the use of more economical engines	21.2328	22.3954	22.84716	30.0308	32.6001	33.5752
Fuel consumption in the transport sector of Ukraine, *OCT*, million tons (reduction of the calculated value due to the transition to other fuels and the use of more economical engines, %)	5.8358 (–0%)	4.8302 (–20%)	4.2827 (–30%)	7.5498 (–0%)	4.0697 (–50%)	3.3501 (–60%)
Projected volume of CO_2 emissions from fuel combustion in the transport sector of Ukraine, E_{CO2}, million tons	21.2328	14.77152	10.66111	30.0308	8.918274	2.269514
Decoupling index relative to the reference year	–0.1726	–0.6921	–0.9817	0.1898	–0.3033	–0.4100

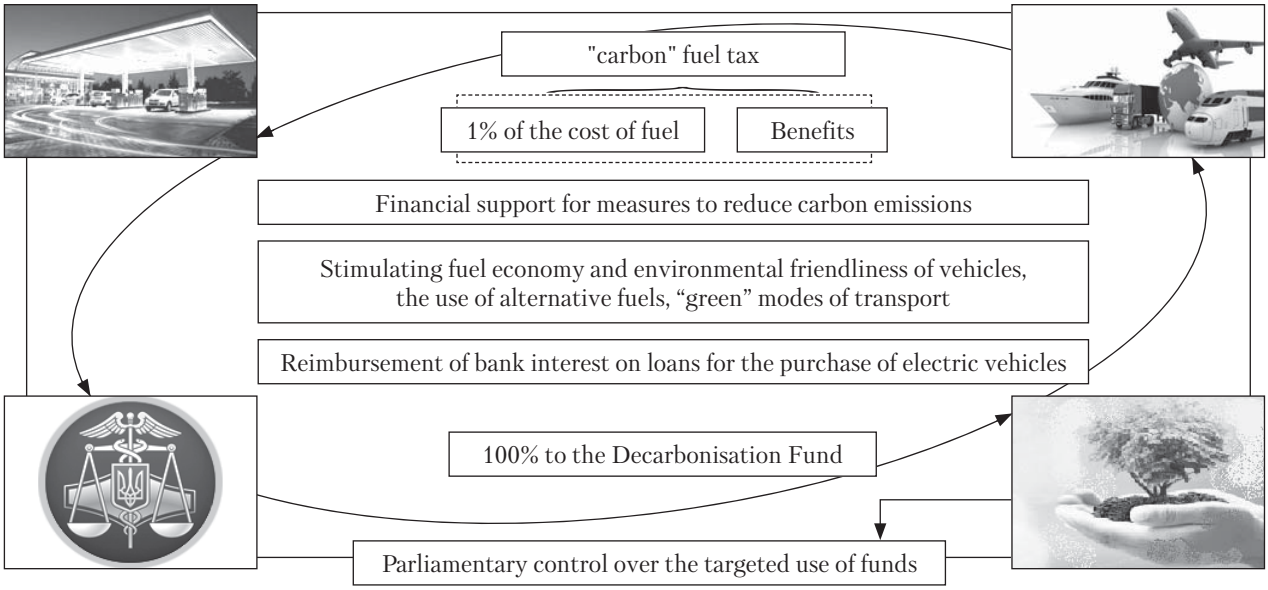

Fig. 7. The mechanism for paying the carbon fuel tax

Having chosen as a strategic guideline for the transformation of Ukraine's economy to climate neutrality, the government should decide to increase the ambition to reduce the carbon trace of multimodal transportation through the use of, first of all, an arsenal of effective fiscal measures. In particular, the introduction of a mechanism for paying the carbon fuel tax, which will ensure fair treatment of environmental pollutants and the formation of the investment potential of the Decarbonisation Fund, the intended use of which should be subject to parliamentary control.

In order to implement the submitted proposals, it is necessary to make additions and changes to:

Tax Code of Ukraine in terms of payment of environmental tax;

Budget Code of Ukraine in terms of formation of state trust funds;

Draft Law of Ukraine *on Amendments to the Budget Code of Ukraine on the introduction of the State Decarbonisation Fund* in terms of forming sources of funding for the State Decarbonisation Fund.

The introduction of this mechanism of taxation of greenhouse gas emissions and pollutants will help reduce the carbon trace of transport through the customs territory of Ukraine, and thus contribute to the implementation of obligations with NDCS2 under the Paris Climate Agreement.

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ПІДВИЩЕННЯ АМБІЦІЙНОСТІ ДО СКОРОЧЕННЯ ВУГЛЕЦЕВОГО СЛІДУ МУЛЬТИМОДАЛЬНИХ ПЕРЕВЕЗЕНЬ В УМОВАХ ТРАНСФОРМАЦІЇ ЕКОНОМІКИ УКРАЇНИ ДО «КЛІМАТИЧНОЇ НЕЙТРАЛЬНОСТІ»

Вступ. Стратегічним орієнтиром трансформації економіки України до «кліматичної нейтральності» обрано підвищення амбіційності до скорочення вуглецевого сліду мультимодальних перевезень завдяки застосуванню арсеналу дієвих регуляторних та фіскальних заходів.

Проблематика. Пошук шляхів підвищення амбіційності до скорочення вуглецевого сліду мультимодальних перевезень в умовах трансформації економіки України до «кліматичної нейтральності».

Мета. Розробка сценаріїв скорочення вуглецевого сліду мультимодальних перевезень задля забезпечення збереження довкілля та благополуччя прийдешніх поколінь.

Матеріали та методи. Використано методи: економіко-математичного моделювання на основі кореляційно-регресійного аналізу — при визначенні залежності обсягів викидів парникових газів від обсягів споживання палива в транспортному секторі, обсягів ВВП та чисельності постійного населення, вантажо- та пасажирообігу; декаплінг-аналізу — при оцінюванні впливу транспортних перевезень на довкілля; компаративного аналізу — при вивченні еластичності викидів парникових газів зі зміною обсягів ВВП у країнах з протяжністю транспортних шляхів, наближених до України; стратегічного аналізу — при оцінюванні реалістичності Національно визначеного внеску; сценарного прогнозування — при визначені альтернативних сценаріїв зміни обсягів викидів парникових газів за умови нарощування обсягів транспортних перевезень.

Результати. Вперше запропоновано механізм сплати «вуглецевого» податку з палива, який забезпечить справедливе ставлення до забруднювачів навколишнього середовища та обґрунтоване формування інвестиційного потенціалу Фонду декарбонізації.

Висновки. Обравши стратегічним орієнтиром трансформації економіки України до «кліматичної нейтральності», уряд країни має прийняти рішення щодо підвищення амбіційності до скорочення вуглецевого сліду мультимодальних перевезень завдяки застосуванню, насамперед, арсеналу дієвих фіскальних заходів.

Ключові слова: антивуглецева політика, вуглецеві викиди, «вуглецевий» податок з палива, декаплінг, мультимодальні перевезення, кліматична нейтральність.