sciendo

RURAL SUSTAINABILITY RESEARCH
47(342), 2022
ISSN – 2256-0939

Received: 17 April 2022 Revised: 20 June 2022 Accepted: 27 June 2022

Global Trends of Decarbonisation as a Determining Factor for the Development of External Economic Activity of Metallurgical Enterprises

Nataliia Levchenko [1], Ganna Shyshkanova [1], *George Abuselidze [2], Yuriy Zelenin [3], Volodymyr Prykhodko [4], Maksym Kovalskyi [5]

[1] National University "Zaporizhzhia Polytechnic", Ukraine
[2] Batumi Shota Rustaveli State University, 35/32 Ninoshvili/Rustaveli street, Batumi, Georgia
[3] Interregional Academy of Personnel Management, Ukraine
[4] State University "Uzhhorod National University" (SU UzhNU), Ukraine
[5] Central-Western Interregional Department of the Ministry of Justice, Ukraine

Abstract. The article states that in the conditions of climate crisis aggravation the decarbonisation of the economy acquires the status of a global initiative aimed at achieving zero CO_2 emissions by 2050. It is emphasised that this initiative is closely accompanied by legislation, business modernisation programmes and the creation of equal conditions for both domestic producers and exporters of carbon-intensive products (in particular, through the introduction of the carbon border adjustment mechanism - CBAM) and new rules of the world market. The consequences of CBAM implementation into Ukrainian metallurgical enterprises and the development of their foreign economic activity are determined in the example of Metinvest Group (Ukraine) enterprises. The ambivalence of CBAM is proven. It is substantiated that CBAM implementation will not accelerate, but, on the contrary, will slow down the process of decarbonisation, which will eventually lead to the loss of domestic metallurgical enterprises' competitive position in the European market of metal products. Regarding the need to take transitional measures to decarbonise the metallurgical business (first of all, to ensure proper investment), the decision should be based on the expected decoupling effect - positive dynamics of economic growth while reducing the negative impact on the environment. The estimating method of the decoupling effect has been modified according to the integrated approach. A trend analysis of the integrated decalin effect indicator and its components was performed in Metinvest Group companies (Ukraine). Based on the results of econometric analysis of the impact of investment on greenhouse gas emissions, the author's model for determining the volume of investment in the process of decarbonisation of metallurgical enterprises for the period up to 2050 is proposed. Comparative analysis is performed regarding investment in the process of decarbonisation under the scenarios by GMK Center, IEA, McKinsey and Roland Berger, as well as the author's model.

Key words: carbon tax, decarbonisation, carbon border adjustment mechanism for imports, emissions trading scheme.

Introduction

At present, one of the key priorities of the developed world is combatting climate change. The latest analysis of the United Nations Intergovernmental Panel on Climate Change (IPCC), published in August 2021, predicts significant progress in global warming with temperatures rising by 1.5 °C by 2030 (Popov *et al.*, 2021). Therefore, representatives of government, business and civil society in developed countries are actively engaged in dialogue at the level of international diplomatic events, economic forums, media on the introduction of the "green course" and the process of decarbonisation and achieving zero CO_2 emissions by 2050. In particular, in the EU, this initiative is closely accompanied by legislation, business modernisation programmes and the creation of a level playing field for both domestic producers and exporters of carbon-intensive products (in particular, through the introduction of a new carbon border adjustment mechanism (CBAM)) (European Commission, 2021).

* Corresponding Author's email: george.abuselidze@bsu.edu.ge

DOI: 10.2478/plua-2022-0008

This creates new rules of the game for business. Thus, producers of carbon-intensive products, and especially metallurgical companies, are forced to rethink their business models considering the requirements of the decarbonisation process (Vervega, 2021). Previously, Ukrainian metallurgical enterprises faced the usual regulatory mechanisms, but now the EU is as close as possible to the introduction of a new CBAM (Makarenko, 2021), the need for which is explained by three main reasons.

The first reason is the globalisation of the decarbonisation trend and the risk of carbon leakage. For example, at the last summit in the summer of 2021, G7 leaders adopted trade ministers' conclusions on "recognising the risk of carbon leakage" and said they would work together on these risks with their trading partners to bring their practices closer to their Paris commitments. With this statement, the G7 countries have sent a clear signal to their trading partners that they see the risk of carbon leakage as a serious problem in the context of international trade and global efforts to mitigate climate change (Makarenko, 2021);

Secondly, CBAM is proposed as an alternative to carbon leakage mitigation measures currently being implemented within the emissions trading system;

The third one is the EU's growing climate ambitions (ambitions to reduce GHG emissions). As such ambitions increase, the gap with other countries will only widen and the risk of carbon leakage will increase accordingly, in particular due to further reductions in total emissions in the European Emissions Trading System (as a result of tougher EU emissions reduction targets as a whole) (Makarenko, 2021).

The introduction of CBAM in the near future means that it is unacceptable to ignore the decarbonisation commitment today, as otherwise Ukrainian metal producers risk losing the status of players in the European metal products market. According to statistics, over the past 5 years, enterprises in the country's steel sector, which is indicative of all metallurgy, have made 1.7 times less capital investment than the global average. Obsolescence of equipment and risks of non-compliance of metal products with environmental standards of the EU, which plans to halve CO2 emissions by 2030 (Zinchenko, 2021), threaten the loss of domestic metallurgical enterprises' competitive position in the European metal market. Therefore, the metallurgical business should learn that the issue of decarbonisation is a long-term global trend that will increasingly affect its competitiveness (Makarenko, 2021), and therefore, its further development should be based on the principles:

- decarbonisation and strategic foresight;
- implementation of environmental behaviour in practice;
- increase of regulatory flexibility;
- accelerated creation of partnerships focused on climate protection;
- digitisation of data and processes to build trust and confirm results (Makarenko, 2021).

The introduction of customs instruments for CBAM has long been discussed in the scientific and political community. In particular, by Christian Hoffmann, Michel Van Hoey, and Benedikt Zeumer in the article "Steel players across the globe, and especially in Europe, are increasingly facing a decarbonisation challenge". Hoffmann et al. (2020) emphasise the introduction of CBAM as a viable tool to reduce carbon emissions by metallurgical enterprises. At the same time, in "Metals Provide an Energy Transition through Their Use in Low-Carbon Technologies" (Whiteside, 2020), James Whiteside notes that growing demand for metal products means that metal production must increase while reducing absolute emissions if we are to achieve the objectives of the Paris Agreement. CBAM is a "blunt instrument" to achieve these goals, which would radically change the economy of production with far-reaching consequences. Every metal has its "sore point - copper in the mine, steel in the factory or aluminium in electricity prices - but each of them will suffer" (Whiteside, 2020).

In "Carbon taxes: more carrots and sticks needed?" (Kettle, 2021), Julian Kettle notes that in order to give the necessary impetus to the decarbonisation of metallurgy, carbon whiplash and gingerbread must be coordinated, i.e., carbon tax and carbon prices must be as close as possible and gradually increase, as carbon emissions prices do not meet funding needs for metallurgy (Kettle, 2021).

Hence, as we can see, the opinions of scientists on the feasibility of introducing CBAM are quite different. In addition, practical experience in its application is still not sufficient. Until recently, the only example of such an instrument was the state of California (USA), where it is used to import electricity (Makarenko, 2021).

The vast majority of countries are trying to solve the issue of reducing carbon emissions (decarbonisation of the economy) through: "green" public procurement; introduction of restrictions on capacity utilisation and volumes of carbon-intensive products ("double control"); introduction of a carbon tax; granting tax preferences on carbon taxation; a system of GHG emission allowance trading or a combination of carbon taxation and GHG emission allowance trading; border carbon adjustment.

Analysis of the decarbonisation policy pursued in different countries

A clear example of tackling carbon reduction through green public procurement is China, which

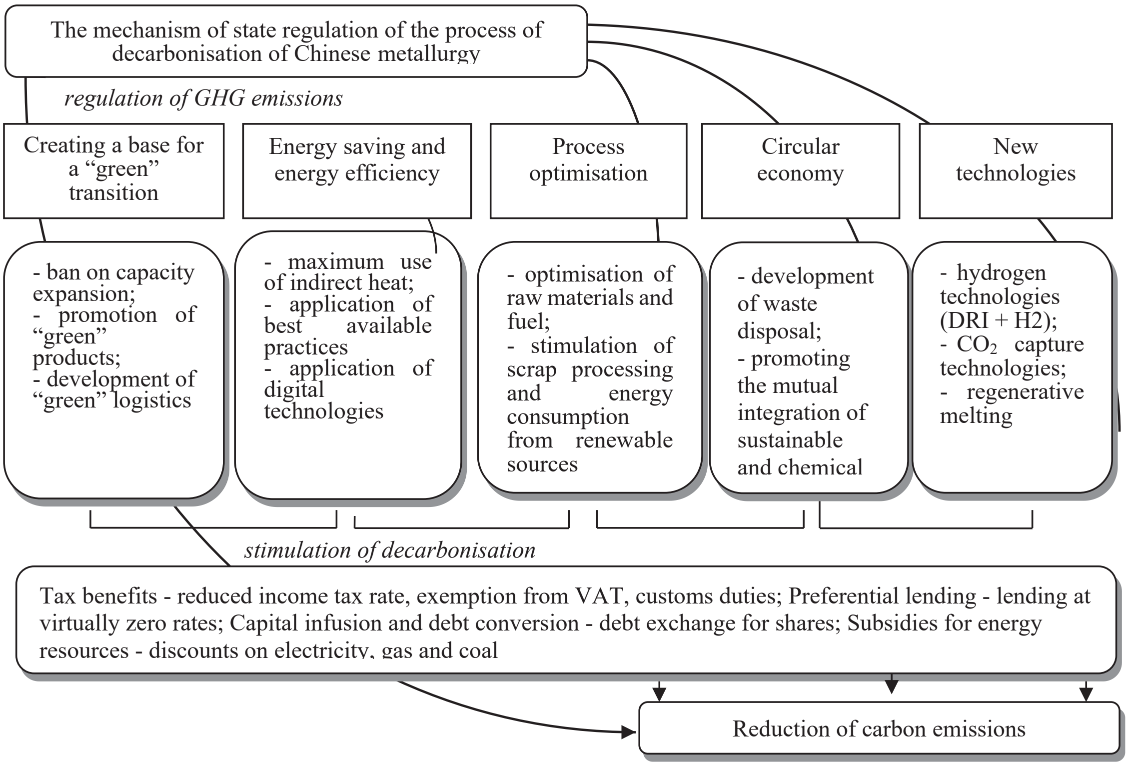

Figure 1. Tools for state regulation of the decarbonisation process of Chinese metallurgy by Working Guidance (Tarasenko, 2021).

published two policy strategy papers on the eve of the COP26 summit, setting out policy priorities for decarbonising the country's economy. The first, "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in the Full and Faithful Implementation of the New Development Philosophy" (The State Council of the People's Republic of China, 2021a), sets out the foundations of China's long-term strategy for decarbonising the economy, setting key goals and measures in a wide range of industries. The second – "Action Plan for Reaching Carbon Dioxide Peak Before 2030" (Action Plan) (The State Council of the People's Republic of China, 2021b) - gives a more detailed description of the tools of state regulation of the decarbonisation process in each of the specific industries. These two documents reflect the formation principle of the document system '1 + N'. In this formula, '1' is the Working Guidance, the document that defines the framework of decarbonisation policy. 'N' is a series of documents detailing the tools for implementing the decarbonisation policy (Tarasenko, 2021). The first point of the Working Guidance Roadmap is "Promoting Green Products" (Figure 1).

Instead, before deciding on the production of "green" products, it is necessary to pay attention to the creation of an appropriate market. This is why Working Guidance envisages the introduction of such an instrument of state regulation of the decarbonisation process as "green" public procurement.

However, China's policy of decarbonisation is not limited to "green" public procurement. In order to achieve the ambitious goals of reducing carbon emissions, the country has introduced the so-called "double control", under which the government sets limits on energy consumption (specific and total) in terms of capacity utilisation and production of carbon-intensive products. That is, a ban on capacity expansion and control of production volumes are also becoming tools to achieve ambitious goals to reduce CO_2 emissions (Tarasenko, 2021).

However, most countries have introduced a carbon tax to reduce GHG emissions, with rates ranging from \$ 1 / t of CO_2e in Poland to \$ 139 / t CO_2e in Sweden. The highest carbon tax savers are in Switzerland and Liechtenstein - \$ 101 / t CO_2e, in Finland - \$ 77, Norway - \$ 64 / t CO_2e and France \$ 55 / t CO_2e. Denmark is within the average rate of EU countries (from \$ 20 to \$ 30). Minimum carbon tax is in Spain, Ireland and Slovenia. It costs less than \$ 10 in Portugal, Latvia and Estonia (Chekunova, 2021).

Characteristic features of carbon tax in Ukraine are:

- low level of CO_2 emissions tax rate. According to the TCU (Verkhovna Rada of Ukraine, 2010), the tax on CO_2 emissions is currently UAH 10 / t CO_2 (USD 0.36 / t CO_2);

- a broad tax base, covering a significant part of the economy. While in foreign countries, the CO_2 tax base is determined taking into account the risks of production outflows ("carbon leakage") and taking into account the vulnerability of the industry;
- lack of sustainability of carbon taxation. G experience shows that carbon taxes are more effective when they are set at a high level and when they are sustainable over time. A clear example of this is the introduction of a carbon tax in Sweden, which has significantly reduced them;
- compensatory nature. Carbon tax is a national mandatory tax, which is determined from the actual amount of emissions into the atmosphere, i.e., only compensates for damage, and incentives for the transformation to low-carbon production are virtually absent;
- does not provide for the targeted use of carbon tax revenues by current legislation, while in foreign practice most countries direct their revenues, in part or in full, to support certain sectors of the economy or households in the form of direct subsidies to households or funding for climate change adaptation and/or transformation of the industry to low-carbon production;
- lack of benefits for vulnerable groups. In most countries, there is no clear policy to reduce the negative impact of carbon tax on vulnerable populations other than direct tax exemptions for such groups. In Alberta, for example, part of the carbon tax revenue goes to households to compensate for rising fuel and electricity prices. In British Columbia, for example, targeted revenue sharing is one of the most important aspects of the carbon tax. The current tax rate in Ukraine is unlikely to have a significant impact on the poor, but this situation may change if the carbon tax is raised to encourage reductions in CO_2 emissions in areas not covered by the System of Monitoring, Reporting and Verification of Gases (MRV) (Ministry of Environmental Protection and Natural Resources of Ukraine, 2019).

Thus, the application of carbon tax in Ukraine alone will not achieve the ambitious goals of decarbonisation of the economy set by NDC2 (Ministry of Environmental Protection and Natural Resources of Ukraine, 2020) to the Paris Agreement (Verkhovna Rada of Ukraine, 2016), which provides for limiting GHG emissions at a level not exceeding 60% by 2030. 1990 Therefore, Ukraine currently plans to introduce a system of CO_2 emissions trading (ETS) for large emission sources in energy and industry, i.e., to implement carbon pricing reform in line with the main objectives of state policy and government priorities, in particular, Ukraine's Energy Strategy for the period until 2035, the Strategy of low-carbon development until 2050 (Ministry of Environmental Protection and Natural Resources of Ukraine, 2018) and other strategies for the economic development of certain industries), as well as Ukraine's international obligations to reduce GHG emissions (Ministry of Environmental Protection and Natural Resources of Ukraine, 2019).

With the introduction of carbon taxation, some countries are trying to address the issue of accelerating the decarbonisation process by encouraging implementation. In this case, the experience of South Korea deserves special attention, the state policy of decarbonisation of which provides incentives for metallurgical enterprises to transform into low-carbon production by:

- providing state aid in promoting foreign investment in the innovative development of metallurgical enterprises;
- stimulating the creation of industrial conglomerates - chaebols;
- providing access to new technologies and knowledge transfer;
- providing low-interest loans to cover debts and develop the country's largest metallurgical corporations.

According to our opinion, the experience of Belarus is also noteworthy. Due to its tax legislation, in order to accelerate the process of decarbonisation, the tax preferences are provided to payers by reducing the environmental tax by the amount of expenses incurred for the implementation of decarbonisation projects.

As for the implementation of the GHG emission allowance trading system as one of the instruments of state regulation of the decarbonisation process, it should be noted that in the early 2000s, according to the EU Directive, a market for GHG emission allowance trading (EU ETS) was created. To date, carbon leakage is addressed by the EU ETS's free allowances system, the fourth phase of which will begin in 2021 and run until 2023. Following the free allocation of emissions certificates, many industries, including metallurgy, will face significantly higher carbon prices. According to the Carbon Pricing Leadership Coalition, carbon prices will be in the range of \$ 50-100 / t CO_2e by 2030 to achieve the goals of the Paris Agreement. This is an incredibly high price for some states and low for others. Therefore, it is believed that the introduction of

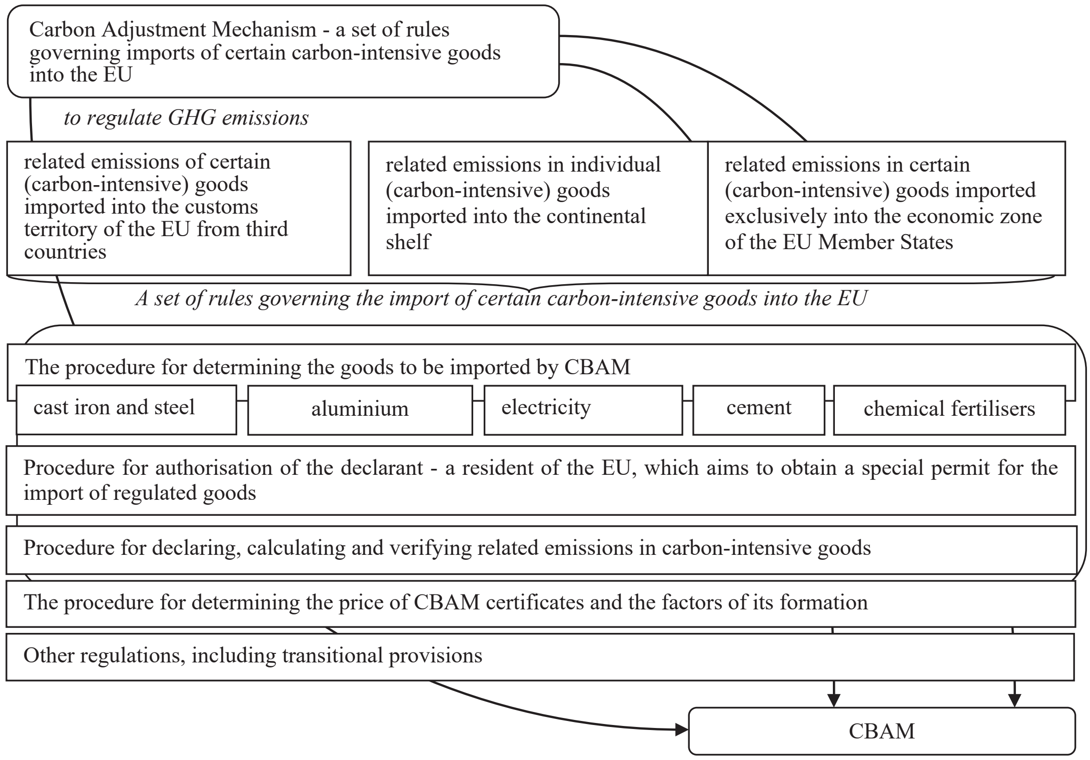

Figure 2. The mechanism of customs carbon adjustment of imports, proposed by the European Parliament.

CBAM (Figure 2) will solve the existing problem of a significant gap between the capabilities of states to decarbonise carbon-intensive production (Chekunova, 2021).

However, the introduction of CBAM requires transitional measures. According to a study by Allianz Research (Allianz Trade, 2020), such measures may be as follows:

- Subsidising transitional investments in technologies and facilities with low carbon emissions (especially those related to the hydrogen economy).
- Introduction of a “blank” test phase for several years, when, for example, free certificates are distributed among all participants.
- Apply EU CBAM to selected sectors only, focusing on “test” sectors such as cement and steel production.
- Implementation of bilateral preferential agreements that release partners from obligations, such as purchasing emission certificates or incurring CBAM-related costs (Chekunova, 2021).

The EU’s task of implementing CBAM is to take into account the expectations, not only of countries with a high level of economy (for example, Germany with its more export-orientated industries), but also emerging countries accelerating the decarbonisation of carbon-intensive sectors (Chekunova, 2021). The introduction of CBAM according to research by Boston Consulting Group – BCG (2020) can have a detrimental effect on carbon-intensive industries, and especially on metallurgy. Therefore, while the EU is developing details of the implementation of the CBAM in relation to third countries (including Ukraine), it is necessary to assess the impact of CBAM on Ukrainian business and use all opportunities to reduce decarbonisation pressure, especially on metallurgical enterprises.

In 2020, the EU was Ukraine’s main trading partner. The share of trade in goods and services with the EU was 40.1% of Ukraine’s total trade. In 2021, Ukrainian companies exported $ 20.75 billion worth of goods to the EU (the EU’s share in merchandise exports was 41.45%). About two thirds of imports are potentially affected by CBAM (Chekunova, 2021).

Therefore, for any of the CBAM formats, it is expected that the payments of domestic metallurgists for CBAM, regardless of the scenario of its implementation, will amount to € 400 million per year (Table 1).

The EU considers CBAM as a special fiscal instrument that will force producers of imported products to pay the same price for CO_2 emissions as European producers (Makarenko, 2021). Thus, the introduction of CBAM will not accelerate, but

Table 1

Consequences of CBAM implementation for metallurgical enterprises of Ukraine (Makarenko, 2021)

Product	Export volume in 2019, thous t	Expected percentage of specific CO_2 emissions, t	The expected average price of emissions during 2023-2027, euros per tonne	Expected tax amount for the year, million euros	The expected amount of tax during 2023-2027, million euros
Cast iron	546	2.1	22.2	24.8	124
Semi-finished products	3 299	2.8	22.2	208.0	1 040
Rolling	1 835	3.0	22.2	122.1	611
Welded pipes	105	3.0	22.2	7.0	35
Ferroalloys	404	2.1	22.2	18.8	94
Pellets	6 258	0.1	22.2	7.4	37
Concentrate	6 465	0.1	22.2	9.8	49
Total				397.9	1990

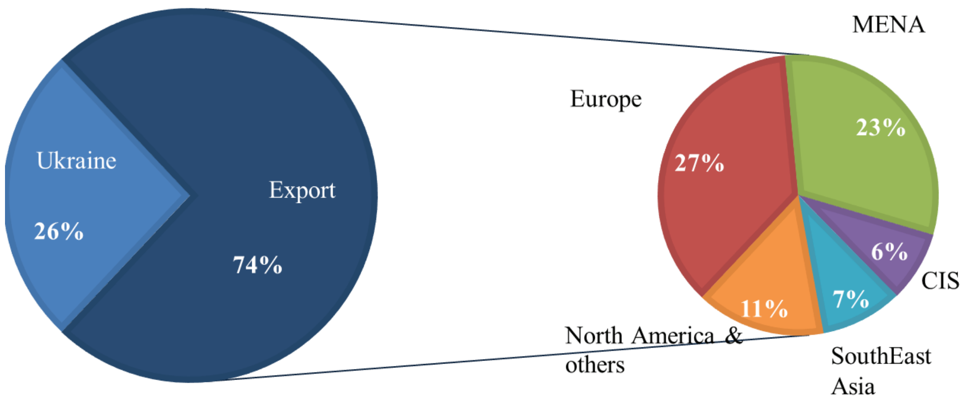

Figure 3. Sales structure by metallurgical segment of Metinvest Group companies (Ukraine) by markets in 2020.

rather slow down the process of decarbonisation, as the capital investment of steel producers may be reduced by 12% or € 130 million per year, which will eventually lead to the loss of their competitive position (Makarenko, 2021).

We analyse the data of Metinvest Group companies (Ukraine) in order to be convinced of the correctness of the forecasts of the effectiveness of the use of CBAM and the correctness of the determination of the vectors of acceleration of the decarbonisation process.

In the structure of consolidated income of Metinvest Group (Ukraine) enterprises in the metallurgical segment, the largest share is occupied by sales to European countries, namely 27% (Fig. 3).

xThus, the amount of income received in 2020 in European countries amounted to 2846 million US dollars, which is 756 million US dollars or 36.2% higher than the previous year. The increase in revenues was due to an increase in sales of semi-finished and flat products by 71% and 12%, respectively, as well as rising prices for all products.

Increasing the volume of imports of metal products to the EU is possible in the future; however, achieving these goals is impossible without the decarbonisation of metallurgical production. This is evidenced by the presence in the industry of a number of problems, including:

- high energy consumption of production;
- inefficient consumption of fuel and energy resources, which leads to the significant consumption of natural gas, increasing the dependence of the industry on energy imports;

- a high degree of depreciation of fixed assets (open-hearth furnaces, energy-intensive equipment of sinter plants, concentrators, rolling mills, blast furnaces, etc.) leads to an increase in unprofitable metallurgical production;
- reduction of foreign investment in the industry;
- inefficient use of production capacity;
- growing environmental problems, etc.

Thus, Ukraine has sufficient production capacity to further increase the import of metal products, but for their full use it is necessary to develop an effective state policy of decarbonisation of the metallurgical industry, based on state support and incentives for metallurgical enterprises by decoupling, and implementing other effective tools for the decarbonisation process and development of foreign economic activity of the metallurgical sector of the economy.

Bob Ward, director of policy and communications at the Grantham Climate and Environment Research Institute at the London School of Economics, says scientists are increasingly concerned that global warming will cause turning points in the Earth's natural systems, leading to a large-scale and possibly, irreparable catastrophe, if no urgent measures are taken. Politicians try to take certain measures, but do not always listen to the advice of scientists (in particular, in this case - the need to use the results of "decapitation" analysis of economic pressure on the environment as a fundamental basis for developing state policies for decarbonisation).

Thus, the purpose of this study is to substantiate the feasibility of forming a state policy of decarbonisation (as a fundamental basis for the sustainability of foreign economic activity of metallurgical enterprises) based on the results of decoupling analysis of economic growth and growth rates of anthropogenic pressure on the environment as coupled, decoupled or negatively decoupled phenomena.

Methods

Phenomena are considered coupled if the value of the Decoupling Index (*DecInd*) is in the range from 0.8 to 1.2. Realising the fact that the *DecInd* can be both positive and negative, researchers have proposed to define expansive and recessive coupling. Depending on the density of the relationship between economic growth and anthropogenic pressures on the environment, researchers, in particular, Tario P., distinguish three subcategories and eight logical stages of the *DecInd* (Tapio, 2005).

It should be noted that 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 (Tapio, 2005; Datsii *et al*., 2021a; Datsii *et al*., 2021b).

According to the OECD methodology, the effect of decoupling is estimated by the *DecInd* and determined (OECD, 2001).

$$DecInd = \frac{\left(\frac{EP}{DF}\right)_{ending}}{\left(\frac{EP}{DF}\right)_{beginning}} = \frac{K_{EPending}}{K_{DFbeginning}}, \qquad (1)$$

where: EP – is an indicator of anthropogenic pressure on the environment (environmental pressure), natural units;

DF – economic growth rate (driving force), most often reflected in gross output, natural units;

K_{EP}, K_{DF} – growth rates of relevant indicators.

The values of the indicators are taken at the ending and beginning periods of the study (years).

Table 2

Dynamics of chain indices of indicators of economic growth and anthropogenic pressure of Metinvest Group (Ukraine) enterprises on the environment during 2011-2020, %

Indices	Years									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gross GHG emissions in CO_2 equivalent per t of steel (T_{E1})	136.3	104.4	101.8	101.3	58.4	101.5	92.3	111.6	94.0	101.3
Water intake per t of steel (T_{E2})	105.3	105.2	89.2	115.4	108.6	89.7	117.6	104.3	87.3	88.0
Generated waste per t of steel T_{E3})	102.3	121.0	101.0	122.3	94.5	84.8	136.8	104.4	101.9	99.9
Total energy consumption per t of steel T_{E4})	90.4	120.5	103.2	167.1	48.1	93.0	113.8	104.8	93.6	93.5
EBITDA (T_{Ebitda})	139.6	55.98	114.7	117.9	18.9	224.7	177.2	122.9	48.2	181.6

We introduce the following notation of indices (chain rates to the previous year):

T_{E1} – gross GHG emissions in CO_2 equivalent per 1 t of steel, %,

T_{E2} – total water intake per 1 t of steel, %,

T_{E3} – volumes of waste generation per 1 t of steel, %,

T_{E4} – total energy use per 1 t of steel, %,

T_{Ebitda} – earnings before interest, taxes, depreciation, and amortisation (EBITDA) of enterprises, %.

Since the *DecInd* characterises the density of economic growth and anthropogenic pressures on the environment as coupled, decoupled or negative decoupled phenomena, we use data from Metinvest Group companies (Ukraine) to determine it; the data are presented in the non-financial statements for 2011-2020, given in Table 2.

Results and Discussion

Based on the data presented in Table 2 to form a clearer view of the support of metallurgical production by Metinvest Group (Ukraine) by the effect of decoupling, we clearly reflect the dynamics of the growth rate of anthropogenic impact on the environment from EBITDA growth, namely:

a) gross GHG emissions in CO_2 equivalent per 1 t of steel;

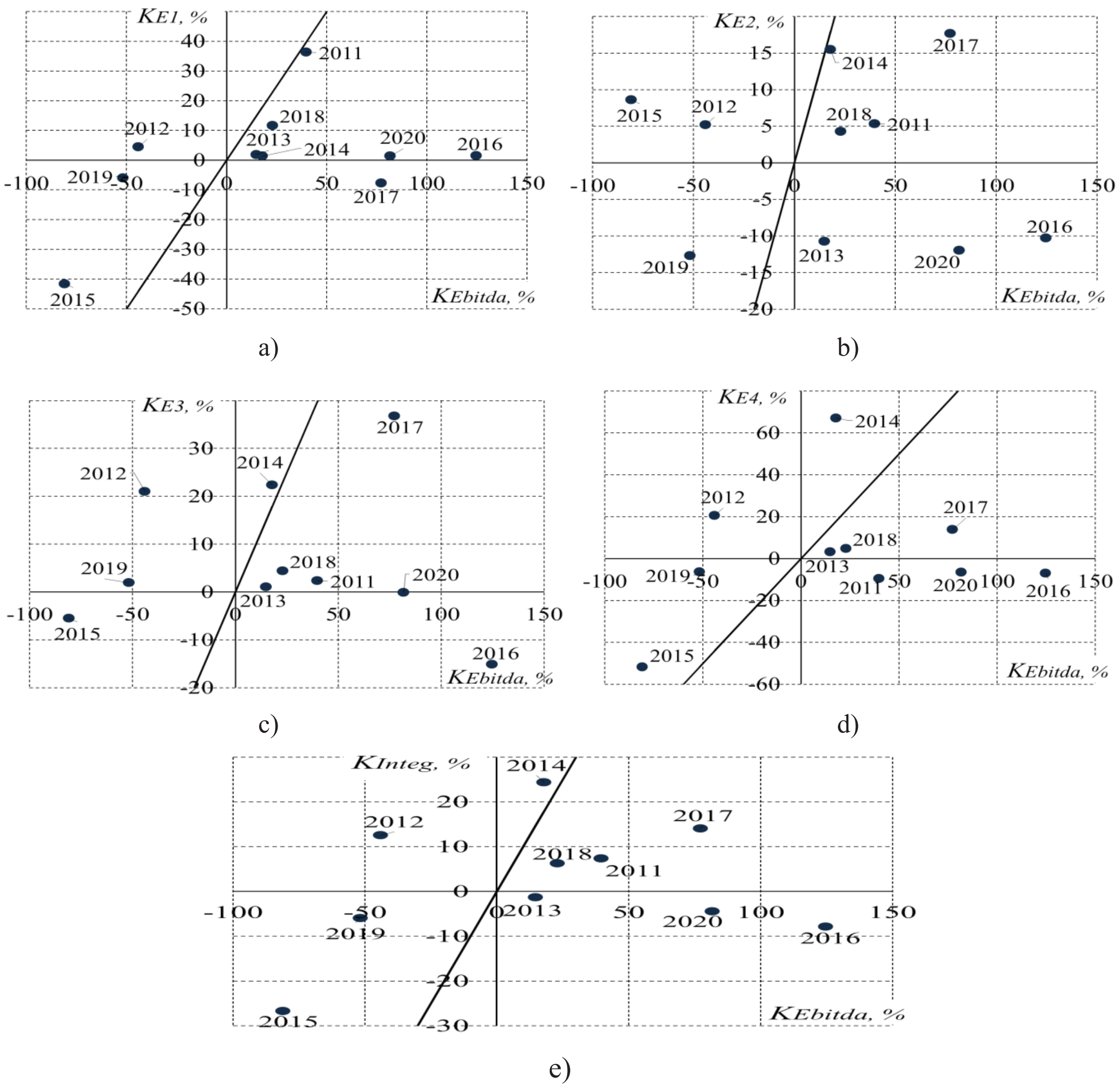

Figure 4. Dynamics of growth rates of economic growth (EBITDA) and anthropogenic pressure on the environment for a) gross GHG emissions in CO_2 equivalent per 1 t of steel; b) total water intake per 1 t of steel; c) volumes of waste generation per 1 t of steel; d) total energy use per 1 t of steel ; e) the integrated indicator of the growth rate of factors with a negative impact on the environment during 2011-2020 (Metinvest Group (Ukraine) enterprises).

b) total water abstraction per 1 t of steel;
c) volumes of waste generation per 1 t of steel;
d) total energy use per 1 t of steel;
f) integrated indicator of anthropogenic impact of enterprises (Figure 4).

For a comprehensive analysis of the dynamics of the impact on the ecology of metallurgical enterprises in the calculation of the decoupling coefficient, we used an integrated indicator, due to the geometric mean of their growth rates (Datsii *et al*., 2021a). The integrated *DecInd* is proposed to be calculated by a formula similar to (1)

$$DecInd(t) = \frac{K_{Integ,t}}{K_{Ebitda,t}},$$

where $i = \overline{1,4}$, t – is the year; K_t – is the chain growth rate of the corresponding indicator

$$K_{Ebitda,t} = T_{Ebitda,t} - 100,\% , \tag{2}$$

T_t - this is the chain indices of the corresponding indicator

$$T_t = \frac{y_t}{y_{t-1}} \cdot 100,\% ,$$

y_t - the value of the relevant indicator in the year under consideration,

y_{t-1} - the value of the corresponding indicator in the previous year to the one considered (Dvigun *et al*., 2022).

Using the chain indices of the respective indicators calculated by Formula (4), the following formula is proposed to find the integrated index of all four indicators of environmental impact, %:

$$T_{Integ,t} = \sqrt[4]{T_{E1,t} \cdot T_{E2,t} \cdot T_{E3,t} \cdot T_{E4,t}} .$$

Now we find an integrated indicator of the growth rate of factors of negative impact on the environment, %, similar to formula (2)

$$K_{Integ,t} = (T_{Integ,t} - 100)\% .$$

Guided by the classification of types of decoupling effect, given in (Tapio, 2005), and data presented in Table 3 and Fig. 4, we note that during the period studied the effect of decoupling in the activities of Metinvest Group (Ukraine) changed from strong negative decoupling (when economic growth decreases and environmental pressures increase) to weak decoupling (when economic growth outpaces the pressure of environmental pressure).

The results of the calculation of *DecInd* for each of the factors and those that are integral, in particular, are given in Table 3.

In order to be able to assess the impact of investment on GHG emissions in CO_2 equivalent per 1 tonne of steel produced by Metinvest Group (Ukraine), we find out the relationship between these indicators.

It is well known that the integrated planning of metallurgical production is impossible without taking into account energy indicators (Hryhoriev *et al*., 2017), and given that GHG emissions are likely to decrease with increasing investment, the nonlinear model was chosen as an inverse relationship showing the feedback between investments and GHG emissions, i.e.,

$$E_{CO2} = \frac{1}{f(E_{nergy}, I_C, I_{Eco}, I_R)}, \tag{3}$$

where E_{CO2} – GHG emissions in terms of CO_2 equivalent, t per t of steel;

E_{nergy} – general energy use, GJ per t of steel;

I_C – capital investment, \$ per t of steel produced;

I_{Eco} – investments in environmental protection, \$ per t of steel produced;

I_R – investment in research and development per 1 tonne of steel, t / t of steel, \$;

Table 3

Dynamics of *DecInd* activity of Metinvest Group enterprises (Ukraine) during 2011-2020

Years	*DecInd*E1	*DecInd*E2	*DecInd*E3	*DecInd*E4	*DecInd* Integ
2011	0.9146	0.1349	0.0590	-0.2409	0.1857
2012	-0.1007	-0.1186	-0.4780	-0.4671	-0.2847
2013	0.1277	-0.7243	0.0744	0.2188	-0.0870
2014	0.0774	0.8638	1.2459	3.7411	1.3597
2015	0.5129	-0.1062	0.0679	0.6397	0.3293
2016	0.0125	-0.0822	-0.1212	-0.0554	-0.0632
2017	-0.0995	0.2286	0.4763	0.1789	0.1817
2018	0.5085	0.1876	0.1941	0.2102	0.2732
2019	0.1154	0.2455	-0.0375	0.1228	0.1143
2020	0.0168	-0.1461	-0.0011	-0.0790	-0.0542

Using correlation-regression analysis (Greene, 2018) and taking into account (3), the authors proposed the following model of nonlinear regression:

$$E_{CO2} = \left(-0.4206 + \frac{0.1847}{\sqrt{E^{*}_{nergy}}} + 0.3929 \cdot I^{*}_{C} + 1.8893 \cdot {I^{*}_{Eco}}^{2} + 0.6922 \cdot \sqrt{I^{*}_{R}} \right)^{-1}, \qquad (4)$$

where: * denotes a dimensionless quantity:

$$E^{*}_{nergy} = \frac{E_{nergy}(current\ year)}{E_{O\ 2}(2020)};\ I^{*}_{Eco} = \frac{I_{Eco}(current\ year)}{I_{Eco}(2020)};\ I^{*}_{C} = \frac{I_{C}(current\ year)}{I_{C}(2020)};\ I^{*}_{R} = \frac{I_{R}(current\ year)}{I_{R}(2020)}.$$

For the simulation, the selected factors must be dimensionless values (Washington *et al*., 2020), while the initial indicators may have different dimensions, obtained by reference to the baseline value. The values for 2020 were chosen as the base values, as the final ones are known in time series.

The coefficients of multifactor nonlinear regression (4) after the initial linearisation and smoothing of the initial data were found by the method of least squares in matrix form (Washington *et al*., 2020). The type of nonlinear dependence was chosen by the method of directed search of power dependences, calculating the potentials of deviations (Washington *et al*., 2020; Greene, 2018). The criterion for the best correspondence of the model to reality was the smallest sum of squares of deviations obtained from (4) data from statistical data.

Verification by the criterion χ^2 showed that with 95% reliability the general multicollinearity in the proposed model is absent because χ^2 = 12.4421 < χ^2 (0.95; 6) = 12.5916, i.e., we believe that the linear relationship between the factors is absent and the application of the least squares method allows us to obtain reliable estimates of coefficient regression. The value of the coefficient of determination R^2 = 0.6092, which characterises the share of variation of the performance trait E_{CO2}, which is explained by regression (4), in the general variation of E_{CO2}. We can say that in 60.92% of cases, changes in selected variables lead to a change in E_{CO2}. In other words - the accuracy of the selection of the regression equation - is not high, but sufficient for economic analysis (Greene, 2018). Fisher's test, F = 2.3383 > F_{τ} (0.75; 4; 6) = 1.7871, showed that with a reliability of 75% (level of significance $\alpha = 0.25$) we can assume that the proposed mathematical model (4) is adequate statistics.

The surfaces of multifactor nonlinear regression regarding the impact of investment volumes on GHG emissions (4) are shown in Fig. 9 at fixed values at the level of 2020; the constant volume of steel production was 8.3 million tonnes and, which are absent on the axes correspondingly.

Looking at Figure 5 and the expression (8) we can conclude that the growth of total energy use leads to an increase in GHG emissions, but the impact of investment is opposite, i.e., the growth of investment is accompanied by a decline in GHG emissions. A lower degree of investment in research and development means less impact on the rate of change of GHG emissions, respectively, a greater degree of capital investment and an even greater degree of investment in environmental protection shows their greater impact on the rate of emission reduction, as shown in Fig. 5.

As Ukraine has committed to reduce specific GHG emissions from steel production to 0.54 t / t of steel by 2050 under the Paris Agreement (Verkhovna Rada of Ukraine, 2016), the decarbonisation of the steel industry is a challenge for the coming decades (2021) and there is an urgent need to introduce the best decarbonisation technologies (BAT, or OJSC - best available technologies), which will bring the level of emissions of Ukrainian metallurgical enterprises in line with European standards, which is one of the conditions of the Association Agreement with the EU (Verkhovna Rada of Ukraine, 2014). This is a big investment burden for the industry. The specific level of total investment according to GMK Center (2021) research should be up to $ 337 per tonne of steel at the volume of steel production under current conditions.

As carbon neutrality can only be achieved through a radical change in production technologies and supply chains, it will require significant investment from the industry, equivalent to building new capacity. The IEA estimates that the required investment in the metallurgical industry by 2050 under the Sustainable Development Scenario should be up to $ 866 per tonne of steel. At the same time, this figure, according to the calculations of international consulting companies McKinsey and Roland Berger, should average up to $ 1,000 per tonne of steel.

According to the calculations of the author's model to reduce carbon emissions to 0.54 t / t of steel

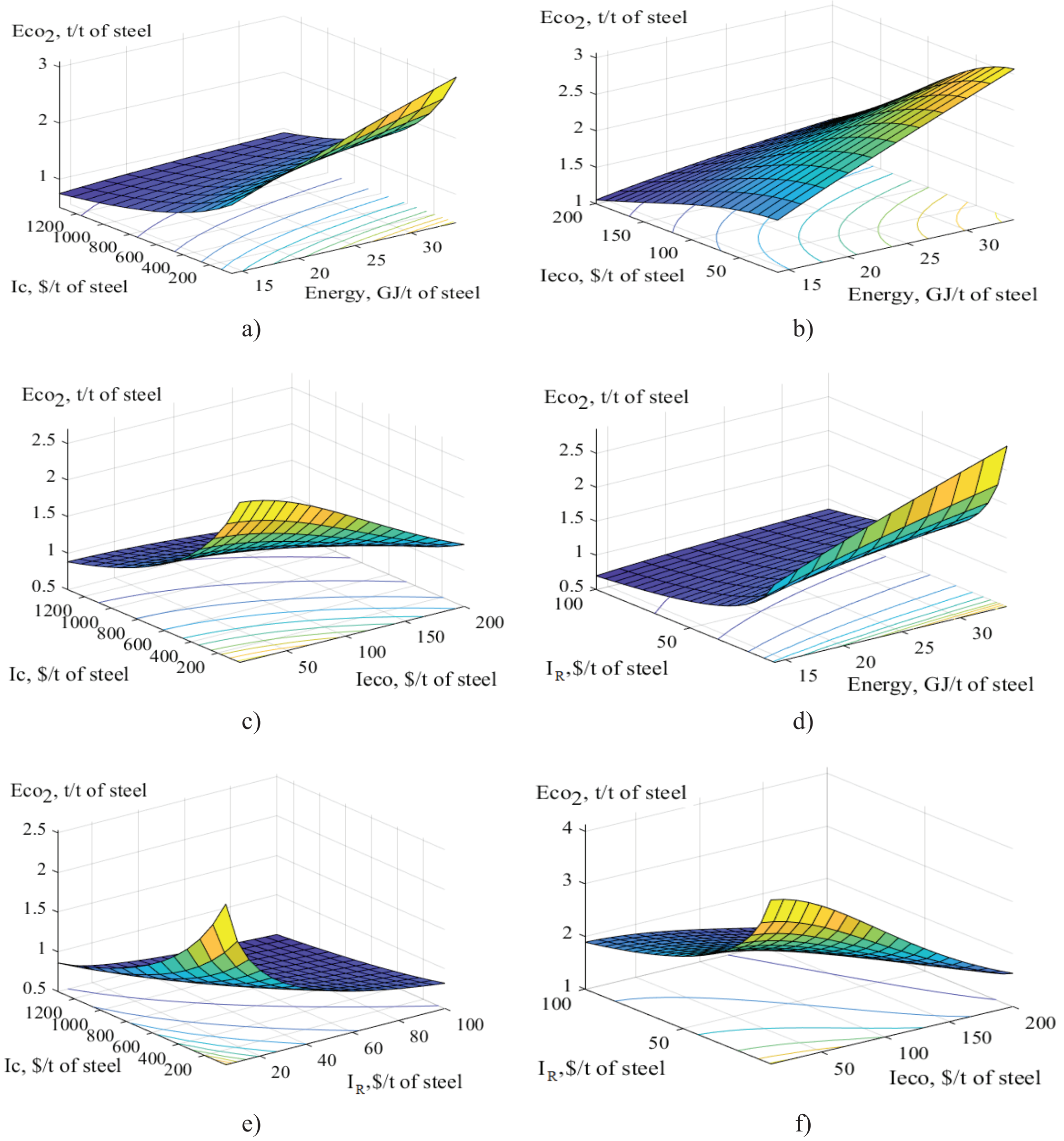

Figure 5. Surfaces of regression regarding the impact of investment volumes on GHG emissions at constant values of the corresponding indicators of 2020, which are absent on the axes: a) I_{Eco} =54.32 \$/t of steel and I_R =5.09 \$/t of steel; b) I_C =79.96 \$/t of steel and I_R =5.09 \$/t of steel; c) I_R =5.09 \$/t of steel and E_{nergy} =25.19 GJ/t of steel; d) I_{Eco} =54.32 \$/t of steel and I_C =79.96 \$/t of steel; e) I_{Eco} =54.32 \$/t of steel and E_{nergy} =25.19 GJ/t of steel; f) E_{nergy} =25.19 GJ/t of steel and I_C =79.96 \$/t of steel.

requires investment up to \$ 1,300 per tonne of steel (Table 4).

In order to reduce the pressure of decarbonisation on the metallurgical sector of Ukraine's economy, we see the need to take measures at the supranational, national and macro levels. At the supranational level, according to a study by MIT (at the Center for Energy and Environmental Policy Research) and the University of Cambridge (the University of Cambridge at the Energy Policy Research Group), within CBAM it is necessary to:

- introduce the so-called Individual Adjustment Mechanism (IAM), which has significant economic, climatic and legal benefits and will allow Ukrainian metallurgical producers to demonstrate their actual carbon intensity (Chekunova, 2021);
- create a basis for the implementation of important and mutually beneficial projects, in particular, by concluding some agreements. The agreements on the development of the low-carbon industrial sector in partner countries

Table 4

Scenarios for investment in the process of decarbonisation of metallurgy over the time horizon until 2050

Indicators \ Scenarios	**GMK Center** investment of the industry until 2050 for the implementation of OJSC	**IEA** investment in the industry until 2050 according to the Sustainable Development Scenario	**McKinsey ta Roland Berger** – industry investment by 2050	Volumes of investment in the industry according to the author's model until 2050
Volumes of investment per 1 tonne of steel, $	337	866	1000	1300
Capital investment, $ million	2177.02	6109.63	7055.00	9171.50
Investments in environmental protection, $ million	294.54	826.59	954.50	1240.85
Investment in research and development (R&D), $ million	89.64	251.57	290.5	377.65
Total energy use, TJ	171471	146377	135922	123375
Total energy use, GJ per 1 tonne of steel	20.6592	17.6359	16.3762	14.8645
Volumes of GHG emissions GHG (according to calculations for (4), t per 1 tonne of steel	1.4626	0.7523	0.6889	0.5400

over a period of time should be conducted. Besides, agreements should be provided on mutual recognition and conformity assessment in relation to certification standards and procedures as well as cooperation agreements to establish special low-carbon industrial zones and/or laboratories to demonstrate best practices in standards and technology, focusing on exports that may be affected by CBAM (Chekunova, 2021).

At the national level, in order to accelerate the process of decarbonisation of metallurgical enterprises it is necessary to perform the next eight steps:

The first step is to conclude an Agreement of Equivalence with the EU, which will prescribe the conditions for decarbonisation.

The second step is to implement Regulation (EU) 2020/852 and the Directive of the European Parliament on the formation of information support for financial and non-financial reporting of enterprises, in order to develop regulations to bring them into a single industry standard for ESG reporting.

The third step is to create a Single Information Panel of ESG-competitiveness of metallurgical enterprises based on the UA XBRL Taxonomy of IFRS 2020 (Financial reporting system, 2021), approved on 9 April 2021 by the Financial Reporting System Management Committee (established under the Memorandum of Understanding on financial development and implementation) reporting dated 18.12.2017 for No. 102/15 (Ministry of Finance of Ukraine, 2017).

The fourth step is to change the nature of carbon taxation from compensatory to incentive, guided by the principle of the maximum possible approximation of domestic legislation to EU legislation, taking into account Ukrainian national characteristics, and make changes and additions to the TCU, in particular:

- in terms of payment of carbon tax by pollutants, namely paragraph 5 of Article 242 of the TCU (Verkhovna Rada of Ukraine, 2010) on the tax base by providing for its reduction by the amount of environmental investment actually spent by taxpayers in the reporting period on innovative projects for environmental modernisation and ensuring the receipt of the environmental effect, confirmed by reporting on the monitoring and verification of $CO2$ emissions;
- in the part of VAT payment by industrial enterprises on waste recycling operations, to make additions to item 1.2 and item 1.3 of Article 195 of the TCU (Verkhovna Rada of Ukraine, 2010) concerning waste recycling operations of metallurgical enterprises. That is, paragraph 1.2 of Article 195 of the TCU (Verkhovna Rada of Ukraine, 2010) to add the paragraph: operations on the supply of goods produced as a result of recycling of waste from metallurgical enterprises are taxed at a zero rate. At the same

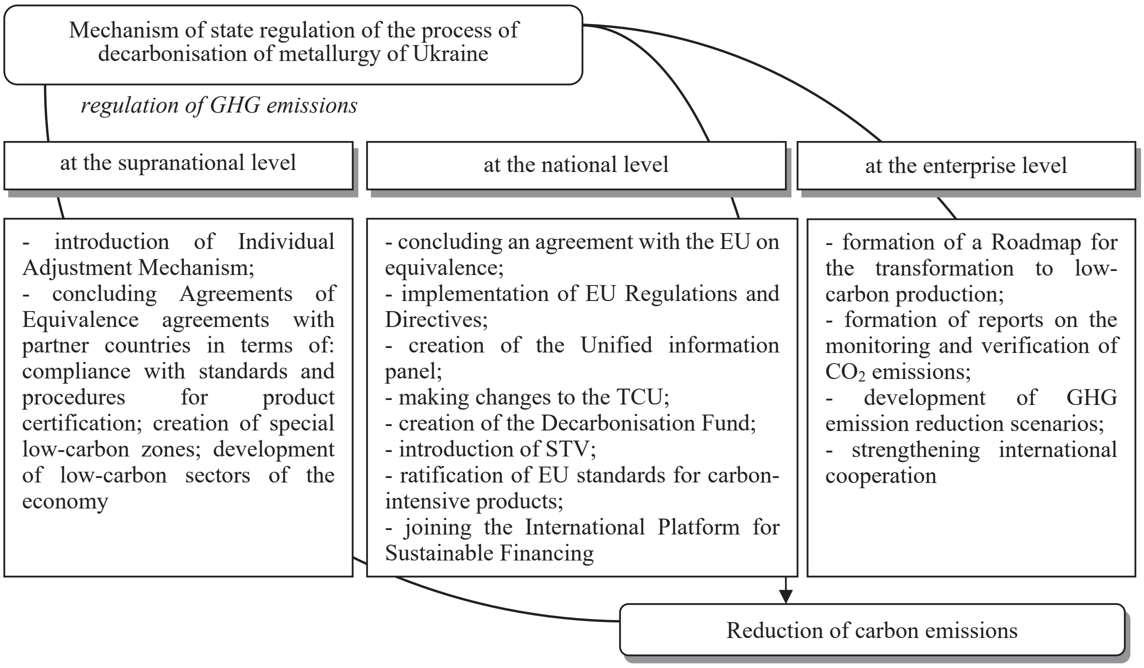

Figure 6. Tools for state regulation of the process of decarbonisation of metallurgy of Ukraine and the development of its foreign economic activity.

time, regarding paragraph 1.3 of Article 195 of the TCU (Verkhovna Rada of Ukraine, 2010), to add: energy and heat supply services are taxed at a zero rate, provided that metallurgical enterprises use waste for their provision.

The fifth step is to speed up the creation of the Decarbonisation Fund.

The sixth step is to introduce the quota trading system as a more effective decarbonisation tool, which will allow a faster start to the European level and integration into the EU-ETS trading system. Procrastination with the launch of ETS damages Ukraine's reputation as a reliable participant in global processes to combat climate change, as well as increases the risks of the possible application of border carbon adjustments to metal products originating in Ukraine.

The seventh step is to ratify European standards for carbon-intensive products and certification procedures.

And lastly, the eighth step is to join the International Platform for Sustainable Financing to obtain grants, loans and guarantees for decarbonisation projects.

At the micro level, in order to accelerate the process of decarbonisation, metallurgical enterprises need:

- to start measuring your carbon footprint, monitor carbon prices and their impact on enterprise costs, develop algorithms for action that should be used in different scenarios of the metallurgical sector of the economy;
- to form reports on monitoring and verification of CO2 emissions in accordance with the requirements of Regulation (EU) 2020/852 and the Directive of the European Parliament on the formation of information support for the financial and non-financial reporting of enterprises;
- to develop a Roadmap for the transformation of the enterprise to low-carbon production;
- to develop scenarios for reducing GHG emissions;
- to strengthen international cooperation and introduce the Neighbourhood Instrument to obtain global assistance to accelerate the decarbonisation process (Figure 6).

Comprehensive measures will contribute to the further development of foreign economic activity of metallurgical enterprises, increase imports of Ukrainian metal products to the EU and mitigate the pressure of decarbonisation on metallurgical enterprises of Ukraine, and thus maintain their competitive position in the European metal market.

Conclusions

Thus, the study shows that one of the global trends is the decarbonisation of the economy, so governments, business and civil societies in developed countries are quite active in dialogue at the level of international diplomatic events, economic forums, media on the introduction of the "green deal" and achieving zero CO_2 emissions by 2050.

Global experience regarding its implementation is considered, showing the advantages and disadvantages.

In order to implement it, the European Parliament has decided to launch a new Carbon Border Adjustment Mechanism (CBAM), the introduction of which will contribute to the creation of equal conditions for carbon-intensive business, and hence the introduction of new rules of the game on the world market.

The ambivalence of CBAM (its dual influence on the development of carbon-intensive enterprises) is emphasised. Based on the data of Metinvest Group enterprises (Ukraine), the possible consequences of CBAM implementation into metallurgical enterprises of Ukraine and the development of their foreign economic activity are substantiated. Emphasis is placed on the need to take transitional measures to decarbonise metallurgy (including ensuring proper investment, etc.), the decision for the use of which should be based on the expected decoupling effect – positive dynamics of economic growth while reducing the negative impact on the environment.

According to IEA forecasts and the Sustainable Development Scenario, the amount of investment in the decarbonisation of metallurgy for the period up to 2050 should be up to $ 866 per tonne of steel. At the same time, this amount should reach an average of $ 1,000 per tonne of steel, according to estimates by the international consulting companies McKinsey and Roland Berger. On the other hand, the calculations based on the author's model show that it is not sufficient to reduce GHG emissions to the level of 0.54 tonnes per tonne of steel provided by NDC2 of the Paris Agreement. Achieving a certain level of GHG emission reductions by metallurgical enterprises is possible provided that investments of at least $ 1,300 per tonne of steel are attracted, which, as a result, will lead to significant pressure of the decarbonisation process on the industry.

It is possible to prevent the oppressive pressure of decarbonisation on the metallurgical sector of Ukraine's economy by taking supranational, national and macro-level measures, the introduction of which will promote the further development of metallurgical enterprises and their foreign economic activity, and thus maintain their competitive position in the European metal market.

References

Allianz Trade. (2020). European Climate Policy Goes Global, Allianze Research, 14 October, 2020. Retrieved April 21, 2022, from https://www.eulerhermes.com/content/dam/onemarketing/ehndbx/eulerhermes_com/e

Boston Consulting Group. (2022). An EU Carbon Border tax could be the next disruptive force in global trade, June 30, 2020. Retrieved April 21, 2022, from https://www.bcg.com/publications/2020/how-an-eu-carbon- border-tax-could-jolt-world-trade

Chekunova, S. (2021). EU Border Carbon Adjustment and Challenges for the Ukrainian Economy / Energy Razumkov center. Retrieved April 21, 2022, from https://razumkov.org.ua/statti/prykordonne-vugletseve-koryguvannia-yes-ta-vyklyky-dlia-ukrainskoi-ekonomiky-energetyky

Datsii, O., Levchenko, N., Shyshkanova, G., Dmytrenko, R., & Abuselidze, G. (2021). State Decoupling Audit of Low-Carbon Agricultural Production. *Rural Sustainability Research*. 45(340), 94-112. DOI: 10.2478/plua-2021-001.

Datsii O, Levchenko N, Shyshkanova G, Platonov O, & Abuselidze G. (2021). Creating a Regulatory Framework for the ESG-investment in the Multimodal Transportation Development. *Rural Sustainability Research*. 46(341), 39-52. DOI: 10.2478/plua-2021-0016.

Dvigun, A., Datsii, O., Levchenko, N., Shyshkanova, G., Platonov, O., & Zalizniuk, V. (2022). Increasing Ambition to Reduce the Carbon Trace of Multimodal Transportation in the Conditions of Ukraine's Economy Transformation Towards Climate Neutrality. S&I. Retrieved April 21, 2022, from https://scinn-eng.org.ua/ojs/index.php/ni/article/view/168

European Commission. (2022). EU Green Deal (Carbon border adjustment mechanism). Retrieved April 21, 2022, from https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12228-Carbon-Border-Adjustment- Mechanism

Financial reporting system. (2021). Taxonomy UA XBRL IFRS 2020: Decision of the Financial Reporting System Management Committee of 09.04.2021: website. Retrieved April 21, 2022, from https://frs.gov.ua/

GMK center. (2021). *Estimation of investments for the implementation of OJSC (BAT) for air emissions in the GMC of Ukraine 2021*. Analytical report. GMK center.

GMK center. (2021). *The decarbonization of the steel industry is a challenge for the coming decades.* Analytical report. GMK center.

Greene, W. H. (2018). *Econometric Analysis*. 8th Edition, Stern School of Business, NY Univ., 2018.

Hoffmann, Ch., Van Hoey, M., & Zeumer, B. (2020). *Steel players across the globe, and especially in Europe, are increasingly facing a decarbonization challenge*. McKinsey & Company. Retrieved April 21, 2022, from https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

Hryhoriev, S., Petryshchev, A., Shyshkanova, G., Yakimtsov, Y., Zhuravel, S., Yamshinskij, M., Fedorov, G., Kruglyak, D., Shevchenko, O., & Goliev , Y. (2017). Study into properties of the resource saving chromium containing briquetted alloying additive from ore raw materials. *Eastern-European Journal of Enterprise Technologies*. 4(12(88)), 38–43.

Kettle, J. (2021). Carbon taxes: more carrots and sticks needed? McKinsey & Company. Retrieved April 21, 2022, from https: //www.woodmac. com / news / opinion / carbon-taxes-more-carrot-and-a-larger-stick-required /

Makarenko, O. (2021). ESG-trends: decarbonization - a new imperative for business. ESG. Game in perspective. KPMG. Retrieved April 21, 2022, from https://assets.kpmg/content/dam/kpmg/ua/pdf/2021/12/review-magazine-11.pdf

Ministry of Finance of Ukraine. (2017). Memorandum of Understanding on the development and implementation of the financial reporting system dated 18.12.2017 №102 / 15. Retrieved April 21, 2022, from https://zakon.rada.gov.ua/laws/show/v0102201-17#Tex

Ministry of Environmental Protection and Natural Resources of Ukraine. (2018). *Low Carbon Development Strategy to 2050*. Retrieved April 21, 2022, from https://mepr.gov.ua/files/docs/Proekt/LEDS_ua_last.pdf

Ministry of Environmental Protection and Natural Resources of Ukraine. (2019). Partnership for Market Readiness in Ukraine (PMR). Proposals for the development of carbon pricing tools in Ukraine: a modeling report, 2019. Retrieved April 21, 2022, from https://mepr.gov.ua/files/docs/Zmina_klimaty/96.pdf

Ministry of Environmental Protection and Natural Resources of Ukraine. (2020). *Ukraine's second nationally determined contribution to the Paris Agreement (WB2): ambition and prospects*. Retrieved April 21, 2022, from https://mepr.gov.ua/news/36563.html

OECD. (2001). *Environmental Strategy for the First Decade of the 21st Century*. Retrieved April 21, 2022, from http://www.oecd.org/dataoecd/33/40/1863539.pdf

Popov, S., Olekhova, O., & Boboshko, O. (2021). *Solving complex legal and tax issues. Game in perspective*. KPMG. 2021. Retrieved April 21, 2022, from https://assets.kpmg/content/dam/kpmg/ua/pdf/2021/12/review-magazine-11.pdf

Tapio P. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy*. 12, 137-151. DOI: 10.1016/j.tranpol.2005.01.001.

Tarasenko, A. (2021). "Green" transition in Chinese: what to learn. GMK. Retrieved April 21, 2022, from https://gmk.center/ua/posts/zelenij-perehid-po-kitajski-chogo-povchitisya/

The State Council the People's Republic of China. (2021a). Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy. Retrieved April 21, 2022, from http://english.www.gov.cn/policies/latestreleases/202110/25/content_WS61760047c6d0df57f98e3c21.html

The State Council the People's Republic of China. (2021b). Action Plan for Reaching Carbon Dioxide Peak Before 2030. Retrieved April 21, 2022, from http://english.www.gov.cn/policies/latestreleases/202110/27/content_WS6178a47ec6d0df57f98e3dfb.html

Vectors of economic development 2030. CMU. (2020). Retrieved April 21, 2022, from https://nes2030.org.ua/docs/doc-vector.pdf

Verkhovna Rada of Ukraine. (2010). *Law of Ukraine "Tax Code of Ukraine"*. Retrieved April 21, 2022, from https://zakon.rada.gov.ua/laws/show/2755-17

Verkhovna Rada of Ukraine. (2014). *Association Agreement between Ukraine, of the one part, and the European Union, the European Atomic Energy Community and their Member States, of the other part*. Retrieved April 21, 2022, from https://zakon.rada.gov.ua/laws/show/984_011#Text.

Verkhovna Rada of Ukraine. (2016).Treaty of Paris. Law of Ukraine "On Ratification of the Paris Agreement" of 14.07.2016 №1469-VIII. Verkhovna Rada of Ukraine. Retrieved April 21, 2022, from https://zakon.rada.gov.ua/laws/show/995_l61#n2

Vervega, T. (2021). Investing in sustainable environmental solutions is one of the areas of transformation of modern business. Game in perspective. KPMG. Retrieved April 21, 2022, from https://assets.kpmg/content/dam/kpmg/ua/pdf/2021/12/review-magazine-11.pdf

Washington, S., Karlaftis, M., Mannering, F., & Anastasopoulos, P. (2020). *Statistical and Econometric Methods for Transportation Data Analysis (3rd ed.)*. Chapman and Hall / CRC. DOI:10.1201/9780429244018.

Whiteside, J. (2020). *Metals provide an energy transition through their use in low-carbon technologies*. Wood Mackenzie. Retrieved April 21, 2022, from https://www.woodmac.com/news/feature/the-pathway-to-net-zero-for-miners/

Zinchenko, S. (2021). *Influence of CBAM on the metallurgical industry of Ukraine*. GMK CENTER. p. 42.