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PRODUCT CARBON FOOTPRINT (PCF) IN THE SYSTEM OF INVESTMENT ATTRACTIVENESS ASSESSMENT OF EXPORT-ORIENTED ENTERPRISES

Statement of the problem. The global transformation of economic systems towards climate neutrality creates fundamentally new challenges for export-oriented enterprises. The introduction by the European Union of the Carbon Border Adjustment Mechanism (CBAM) from 2026 radically changes the rules of international trade, transforming the Product Carbon Footprint (PCF) from a voluntary corporate social responsibility tool into a mandatory component of competitiveness [2]. For Ukraine, where over 40% of commodity exports are directed to the EU, this transformation carries existential risks: according to estimates by Paroussos et al., potential losses for Ukrainian exporters from CBAM implementation during the period 2026-2030 may exceed \$4.7 billion [10].

Simultaneously, changes in the global financing system create unprecedented opportunities. An MSCI study covering 4,319 issuers over 2015-2024 demonstrated that companies with higher ESG ratings, a component of which is the quality of emissions reporting, obtain access to capital 110 basis points cheaper compared to companies with low ratings [7]. Ernst and Woithe confirmed these findings on an S&P 500 sample, identifying a statistically significant negative relationship between ESG ratings and both cost of equity and cost of debt [4]. For Ukrainian enterprises facing a deficit of investment resources in the period of post-war reconstruction, such a difference in the cost of capital can become a decisive factor for survival and development.

However, implementation of PCF measurement and reporting systems remains a complex task, especially for enterprises from developing countries. Liew, in a systematic literature review on carbon emissions accounting through green supply chain management, found that Scope 3 emissions constitute over five times the magnitude of Scope 1 and Scope 2 emissions combined, yet their accounting remains most problematic due to the need for extensive collaboration with suppliers and partners [8]. Busch et al., in their study of corporate carbon efficiency data, emphasize critical problems of data quality and accessibility, which is particularly relevant for the Ukrainian context with its limited institutional infrastructure for climate monitoring [1].

Analysis of recent research and publications.

The academic literature on PCF issues has formed at the intersection of several disciplinary directions. Fundamental methodological foundations are laid in the ISO 14067:2018 standard, which defines principles and requirements for quantitative assessment of product carbon footprint based on Life Cycle Assessment (LCA) [5]. Practical operationalization of these principles is provided by the Product Life Cycle Accounting and Reporting Standard, developed jointly by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) as part of the GHG Protocol [13]. Recent developments in this area are represented by the PACT (Pathfinder Framework) methodology, which focuses on PCF data exchange in supply chains and uses a «cradle-to-gate» approach [9], as well as industry-specific standards, particularly the Tfs PCF Guideline for the chemical industry [12].

The regulatory dimension of the problem is detailed in studies of the impact of CBAM and European Sustainability Reporting Standards (ESRS). The ESRS E1 standard, adopted by the European Commission in 2023, establishes mandatory requirements for disclosure of climate change information, including detailed reporting on emissions of all three Scope categories [3]. Yang et al. analyzed the impact of CBAM on international trade in the context of the Russia-Ukraine war, finding that effects will be significant and will vary by country and industry [14]. Paroussos et al., in their 2021 study, specifically focused on the Ukrainian context, identifying Ukraine as the most vulnerable country among EU trading partners with a potential decline in per capita income of 0.4% and a reduction in steel production of 3.9% [10].

The relationship between PCF and investment attractiveness is examined through the prism of ESG factors and cost of capital. In 2024, MSCI published a study covering the period from August 2015 to May 2024 and 4,319 unique issuers, revealing a significant correlation between companies' ESG ratings and cost of capital: companies with the highest ratings financed themselves at an average rate of 6.8%, while companies with the lowest ratings at 7.9% [7]. Ernst and Woithe expanded this research by analyzing S&P 500 companies and confirming the negative relationship between ESG ratings and both components of cost of capital [4]. Purbasari



and Rokhim extended these findings to the ASEAN+3 region, demonstrating the universality of the phenomenon [11].

The specifics of the Ukrainian context are examined in works devoted to post-war reconstruction. Ackermann et al., in a study by the International Institute for Sustainable Development, emphasize the importance of integrating sustainability and climate neutrality principles into infrastructure reconstruction processes, creating a unique opportunity for simultaneously addressing economic modernization and environmental transformation tasks [6]. Lukash and Namoniuk, in their analysis of post-war energy scenarios, demonstrate the critical role of international climate finance in catalyzing investments to achieve tipping points in decarbonization [15].

Purpose of the article. is to develop a conceptual model for integrating Product Carbon Footprint into the system of investment attractiveness assessment of export-oriented enterprises in Ukraine, taking into account the specifics of EU regulatory requirements (CBAM, ESRS E1), methodological requirements of international standards (ISO 14067, GHG Protocol, PACT), and the features of the Ukrainian context of post-war reconstruction.

Research results.

1. Methodological foundations of PCF calculation: comparative analysis of standards

The modern system of product carbon footprint accounting is based on the concept of Life Cycle Assessment (LCA) and the three-tier classification of greenhouse gas emissions according to the GHG Protocol standard [13]. The methodological base is represented by several complementary standards that differ in scope of coverage, level of detail, and intended purpose.

ISO 14067:2018 establishes the most comprehensive approach, requiring full life cycle assessment from raw material extraction to product disposal (cradle-to-grave) with mandatory consideration of all three Scope categories [5]. GHG Protocol Product Standard, developed by WBCSD and WRI in 2011, provides practical operationalization of ISO principles through detailed methodological recommendations on data collection, emission allocation, and calculation of emission factors [13]. The PACT methodology, presented in 2023, offers a simplified «cradle-to-gate» approach optimized for data exchange between supply chain participants [9].

As comparative analysis shows (Table 1), EU regulatory standards (ESRS E1, CBAM) create additional requirements that go beyond traditional PCF measurement methodologies. ESRS E1 requires not only quantitative assessment of emissions but also disclosure of decarbonization strategy, emission reduction targets, and progress in achieving them [3]. CBAM in the initial stage (2026-2034) focuses primarily on Scope 1 emissions and partially Scope 2, but provides for gradual expansion of coverage [2].

Table 1. Comparative analysis of main product carbon footprint standards

Standard/Methodology	Developer Organization	Year of Adoption	Scope Coverage	Main Purpose
ISO 14067: 2018	International Organization for Standardization	2018	Scope 1, 2, 3 (full LCA)	Quantitative assessment of product carbon footprint
GHG Protocol Product Standard	WRI/WBCSD	2011	Scope 1, 2, 3 (full LCA)	GHG accounting and reporting
PACT Methodology	WBCSD	2023	Scope 1, 2, 3 (cradle-to-gate)	PCF data exchange in supply chain
TfS PCF Guideline	Together for Sustainability	2024	Scope 1, 2, 3 (modular)	Industry standard for chemical industry
ESRS E1	European Commission	2023	Scope 1, 2, 3 (mandatory)	Corporate reporting on climate change
CBAM Requirements	European Commission	2023	Scope 1, 2 (partially 3)	Trade regulation of import carbon footprint

Source: compiled by the author based on [2; 3; 5; 9; 12; 13]

2. Structure of emissions and accounting features by Scope categories

The three-tier classification of greenhouse gas emissions (Fig.1) introduced by the GHG Protocol reflects different levels of enterprise control over emission sources and the complexity of their accounting [13]. Scope 1 emissions cover direct emissions from sources owned or controlled by the enterprise, including stationary fuel combustion, mobile sources, and technological processes. Their share in the total carbon footprint typically constitutes 10-15% for industrial enterprises, yet these emissions are the most manageable and subject to the most accurate measurement.

Scope 2 emissions represent indirect emissions from generation of purchased electricity, heat, and steam by the enterprise. Their share constitutes 5-10% of the total footprint, but for Ukrainian enterprises this category acquires special significance due to the high carbon intensity of the national energy system, which is largely based on coal and gas thermal power plants. The Scope 2 accounting methodology provides two approaches: location-based (based on the average emission factor of the national power grid) and market-based (based on actual energy purchase contracts).

The most problematic is the Scope 3 category, which covers all other indirect emissions in the enterprise's value chain and typically constitutes 75-85% of the total product carbon footprint [8]. The GHG Protocol distinguishes 15 Scope 3 subcategories, divided into upstream (purchased goods and services, capital equipment, supplier transportation and distribution, waste

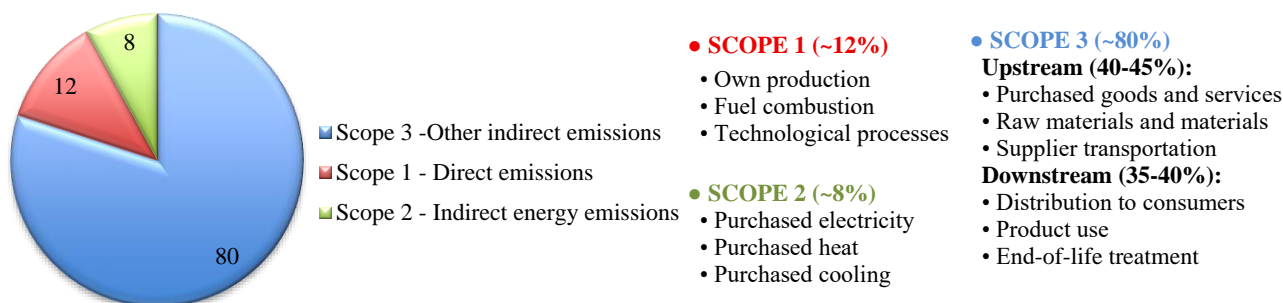


Fig. 1. Structure of greenhouse gas emissions by Scope categories

Source: constructed by the author based on [1; 8; 13].

Note: Typical structure for industrial enterprises. Actual distribution varies depending on the industry.

from operations) and downstream (transportation and distribution to consumers, processing of sold products, use of sold products, end-of-life treatment of sold products) [13].

Liew, in a systematic literature review on carbon emissions accounting through green supply chain management, found that Scope 3 emissions constitute over five times the magnitude of Scope 1 and 2 emissions combined, yet their accounting requires extensive collaboration with suppliers and partners along the value chain [8]. Busch et al. emphasize critical problems of quality and availability of data for Scope 3 calculation, which is particularly relevant for enterprises from developing countries, where suppliers often lack their own emission measurement and reporting systems [1].

3. PCF as a factor of investment attractiveness: empirical evidence

Integration of PCF into the system of investment attractiveness assessment occurs through two main channels: direct impact on market access and indirect impact through cost of capital and ESG ratings. The direct channel is realized through regulatory requirements, primarily CBAM, which from 2026 effectively transforms PCF into an «entry ticket» to the European market for exporters of carbon-intensive goods [2].

The indirect channel operates through financial markets and institutional investors. The MSCI study covering 4,319 issuers during the period from August 2015 to May 2024 revealed a significant correlation between companies' ESG ratings (a component of which is the quality of emissions reporting) and cost of capital [7]. Companies with the highest ESG ratings (upper quintile) financed themselves at an average rate of 6.8%, while companies with the lowest ratings (lower quintile) at 7.9%, representing a difference of 110 basis points. This pattern was observed both in developed markets and emerging markets, and manifested in both cost of equity (through lower beta) and cost of debt (through lower credit spreads).

Ernst and Woithe confirmed these findings on a sample of S&P 500 companies, demonstrating that companies with better ESG ratings have statistically significantly lower cost of both equity and debt [4]. Purbasari and Rokhim extended the geography of research to ASEAN+3 countries, identifying similar trends in the region and confirming the universality of the phenome-

non [11]. The mechanism of this impact is explained by several factors: reduction of regulatory and reputational risks, improvement of operational efficiency through optimization of resource consumption, increased attractiveness to ESG-oriented investors (who manage over \$30 trillion in assets globally), and reduction of the probability of «stranded assets» in the context of transition to a low-carbon economy.

For Ukrainian export-oriented enterprises, these mechanisms acquire special significance in the context of post-war reconstruction. According to estimates by the World Bank and European Commission, the cost of Ukraine's recovery exceeds €500 billion, creating enormous need for external financing [6]. In these conditions, a difference in cost of capital of 110 basis points can become a decisive factor in access to financing: for a project worth €100 million, this means savings of over €1 million annually or €10+ million over a typical ten-year lending period.

4. Challenges of PCF implementation for Ukrainian export-oriented enterprises

Ukrainian export-oriented enterprises face a unique combination of challenges in implementing PCF measurement and reporting systems. First, the absence of national support infrastructure: unlike EU countries, where national databases of emission factors, systems for accreditation of verifiers, and state programs for financial support of PCF implementation function, Ukraine does not yet have such institutional mechanisms. Second, deficit of qualified personnel: calculation of PCF according to ISO 14067 or GHG Protocol Product Standard requires specialized knowledge in the field of LCA, combining engineering understanding of production processes with expertise in climate science [5; 13].

Third, the problem of data collection for Scope 3 calculation is particularly acute. As Liew's study shows, Scope 3 emissions constitute over 75% of the total product carbon footprint, yet their accounting requires extensive cooperation with suppliers and partners [8]. For Ukrainian enterprises, this problem is exacerbated by the fact that many of their suppliers do not have their own emission measurement systems, forcing the use of industry average values that may significantly overstate the actual carbon footprint.

Fourth, financial constraints in the context of war. Implementation of a full-fledged PCF system according to ISO 14067 requires investments from €25 thousand (for small enterprises using simplified methodologies) to €500 thousand+ (for large industrial complexes with the need to install measurement equipment, implement IT systems, and annual verification) [9; 12]. In conditions where many enterprises have suffered direct destruction from military actions, lost access to part of markets, and face an energy crisis, such investments may seem an unbearable burden.

Fifth, a specific problem of the Ukrainian context is the high carbon intensity of production due to outdated technologies and energy structure. According to Paroussos et al., precisely because of this Ukraine is identified as the most vulnerable country to CBAM implementation among all EU trading partners [10]. This means that for Ukrainian enterprises it is insufficient simply to measure PCF – large-scale investments in technological modernization are needed for actual emission reductions.

5. Strategic recommendations: SWOT analysis and action priorities

To systematize the challenges and opportunities facing Ukrainian export-oriented enterprises in the context of PCF implementation, it is appropriate to apply SWOT analysis (Tabl. 2) that takes into account the specifics of post-war reconstruction and European integration processes.

Table 2. SWOT analysis of PCF implementation for Ukrainian export-oriented enterprises

<p>STRENGTHS</p> <ul style="list-style-type: none"> • Maintaining access to EU market • Increased competitiveness • Reduced cost of capital (up to 110 b.p.) • Access to «green» financing • Improved ESG ratings • Optimization of resource efficiency • Possibility of premium pricing 	<p>WEAKNESSES</p> <ul style="list-style-type: none"> • High initial costs (€25-500 thousand) • Lack of qualified personnel • Complexity of Scope 3 data collection • Shortage of measurement equipment • Absence of national infrastructure • High dependence on suppliers • Limited financial resources due to war
<p>OPPORTUNITIES</p> <ul style="list-style-type: none"> • EU integration through Article 9 CBAM • Post-war reconstruction as «green» • International climate financing • Technology transfer from EU • New export markets (not only EU) • Differentiation from competitors • Development of «green» economy • Participation in global value chains 	<p>THREATS</p> <ul style="list-style-type: none"> • CBAM payments \$4.7 billion (2026-2030) • Loss of market share in EU • Strengthening of EU requirements by 2030 • Competition from other countries • Prolonged war and destruction • Outflow of qualified personnel • Energy crisis • Absence of state support

Source: developed by the author based on [2; 6; 7; 10; 14]

Based on the SWOT analysis strategic priorities can be formulated for different levels of decision-making. For individual enterprises, it is critically important to begin phased implementation of PCF systems now, without waiting for complete institutional infrastructure. The PACT methodology offers a simplified cradle-to-gate approach that allows starting with measurement of Scope 1 and 2 (which are relatively easy to account for) and gradually expanding coverage to Scope 3 [9]. Use of free calculators (for example, from Together for Sustainability for the chemical industry) can significantly reduce initial costs [12].

At the state policy level, the priority should be creation of a national PCF support ecosystem: development of a national database of emission factors adapted to the specifics of Ukrainian production; implementation of a system for accreditation of PCF verifiers according to international standards; creation of financial support programs for PCF implementation integrated into a broader strategy of post-war green reconstruction [6].

Yang et al., in their analysis of CBAM impact, emphasize that countries that proactively implement national carbon pricing systems can use the Article 9 CBAM mechanism to reduce their obligations to the EU [14].

For industry associations, the key is creation of collective mechanisms: joint databases of suppliers with verified PCF indicators; industry methodological recommendations adapted to sector specifics; training and certification programs for PCF specialists. The TfS experience in the chemical industry demonstrates the effectiveness of such a collective approach [12].

Critical is the synchronization of efforts with post-war reconstruction. Lukash and Namoniuk show that strategic use of international climate finance can catalyze investments in decarbonization [15]. According to estimates, the cost of Ukraine's reconstruction exceeds €500 billion, and integration of PCF requirements into reconstruction projects from the very beginning will be significantly cheaper than retroactive adaptation. Ackermann et al. emphasize that post-war reconstruction provides a unique opportunity for simultaneously addressing economic modernization and environmental transformation tasks [6].

Conclusions. The conducted research confirms that PCF has transformed from a voluntary corporate social responsibility tool into a critical factor of competitiveness and investment attractiveness of export-oriented enterprises. The introduction of CBAM by the European Union from 2026 creates an existential threat for Ukrainian exporters: according to Paroussos et al.'s estimates, potential losses may exceed \$4.7 billion during the period 2026-2030, with Ukraine identified as the most vulnerable country among all EU trading partners [10].

At the same time, empirical research convincingly demonstrates that proper PCF management opens significant opportunities. The MSCI study covering 4,319 issuers during 2015-2024 found that companies

with higher ESG ratings obtain access to capital 110 basis points cheaper [7]. For Ukrainian enterprises in the context of post-war reconstruction requiring over €500 billion in investments, such a difference in cost of capital can become a decisive factor for survival and development.

Methodological analysis revealed that the modern system of PCF standards (ISO 14067, GHG Protocol, PACT, Tfs) provides sufficient methodological base for implementation [5; 9; 12; 13], but Ukrainian enterprises face specific challenges: absence of national support infrastructure, deficit of qualified personnel, particular complexity of data collection for Scope 3 (which constitutes 75-85% of total carbon footprint), and financial constraints in the context of war [1; 8].

SWOT analysis revealed that successful PCF integration requires coordinated actions at three levels. Enterprises should begin phased implementation of measurement systems using simplified approaches (PACT) and free tools to minimize initial costs [9]. State policy should focus on creating a national support ecosystem: database of emission factors, system for accreditation of verifiers, financing programs synchronized with the

strategy of green post-war reconstruction [2; 6]. Industry associations can provide collective solutions through joint supplier databases and industry methodological recommendations.

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Further research should focus on: (1) development of industry-specific PCF methodologies for key Ukrainian export sectors (metallurgy, agro-industry, chemistry); (2) empirical analysis of the impact of PCF reporting on the cost of capital of Ukrainian companies; (3) assessment of the effectiveness of different models of state support for PCF implementation; (4) study of possibilities for using renewable energy sources to reduce Scope 2 emissions in the context of post-war reconstruction of energy infrastructure.

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Donets D. Product Carbon Footprint (PCF) in the system of investment attractiveness assessment of export-oriented enterprises

This study examines Product Carbon Footprint (PCF) as a critical factor in investment attractiveness assessment for Ukrainian export-oriented enterprises. The research analyzes PCF calculation methodologies according to international standards (ISO 14067, GHG Protocol, PACT) and EU regulatory requirements (CBAM, ESRS E1). Empirical evidence from MSCI (4,319 issuers, 2015-2024) demonstrates that companies with superior ESG ratings access capital 110 basis points cheaper. For Ukraine, CBAM implementation poses existential risks: potential export losses may exceed \$4.7 billion during 2026-2030 (Paroussos et al.). SWOT analysis identifies key challenges (high costs, personnel shortage, Scope 3 data complexity) and opportunities (green post-war reconstruction, climate finance). Strategic recommendations are developed for enterprises, government policy, and industry associations.

Keywords: product carbon footprint, PCF, investment attractiveness, CBAM, ESRS E1, ESG ratings, export-oriented enterprises, post-war recovery.

Донець Д. А. Product Carbon Footprint (PCF) у системі оцінки інвестиційної привабливості експортоорієнтованих підприємств

Стаття присвячена дослідженню трансформації вуглецевого сліду продукції (Product Carbon Footprint, PCF) з добровільного інструменту корпоративної соціальної відповідальності у критичний фактор конкурентоспроможності та інвестиційної привабливості експортоорієнтованих підприємств. Актуальність дослідження обумовлена введенням Європейським Союзом механізму вуглецевого коригування на кордоні (CBAM) з 2026 року, що створює екзистенційні виклики для українських експортерів, понад 40% продукції яких спрямовується до ЄС.

Методологічну основу дослідження становить порівняльний аналіз міжнародних стандартів вимірювання PCF (ISO 14067, GHG Protocol Product Standard, PACT Methodology, TfS PCF Guideline) та регуляторних вимог ЄС (ESRS E1, CBAM). Проаналізовано структуру викидів парникових газів за тривірневою класифікацією Score 1, 2, 3, виявлено, що категорія Score 3 становить 75-85% загального вуглецевого сліду продукції, проте саме її облік залишається найбільш проблематичним.

Емпіричне дослідження базується на аналізі робіт MSCI (4319 емітентів, період 2015-2024), Ernst та Woithe, Purbasari та Rokhim, які доводять, що компанії з вищими ESG-рейтингами отримують доступ до капіталу на 110 базисних пунктів дешевше порівняно з компаніями з низькими рейтингами. Для українського контексту критичним є дослідження Paroussos та співавторів, які ідентифікували Україну як найбільш вразливу країну до впровадження CBAM з потенційними втратами експорту понад \$4,7 млрд у період 2026-2030 років.

SWOT-аналіз виявив ключові виклики впровадження PCF: високі початкові витрати (€25-500 тис.), дефіцит кваліфікованого персоналу, складність збору даних Score 3, відсутність національної інфраструктури підтримки. Водночас визначено стратегічні можливості: післявоєнна відбудова як платформа для зеленої трансформації, доступ до міжнародного кліматичного фінансування, використання механізму Article 9 CBAM для зниження зобов'язань.

Розроблено практичні рекомендації для трьох рівнів: підприємства (поетапне впровадження, використання спрощених методик PACT), державна політика (створення національної бази емісійних факторів, програми фінансової підтримки), галузеві асоціації (колективні бази даних постачальників, програми навчання персоналу).

Ключові слова: вуглецевий слід продукції, PCF, інвестиційна привабливість, CBAM, ESRS E1, ESG-рейтинги, експортоорієнтовані підприємства, післявоєнне відновлення.