

ЕКОНОМІКА ПРИРОДОКОРИСТУВАННЯ ТА ОХОРОНИ НАВКОЛИШНЬОГО СЕРЕДОВИЩА

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DECARBONIZATION OF THE STEEL INDUSTRY: THE ROLE OF STATE ECONOMIC POLICY

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Decarbonization of the Steel Industry: the Role of State Economic Policy

The aim of the article is to analyze the potential areas of decarbonization of steel production in order to propose government policy measures for reducing CO₂ emissions. The study examines the structure of global carbon dioxide emissions, the trends in CO₂ emissions from the steel industry, and the environmental policies of the EU and China. Moreover, economic and technological factors complicating the decarbonization of the steel industry are characterized. The main sources of carbon dioxide emissions at steel-producing enterprises are considered. Using the example of a European company, the volume of capital investment for decarbonization of steel production is shown. The key groups of measures that can help solve the problem of CO₂ emissions (carbon capture and storage, carbon capture and utilization, prevention of emissions) are identified. The possibilities and limitations for the application of specific decarbonization measures including melting steel in electric arc furnaces, replacing coke with charcoal, using hydrogen in a blast furnace and for direct reduction of iron, and employing electrolysis of iron are analyzed. The carbon intensity of various decarbonization technologies as well as the potential terms for their commercial implementation are compared. As a result of the study, instruments of economic policy for accelerating the decarbonization of the steel industry are identified. The advantages and disadvantages of these instruments are analyzed. The conclusion about the impossibility of decarbonization without state participation, due to the fact that enterprises in the free market do not receive sufficient competitive advantages from investments to considerably reduce CO₂ emissions, is made. The prospects for further research are associated with an in-depth study of the instruments of state policy for decarbonization as well as development of directions for decarbonization of other sectors of the economy.

Keywords: decarbonization, carbon capture and utilization, direct reduction of iron ore, instruments of state financing.

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Глуценко А. М. Декarbonізація металургії: роль економічної політики держави

Мета статті полягає в аналізі потенційних напрямів декarbonізації металургійного виробництва, щоб запропонувати заходи державної політики, які сприяють зниженню викидів CO₂. У ході дослідження вивчено структуру глобальних викидів вуглекислого газу, динаміку викидів CO₂ металургією, особливості екологічної політики ЄС і Китаю. Також охарактеризовано економічні та технологічні чинники, які ускладнюють декarbonізацію металургії. Розглянуто основні джерела викидів вуглекислого газу на металургійних підприємствах. На прикладі європейської компанії показаний обсяг капітальних інвестицій для декarbonізації виробництва сталі. Виявлено основні групи заходів, що здатні вирішити проблему викидів CO₂ (уловлювання та захоронення CO₂, уловлювання та використання CO₂, запобігання викидам). Проаналізовано можливості й обмеження для використання конкретних заходів декarbonізації, включаючи виплавку сталі в електродугових печах, заміну коксу деревним вугіллям, використання водню в доменній печі та для прямого відновлення заліза, електроліз заліза. Проведено порівняння інтенсивності вуглецевих викидів для різних технологій декarbonізації, а також потенційних термінів їх комерційного впровадження. У результаті дослідження виділено інструменти економічної політики для прискорення декarbonізації металургії. Проаналізовано

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Глуценко А. Н. Декarbonизация металлургии: роль экономической политики государства

Цель статьи заключается в анализе потенциальных направлений декarbonизации металлургического производства, чтобы предложить меры государственной политики, способствующие снижению выбросов CO₂. В ходе исследования изучены структура глобальных выбросов углекислого газа, динамика выбросов CO₂ металлургией, особенности экологической политики ЕС и Китая. Также охарактеризованы экономические и технологические факторы, осложняющие декarbonизацию металлургии. Рассмотрены основные источники выбросов углекислого газа на металлургических предприятиях. На примере европейской компании показан объем капитальных инвестиций для декarbonизации производства стали. Виявлены основные группы мер, которые способны решить проблему выбросов CO₂ (улавливание и захоронение CO₂, улавливание и использование CO₂, предотвращение выбросов). Проанализированы возможности и ограничения для использования конкретных мер декarbonизации, включая выплавку стали в электродуговых печах, замену кокса древесным углем, использование водорода в доменной печи и для прямого восстановления железа, электролиз железа. Проведено сравнение углеродоемкости различных технологий декarbonизации, а также потенциальных сроков их коммерческого внедрения. В результате исследования выделе-

переваги та недоліки цих інструментів. Зроблено висновок про неможливість декарбонізації без участі держави, оскільки на вільному ринку підприємства не отримують достатніх конкурентних переваг від інвестицій в значне зниження викидів CO₂. Перспективи подальших досліджень пов'язані з поглибленим вивченням інструментів державної політики декарбонізації, а також розробкою напрямів декарбонізації інших секторів економіки.

Ключові слова: декарбонізація, уловлювання та використання CO₂, пряме відновлення заліза, інструменти державного фінансування.

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ны инструменты экономической политики для ускорения декарбонизации металлургии. Проанализированы преимущества и недостатки этих инструментов. Сделан вывод о невозможности декарбонизации без участия государства, поскольку на свободном рынке предприятия не получают достаточных конкурентных преимуществ от инвестиций в значительное снижение выбросов CO₂. Перспективы дальнейших исследований связаны с углубленным изучением инструментов государственной политики декарбонизации, а также разработкой направленной декарбонизации других секторов экономики.

Ключевые слова: декарбонизация, улавливание и использование CO₂, прямое восстановление железа, инструменты государственного финансирования.

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Introduction. For a long period of time (from the industrial revolution of the 18th century in England to the beginning of the 1990s), the main attention of government bodies was paid to the economic growth, primarily due to industrial manufacturing, while negative side effects (in the form of environmental problems) remained in the background. With the increasing saturation of markets with industrial products and satisfaction of basic consumer needs, the situation began to change.

In the 1970-1980s, the concept of sustainable development appeared. It was focused on ensuring a balance between economic growth, improvement of social welfare and preservation of the environment. In the 1980s, environmental taxes appeared in the Scandinavian countries. Later, these taxes were adopted by other countries in order to counter environmental pollution.

In 1992, the United Nations Framework Convention on Climate Change was embraced: its participants agreed to take measures to reduce greenhouse gas emissions into the atmosphere. In 1997, the Kyoto Protocol was signed. This document defines specific quantitative obligations of countries to reduce greenhouse gas emissions. In 2015, the Paris Agreement was signed. The purpose of Paris Agreement is to restrain the growth of the average temperature on the planet within 2 °C compared to the pre-industrial era, and ideally reduce the growth to 1.5 °C. Nowadays, the fight against climate change has become the main issue in the environmental agenda. The need for decarbonization of industry is no longer in doubt – the question remains how to achieve it.

Analysis of recent publications. In Ukrainian scientific literature, decarbonization of the economy is not a popular research topic. The Ukrainian economy has important problems that impede its entire development, which is why less attention is paid to environmental issues. Therefore, research on decarbonization is mainly carried out by foreign scientists.

In scientific publications decarbonization is mainly associated with the electric power industry, which is not surprising since the electric power industry is the main source of

carbon dioxide emissions. Studies of R. Leal-Arcas, V. Nalule, L. Li, A. Taelhagh, S. I. Melnikova, and others [1-4] analyze the decarbonization experience of the electric power industry in different countries (Malta, Romania, China, the EU). There are also papers considering the decarbonization of other economic sectors: industry in general (R. Duff, M. Lenox [5]) and the steel industry, in particular (L. Hermwille [6]).

The articles published by D. Newbery, J. Meckling, F. Landis, S. Daniele, and others [7-10] are mainly focused on the effectiveness of various instruments of economic policy in the field of decarbonization. Forecasting CO₂ emissions was made by R. B. Jackson with the co-authors [11].

As follows from the review of the literary sources, the scientific discussion still does not pay enough attention to the decarbonization of other economic sectors (outside the electric power industry), in particular, the steel industry. In addition, considering economic policy instruments, studies focus mainly on restrictive measures (taxes, emission limits) while the range of possible instruments is wider.

Therefore, the **purpose** of this article is to analyze the potential decarbonization areas for the steel industry in order to propose government policy measures to reduce the CO₂ emissions.

Research findings. In 2017 the global carbon dioxide emissions amounted to 40 billion tons. The electric power industry was in the first place in terms of the emissions (34 % of the emissions). The buildings sector was in the second place (24 % of the emissions). Transport was in the third place (20 % of the emissions). The steel industry accounted for only 5 % of the global CO₂ emissions (Fig. 1).

From 2015 to 2017 CO₂ emissions in the steel industry fell by 4.8 %, while the global steel production increased by 4.3 % over this period [12, 13]. Thus, increasing the production volumes, the steel industry is gradually improving production processes and striving to reduce CO₂ emissions. First of all, this is stimulated by government bodies, which are responsible for the implementation of environmental policies and international agreements to combat climate change.

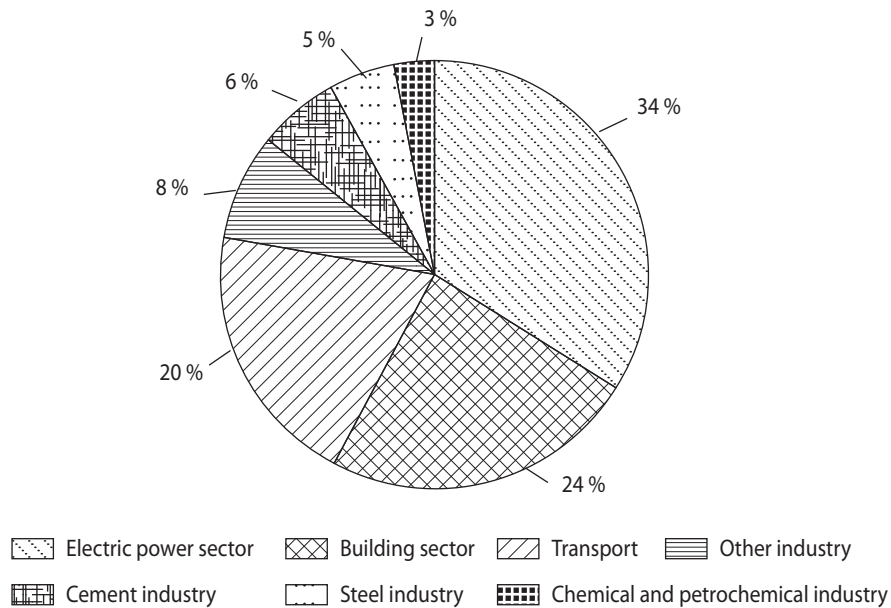


Fig. 1. Sectoral structure of global CO₂ emissions in 2017

Source: developed by the author based on [12]

The EU launched the Emissions Trading System (ETS), which sets a limit on greenhouse gas emissions for enterprises. If this limit is exceeded, enterprises are obliged to purchase the missing volumes of quotas in the open market. Free emission limits are decreasing every year, and the price for CO₂ emission allowances is increasing, prompting enterprises to actively reduce emissions.

In 2016–2018, the Chinese government pursued a policy for reducing excessive production capacities in the steel industry. First of all, obsolete production facilities were closed. In total, steel production volume was reduced by 150 million tons annually.

In addition, in the autumn-winter period, Chinese authorities impose restrictions on the activities of steel enterprises in order to limit the pollution level.

The volume of restrictions depends on the level of emissions (the lower the level of emissions is, the less production restrictions are). So, it is beneficial for steel plants to carry out environmental modernization since due to it they will be able to continue their activities and not lose profits in the autumn-winter period.

The decarbonization of the steel industry in general goes slow since the following reasons inhibit this process [6; 14]:

- a) CO₂ emissions occur at different production stages (sinter plant, coke plant, blast furnace (BF), basic oxygen furnace (BOF) etc.).

At each of the listed stages (Fig. 2), specific efforts are needed to reduce emissions. The source of emissions is also the raw materials used (iron ore, coking coal). At the integrated steel plant, pig iron production is responsible for 70–80 % of CO₂ emissions, of which 24 % are associated with the coke use [5].

Carbon contained in coke releases oxygen from iron ore and reduces iron. Thus, the presence of carbon is a neces-

sary condition for the production process. In addition, carbon is an essential component of steel (up to 1 % in high-carbon grades).

- b) steel production requires heating to a high temperature. According to McKinsey's estimates, 45 % of CO₂ emissions at a steel plant are associated with high-temperature heating (over 500 °C) [14]. Few alternative technologies may be suitable for this purpose. In addition, these technologies are at the initial development level (biomethane, hydrogen).
- c) the various stages of steel production are deeply integrated with each other. A change at one stage entails the need for changes at other stages. Therefore, to reduce CO₂ emissions, the entire production chain needs to be changed.
- d) the introduction of new technologies at existing steel plants requires high capital investments. According to Voestalpine, under the current conditions, the decarbonization of steel production (annual capacity – 7.5 million tons of steel) will require:
 - 7 billion euros for the introduction of a breakthrough technology (direct reduction of iron with hydrogen);
 - 3 billion euros for the electrolysis unit, which will produce hydrogen from water;
 - 20 billion euros for the renewable electricity generation by wind farms. This electricity will be used in the hydrogen electrolysis [16].
- e) the use of low-carbon technologies leads to an increase in production costs. Countries that impose low CO₂ requirements actually reduce the competitiveness of domestic producers.

There are several parallel decarbonization directions in the steel industry (Fig. 3).

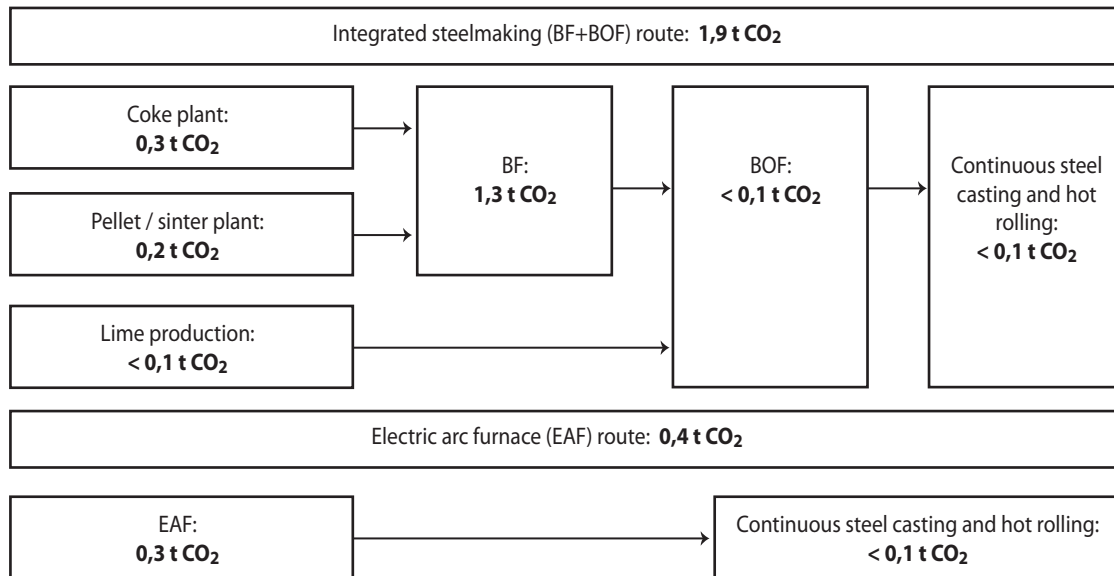


Fig. 2. CO₂ emissions at the stages of steel production, tons of CO₂ per ton of steel

Source: [15]

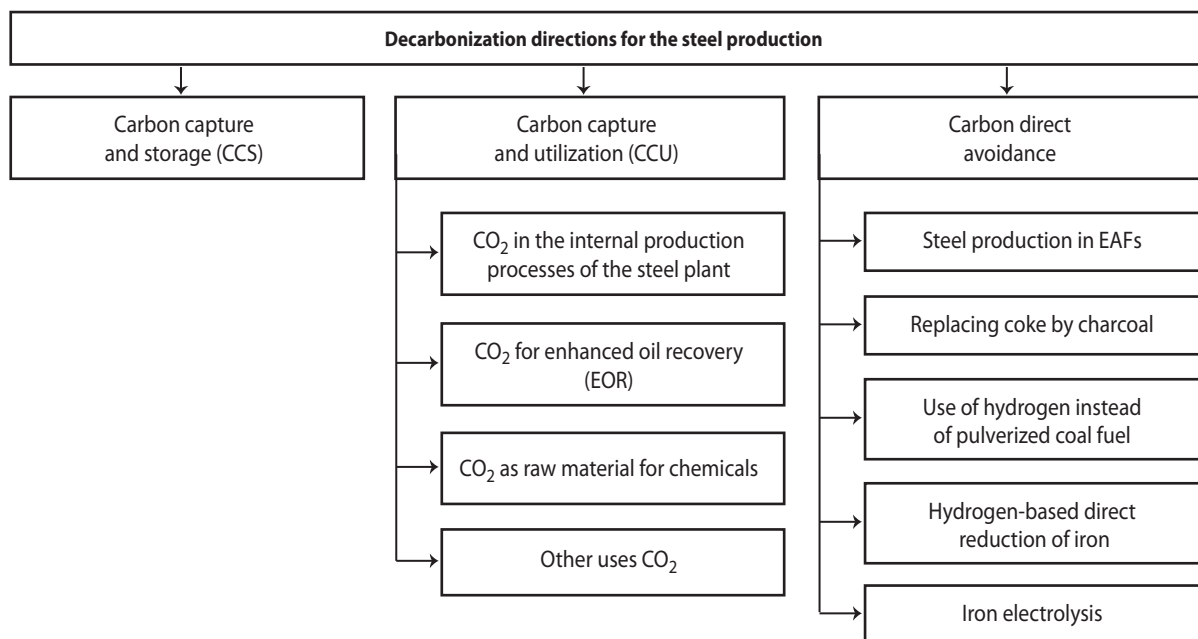


Fig. 3. Decarbonization directions for the steel production

Source: developed by the author based on [6; 14; 15; 17]

Carbon capture and storage (CCS) involves separation of carbon dioxide from emission sources and subsequent permanent isolation from the atmosphere (usually in the underground storage).

Carbon capture and utilization (CCU) is a similar process, which differs in one feature – CO₂ is not just stored in special storage facilities but is used in other production processes. This is the advantage of such technologies – CO₂ generates revenue, increasing the economic feasibility of its capture. The most interesting opportunities for carbon utilization include:

- a) the CO₂ conversion into synthesis gas, which is fed into the blast furnace instead of coke and pulverized coal fuel (IGAR project implemented by ArcelorMittal);
- b) CO₂ injection into oil wells to increase their debit (enhanced oil recovery);
- c) production of methanol, polymers, ammonia, higher alcohols (Carbon2Chem project implemented by Thyssenkrupp);
- d) bioethanol production (Steelanol project implemented by ArcelorMittal);

e) naphtha production (Everest project implemented by Tata Steel).

Currently, the application of CCU/CCS technologies in the steel industry is complicated because of several emission sources, which makes it difficult to capture more than 60 % of CO₂ [15].

A possible solution to the problem is the transition to smelting reduction. It allows pig iron to be smelted in one production unit, into which coal (not necessarily coking) and iron ore are loaded.

Accordingly, the sinter plant, the coke plant, the blast furnace are excluded from the production process, and CO₂ emissions are concentrated in one place.

An alternative is to increase the use of blast furnace gases in steel production and to capture the remaining CO₂ emissions.

Steel production in EAFs is the most advanced technology to prevent CO₂ emissions. Scrap is used as the main raw material. The spread of this technology is restrained by such factors as the scrap availability, the degree of scrap contamination with various impurities, especially copper (worsen the quality of produced steel), the need to supply large electricity volumes for the electric arc furnaces. In addition, the transition to renewable energy sources is also necessary for a successful decarbonization of EAFs. This step will eliminate CO₂ emissions associated with electricity generation.

Replacing coke by charcoal can be used only in mini-blast furnaces. The use of charcoal instead of coke can reduce CO₂ emissions by 32–58 % [18]. This approach is practiced by Brazilian enterprises that grow eucalyptus on special plantations and then produce charcoal from it. New seedlings are immediately planted in place of felled trees. Eucalyptus resources are renewed every 6–7 years.

For many countries (including Ukraine), replacing coke with charcoal is not suitable for the following reasons: firstly, the lack of appropriate forest resources; secondly, the large size of existing blast furnaces; thirdly, the transition to small blast furnaces will lead to increased energy costs and losses of competitiveness by domestic producers.

The use of hydrogen instead of pulverized coal fuel for a blast furnace is possible since hydrogen, like carbon, is able to reduce iron from iron ore. The advantage of hydrogen is that when it is used, water vapor is released instead of CO₂. Currently the use of hydrogen in a blast furnace is being investigated at the ThyssenKrupp plant in Germany.

Direct reduction of iron ore is a manufacturing process that provides alternative raw materials for electric arc furnaces: DRI-pellets (DRI – Direct Reduced Iron) and hot briquetted iron (HBI). For these products rich iron ore (with iron content of at least 70 %) is used. Such ore is reduced at high temperatures to iron content of 90 % or more. Natural gas is used as a traditional reducing agent.

Direct reduction of iron ore followed by steel production in EAF emits 40 % less CO₂ compared to the BF-BOF route (Fig. 4). However, in the EU, as in Ukraine, direct reduction of iron ore is not common due to the lack of cheap natural gas. The production of DRI and HBI is concentrated mainly in the Middle East, North Africa and Latin America. The main idea for reducing emissions is to replace natural gas with hydrogen.

The possibility of using hydrogen to reduce iron ore does not raise questions – in a conventional DRI production process, which is based on natural gas, hydrogen reduces up to 50 % of iron ore, the rest is reduced by carbon.

However, the transition to hydrogen for the decarbonization purpose raises a number of challenges. Firstly, hydrogen should be produced without CO₂ emissions. This can be achieved either by capturing carbon dioxide (in the production of hydrogen from natural gas) or using alternative sources of electricity (in the production of hydrogen by water electrolysis).

Secondly, there is a need to create hydrogen storage facilities.

Thirdly, to reduce CO₂ emissions throughout the whole production chain, alternative energy sources are needed for sintering / pelletizing iron ore as well as for the EAFs and furnaces that heat billets before rolling.

The iron electrolysis begins from iron ore dissolution in an electrolyte (molten oxide or a mixture of oxides, e. g. calcium oxide, aluminum oxide, magnesium oxide) at about 1600 °C.

Then an electric current is passed through this solution. As a result, reduced iron is collected on the cathode, and oxygen is on the anode. This method is at the stage of laboratory research. Siderwin is the most famous iron electrolysis project, which is implemented by ArcelorMittal.

Among the methods that prevent CO₂ emissions, the most promising are electric arc steelmaking and hydrogen-based direct reduction of iron ore. These breakthrough technologies can reduce CO₂ emissions to almost zero (Fig. 4).

At the same time, considering potential implementation speed, the most likely candidates to be applied in the steel industry are CCS/CCU technologies (Tbl. 1).

An active state policy can accelerate the decarbonization of the steel industry. Such policy should include the following measures:

- *Development and implementation of long-term plans for decarbonization.*

Such plan should coordinate the actions of various economic sectors, in particular, steel industry and electric power industry (the development of alternative electric power industry is a necessary condition for decarbonization of steel production). The plan should also include steps to develop an appropriate infrastructure for the transportation and storage of hydrogen, CO₂, etc.

On the one hand, an indicative decarbonization plan will help companies improve their business planning. On the other hand, this plan should involve specific actions of the state institutions.

- *Reduction of import tariffs on equipment needed for decarbonization.*

This measure reduces capital expenses and encourages enterprises to invest in the decarbonization projects. The state refuses part of the potential tax revenues in exchange for the implementation of environmental projects.

- *Limiting exports of raw materials used in low-carbon technologies.*

It allows fully meeting the needs of domestic manufacturers in materials necessary for decarbonization as well as preventing a surge in prices.

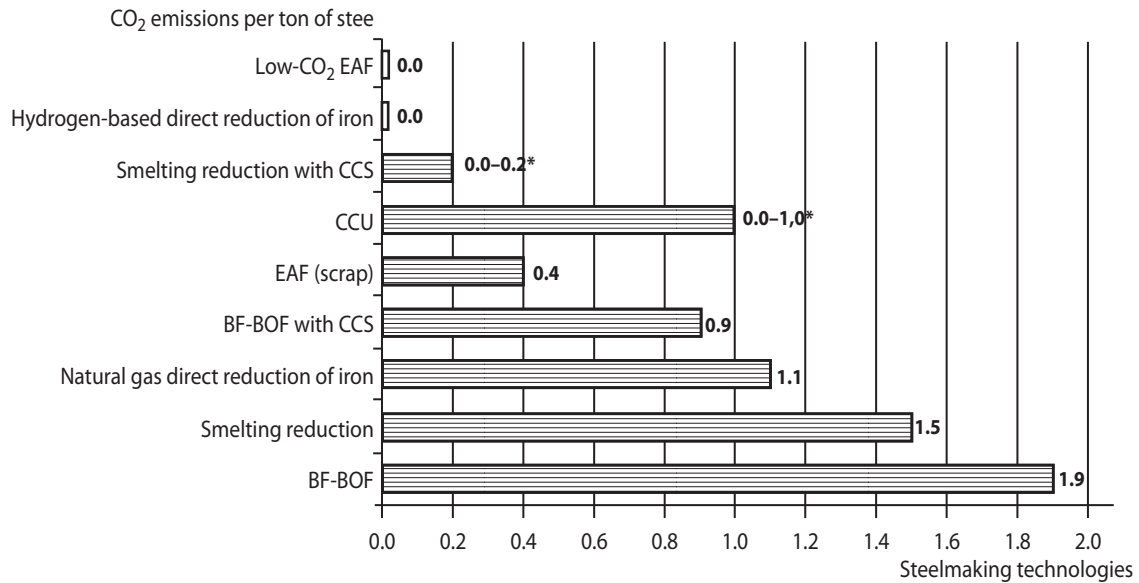


Fig. 4. Carbon intensity of different steelmaking technologies, CO2 emissions per ton of steel

* – depends on the technologies used

Source: [15]

Table 1

Prospects for the commercialization of decarbonization technologies

Technology	Potential implementation period
Blast furnace with carbon capture	5-10 years
Carbon capture and utilization in BF-BOF route	5-10 years
Conventional DRI production (existing DRI technology + CCU)	5-10 years
DRI production based on green hydrogen (produced from water with help of clean electricity)	10-20 years
DRI production based on hydrogen received from natural gas (with CCS)	10-20 years
Iron electrolysis	20-30 years

Source: developed by the author based on [19]

- Increase in carbon dioxide emission charges (implemented in the mechanism of the EU Emissions Trading System).

Logically, the increase in costs associated with CO₂ emissions strengthens the interest of enterprises in carrying out environmental modernization. Accordingly, enterprises must reduce their CO₂ emissions to avoid ever-increasing emissions costs.

However, in practice there arise problems:

- 1) increase in emission charges may not be in line with the technological capabilities of decarbonization;
- 2) the problem of finding sources for financing environmental activities is not being resolved;
- 3) an increase in the charge for CO₂ emissions should be implemented synchronously in all countries.

Otherwise, manufacturers from countries where CO₂ charges are low or absent will receive competitive advantages. Accordingly, there will be stimuli to transfer polluting industries to countries with low environmental standards and global emissions will not be reduced.

- Import restrictions for products manufactured with high CO₂ emissions.

It can be implemented in the EU in the form of carbon border adjustment (carbon border tax) – a special tax tied to the difference in CO₂ emissions from steel production in different countries and the difference in costs related to payments for CO₂ emissions.

It is a response to gaining competitive advantages by producers from countries where CO₂ charges are low or absent.

- Development of product standards that allow only low CO₂ emissions.

It can be used in combination with other measures. Its isolated use will lead to an increase in the production costs and the crowding out of environmentally friendly products since manufacturers from countries with low environmental standards will gain competitive advantages.

- Simplification of patent procedures for decarbonization technologies.

It is a regulatory measure aimed at reducing the patenting costs for relevant technologies and accelerating their launch.

- State funding for decarbonization projects.

Currently, many decarbonization technologies are at an initial level of development. The state is involved in financing their development, especially for scaling them from laboratory research to commercial use opportunities.

Government financing tools are grants, loans, loan guarantees, interest rate compensation.

Furthermore, enterprises can be provided with tax incentives in case of implementation of decarbonization projects.

- *Measures in the employment field.*

They are necessary for providing new production processes with qualified staff and finding jobs for employees dismissed during the “green transition”.

Conclusions. Decarbonization of the steel industry is a complex process that will change this sector in general. To successfully reduce CO₂ emissions, several conditions must be met including the availability of appropriate decarbonization technologies (ready for commercial use), the ability of enterprises to implement these technologies (including the ability to attract external financing for decarbonization projects), and protecting the domestic market from import inflows of products that are produced with large CO₂ emissions. Each of these conditions implies a specific economic policy of the state. Without state participation, decarbonization is impossible since for enterprises investments in reducing CO₂ emissions are additional costs that do not allow increasing competitiveness compared to other enterprises that do not bear such costs.

The task of state authorities is to make decarbonization mandatory for everyone (both for domestic producers and importers). Only in this case decarbonization will lead to a real reduction of harm to the environment. To achieve this result, it is necessary to continue research on separate instruments of the state decarbonization policy and directions for decarbonization of other economic sectors.

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