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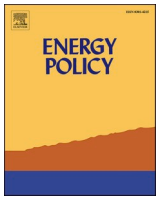

Industrial decarbonization in a fragmented world: Carbon pricing with border adjustments using standardized values

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A B S T R A C T

The European Carbon Border Adjustment Mechanism (CBAM) has the dual objective of preventing carbon leakage and encouraging adoption of low-carbon technologies abroad. Yet, pursuing both objectives with the same mechanism results in incomplete carbon leakage protection unless global carbon prices converge. As the current geopolitical situation makes rapid convergence seem unlikely, an extension of free allowance allocation is being discussed for affected sectors. This would, however, mute most carbon pricing incentives and reduce carbon pricing revenues. This paper argues that until progress on global carbon pricing is reached, the CBAM should be reformed to use standardized values rather than production-specific emission intensities for materials with complex value chains. With the reform, emission trading with free allowances at benchmark level continues to provide the carbon price and incentives for conventional producers. To close the carbon pricing gap, a standardized liability per ton of material is included, independent of production process or location. It can be subject to established border adjustments along the full value chain, including export relief. Such a reform would not create direct incentives for climate-friendly material production and carbon pricing in third countries but would ensure carbon pricing incentives along the domestic value chain and carbon pricing revenue to fund climate action. This would enhance investment stability, support industrial transformation, and address carbon leakage risks in a fragmented global policy landscape.

1. Introduction

Global efforts to combat climate change are entering a critical phase. At the same time, the international landscape is becoming increasingly fragmented. The second Trump Administration in the US and the rise of protectionist policies signal a shift away from multilateral cooperation towards a more divided global order. This fragmentation poses significant challenges for the European Union (EU), whose climate and industrial strategy relies heavily on carbon pricing as a key driver of investment towards climate neutrality (Köveker et al., 2025). A core

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element of this strategy is the phased transition from free allocation of EU Emissions Trading System (ETS) allowances for industry to full auctioning by 2034 (European Commission, 2019). This shift is intended to strengthen the effectiveness of the carbon price in driving green investments while generating revenue to support climate action. However, higher ETS carbon prices relative to those in other regions increase the risk of carbon leakage, where production and emissions shift to jurisdictions with weaker climate policies (Grubb et al., 2022). Carbon leakage risks also undermine carbon cost pass-through, the process by which carbon costs are reflected in product prices along the value chain. Effective pass-through is crucial both for financing the incremental costs of climate-neutral production and for incentivizing circularity, material efficiency and substitution towards greener products.

To address these risks, the EU introduced the Carbon Border Adjustment Mechanism (CBAM) as a safeguard against carbon leakage during the transition from free allocation to full auctioning (European Union, 2023a,b). The UK is set to implement a similar mechanism by 2027 (HM Revenue & Customs, 2026). The CBAM aims to level the playing field between domestic producers subject to the ETS and foreign producers in regions with lower carbon pricing. It requires the surrender of ETS allowances for emissions embedded in imported goods. The current CBAM is based on the specific emissions embedded in the production of the imported commodities and carbon prices paid in third countries. Thereby, it seeks to encourage carbon-efficient production in third countries and to create incentives for global adoption of comparable carbon pricing mechanisms and thus to reduce international carbon price disparities.

The use of production-specific values marks a significant deviation from established border adjustments for excise duties or value added taxes (VAT). Because excise duties and value added taxes are charges on the quantity or value of domestic products, rather than on production inputs, World Trade Organization (WTO) rules allow for applying the same charges on imports and for waiving them on exports. By contrast, as the ETS is based on specific emissions, CBAM also uses production-specific emissions for imports to avoid unjustified discrimination against importers. Reflecting concerns about the compatibility of export rebates with WTO rules (Mehling et al., 2019), export adjustments are generally not considered under the current CBAM design (Espa et al., 2022).

Beyond the absence of an export solution, production-specific values present further drawbacks. They create higher circumvention risks compared to standardized values. Additionally, their stringent administrative requirements prevent the current CBAM from comprehensively covering material embedded within products or semi-finished products (European Union, 2023a,b). These limitations can result in significant carbon leakage risk for materials with complex value chains: steel, organic chemicals, and aluminum. If other countries do not adopt comparable carbon pricing mechanisms and carbon price differences remain large, the CBAM may not suffice to provide a level playing field. Indeed, few anticipated the scale at which protectionism is now taking precedence over coordinated climate action (Altenburg, 2024). The second Trump Administration's continuing retreat from multilateralism, including its withdrawal from the Paris Agreement and the United Nations Framework Convention on Climate Change, underscores this risk. It raises pressing questions about the adequacy of a CBAM based on production-specific emissions in a world of persistently divergent carbon prices. In this global context, European climate policymakers must consider additional options to safeguard the resilience of their industrial strategy.

Border adjustments based on standardized values offer an alternative, pragmatic solution for materials with complex value chains, and one that was already considered and positively evaluated during the EU impact assessment (European Commission, 2021). This approach would align the CBAM with the long-standing practices of border tax adjustments for indirect taxes (Pirlot, 2017; OECD, 1968; WTO, 1970). Producers would remain covered by the ETS and would receive free allocation proportional to their production volume such that they only incur costs for emissions exceeding a benchmark. In addition, the producers would incur a standardized liability per ton of material produced, equal to emissions of the benchmark multiplied by the carbon price of the preceding year.

As the liability would apply regardless of the production process or location, it would be subject to standard border adjustments: it would be waived on exports and imposed on imports, including for imports of materials embedded in products. Together with complementary instruments such as Carbon Contracts for Difference (CCfDs) for clean material producers, this would create effective carbon prices and contribute to a reliable investment framework for all domestic actors (Neuhoff et al., 2014a; Neuhoff et al., 2014b; Roth et al., 2016) while avoiding carbon leakage risks. For materials covered by this standardized liability, reporting and financial liability under the production-specific CBAM would be paused, avoiding the administrative difficulties associated with complex value chains. Such a CBAM would, however, not create direct incentives for third countries to implement carbon pricing or for foreign producers to adopt clean production process though it could help fund complementary measures to contribute to this objective.

2. Understanding the practical implications of the current CBAM

2.1. Objectives and scope of CBAM

In 2023, the EU formally adopted a CBAM to reduce the risk of carbon leakage and to incentivize third countries to strengthen carbon pricing. The UK CBAM will adopt a similar structure, albeit with differences in timescale and scope. In terms of trade flows, and due to concerns over WTO compliance discussed above, the CBAM Regulation provides adjustment for imports but not exports. In terms of sectoral coverage the EU CBAM covers in its initial phase a limited range of emissions-intensive materials and basic materials products (European Union, 2023a,b): iron and steel, cement, aluminium, fertilizers, electricity and hydrogen. Finished or semi-finished products were initially excluded from its scope, though future expansions under consideration include plastics and other basic materials. The focus on these materials reflects their disproportionate contribution to industrial emissions, accounting for over 70% of global industrial emissions and around 25% of total global emissions (IEA, 2017), and the expectation that the carbon liability will be passed through along the value chain.

2.2. Limitations of the EU CBAM

The CBAM has three significant limitations that may undermine its effectiveness.

First, the absence of export rebates for carbon costs creates a competitive disadvantage and carbon leakage risk in international markets (Böhringer et al., 2022). If other regions do not implement comparable carbon pricing, European exports will be exposed to competition from these regions (Marcu et al., 2024). Stede et al. (2021) estimate that at a carbon price of €75 per ton of CO_2, nearly 23% of European manufacturing exports are – according to EU criteria on carbon-pricing-related cost increase – at risk of carbon leakage in international markets. However, offering export rebates could violate WTO rules, dilute incentives to decarbonize production for export markets, and fail to support the additional costs of operating low-carbon facilities, thereby limiting long-term decarbonization in export-oriented sectors.

In December 2025, the European Commission proposed financial support for all basic material producers in a CBAM sector, effectively muting carbon pricing incentives in a manner similar to free allowance allocation (European Union, 2025a). Proposals for selective support for exporting firms were not pursued (Marcu et al., 2022), as they would add administrative and legal complexity, especially if applied across

extended value chains.

Second, since CBAM currently applies only to imports of basic materials and not semi-finished or finished goods, European manufacturers face higher input costs compared to competitors in countries without carbon pricing. This undermines the competitiveness of European manufacturers in domestic markets (Bellora and Fontagné, 2023), favoring dirtier and cheaper alternatives and thereby creating additional carbon leakage risk. The December 2025 Commission proposal also envisages covering imports of 180 selected manufactured products with high carbon leakage risk (European Union, 2025b) which would allow carbon costs to be passed along domestic value chains. However, this comes at increased administrative cost and does not address the export problem. Manufacturers of semi-finished products still face higher input costs and reduced competitiveness in international markets, leading to increased carbon leakage risk.

Third, the CBAM may incentivize resource shuffling, where foreign producers export their least carbon-intensive products to Europe while supplying other markets with more CO_2-intensive output (CRU Consulting, 2021). This practice can increase competitiveness of imports over domestic production and thus undermine domestic political support for ETS. It can also contribute to indirect carbon leakage: firms in third countries increasing their exports may do so by increasing production from underutilized plants that tend to be carbon intensive. If their carbon intensity were higher than from the European plants that lost market share, then global emissions would increase.

To avoid resource shuffling, it has been proposed to assess the carbon intensity of imported materials using mandatory default values. Under the current system, mandatory default values would, however, result in discrimination against cleaner producers in third countries, raising WTO concerns. The December 2025 proposal facilitates the use of voluntary default values to reduce administrative costs, but importers retain the right to use production-specific values and resource shuffling risks therefore remain.

Despite these proposals, no clear solution has emerged to ensure full protection against carbon leakage if global carbon price differences persist. The current CBAM design leaves European policymakers with a difficult dilemma: either accept incomplete carbon leakage protection, risking loss of competitiveness and production reallocation; or delay the phase-out of free allocation and CBAM implementation, thus weakening carbon price signals, reducing ETS revenues, and undermining the investment framework necessary for modernizing EU industry.

This policy challenge is not unique to the EU. Other jurisdictions considering options to strengthen carbon pricing for industry, including the UK and Australia, face similar trade-offs (DCCEEW, 2024). Innovative policy approaches beyond conventional carbon pricing will be needed to balance climate ambition with industrial competitiveness.

Ultimately, the EU must ensure that its carbon leakage measures are robust in a fragmented global policy landscape, while preserving the economic foundations needed to modernize industry and achieve climate neutrality. If global carbon price divergence continues, Europe's leadership in decarbonizing industry will hinge on its ability to navigate these complex trade-offs.

3. Shifting to border adjustments using standardized values

Given the limitations of the current CBAM, it is worth revisiting an alternative border adjustment design for materials with complex value chains: the use of standardized values. This approach was already considered and positively evaluated during the EU impact assessment (European Commission, 2021).

3.1. Building on globally established border adjustment mechanisms

In line with established border adjustment procedures, a standardized liability for carbon costs would apply to carbon-intensive basic materials, such as steel, aluminum or organic chemicals (Ismer et al., 2016). To reduce risks of WTO incompatibility, the liability would not be differentiated by production location or process. Both domestic producers and importers would incur the same liability regardless of their technology or country of origin. The liability would be calculated as the weight of the material multiplied by the reference emission intensity value for the material and the ETS carbon price of the preceding year. For administrative simplicity, the same liability would apply across different types of steel or different types of organic chemicals.

Producers and importers would either pass the liability to firms purchasing the material or product or would pay the liability and include the costs in the product price. Purchasers would select to have the liability passed on to them, rather than reflected in the product price, if they export to third countries since the liability would be waived in such cases (Ismer et al., 2020). This approach simplifies administration for both authorities and businesses and facilitates extension along the value chain. Importantly, the use of standardized values avoids the risk of resource shuffling.

If such a standardized liability were to replace the ETS rather than supplement it, incentives for efficiency improvements in conventional production and for clean production processes would be forgone. Moreover, without coverage of industrial emissions under ETS, the system would no longer generate a market-based carbon price. It is therefore important to integrate border adjustment with standardized values into the ETS.

3.2. Integrating border adjustments with standardized values in the EU ETS

Border adjustment with standardized values would complement existing climate policy tools – including the EU and UK ETS, free allocation of allowances, and Carbon contracts for Differences (CCfDs) (Fig. 1). More importantly, they would close the carbon pricing gap caused by free allowance allocation and should therefore be considered in the ongoing ETS and CBAM review process.

Production of basic materials would remain covered by the ETS, and producers would continue to receive free allocation at a benchmark level based on the best available conventional technology without the use of biomass, proportional to their current production. The costs incurred to pay for emissions above the benchmark would therefore be moderate and would not trigger carbon leakage risks. At the same time, the coverage of all emissions under the ETS would ensure that the carbon price formation remain intact. Incentives to improve plant level carbon efficiency would be retained as free allowance allocation is benchmark based: all carbon savings for a given production level would be fully rewarded at the carbon price.

With full free allocation at the benchmark level proportional to production volume, material producers would not bear costs for emissions up to the benchmark and would therefore also not pass these costs through to product prices. This would mute the carbon price signal for efficient material use, material choice and circularity. Also, allowances allocated for free could not be auctioned, and hence carbon pricing revenue would be forgone.

This gap would be filled by the standardized liability subject to border adjustment, imposed on material producers in proportion to the weight of their production (Fig. 1). Material producers would thus be liable for the full carbon footprint: for emissions at the benchmark level, reflected in the standardized liability; and for emissions exceeding the benchmark, for which allowances must be purchased under the ETS. In this way, the ETS combined with border adjustments based on a standardized value would create an effective carbon price while avoiding carbon leakage risks.

For investments in near climate-neutral material production, several EU Member States and the UK are using or introducing various types of CCfDs (Richstein and Neuhoff, 2022). These contracts ensure financial predictability by covering the cost gap between conventional and carbon-neutral production with payments adjusted to reflect the carbon

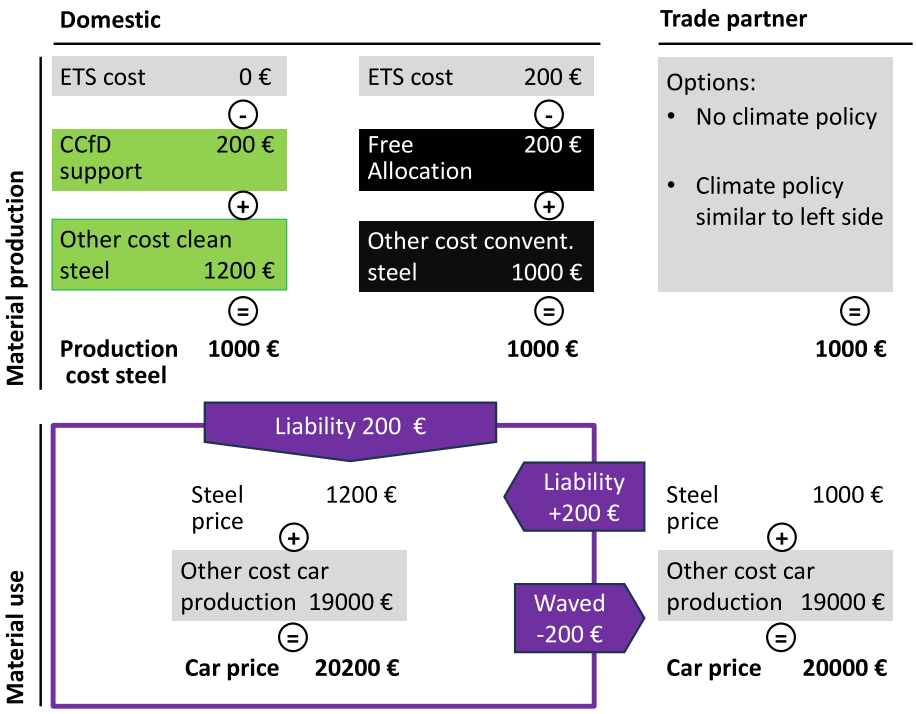

Fig. 1. Illustration of how the ETS in combination with border adjustments based on liability with standardized value deliver a single carbon price for domestic material production and use.

costs already incurred under the ETS to avoid over-compensation. CCfDs or similar instruments remain essential to address regulatory risks for clean investments.

One major challenge, however, is ensuring adequate and harmonized financing for CCfDs across Europe. Effective carbon pricing on the use of materials addresses this by generating dedicated revenue to support these investments, crucial for industrial modernization and global climate cooperation (Cornago and Berg, 2024). If 50% of current primary production of steel, organic chemicals and aluminum were to shift to clean processes, assuming an average abatement costs of 150 €/t CO2, this would require revenue of approximately 12 billion EUR/year.[1]

The carbon leakage concerns associated with the current CBAM design have triggered a strong political momentum across the EU to extend free allowances allocation in the steel sector and to further delay the introduction of a CBAM for organic chemicals. This would severely limit the carbon pricing revenues from auctioning under EU ETS and from the CBAM from the industrial sector. Compared to this, the proposed shift to border adjustments with standardized values would yield additional revenue of 34 billion €/yr at carbon price of 75 €/t CO2 for steel, organic chemicals and aluminum (Stede et al., 2021).

Producers of near climate-neutral material would opt-out from receiving free allowances, if they obtain CCfDs. Allowances under the ETS cap would thus only be required for conventional production processes, whose emissions should, by definition, not exceed the cap. Sufficient allowances would therefore be available to grant full benchmark-level free allocation to material producers as they transit step-by-step to clean production processes.

To ensure that conventional firms do shift to clean processes, continued free allocation must be conditional on transition plans that are consistent with the overall transition strategy. This conditionality is already required for the 20% worst-performing firms (European Union, 2023a,b), and would need to be expanded to all firms. Linking free allocation to decarbonization commitments is essential to spur investment in climate-neutral technologies (Algers and Åhman, 2024). It is also required to allow public policy-makers to ensure provision of adequate infrastructure for clean processes such as. electricity interconnection, hydrogen and CO2 pipelines.

Together, the combination of the ETS with free allocation, border adjustments with a standardized liability at the value of the free allocation, and CCfDs would deliver a single carbon price, encouraging efficient material use, recycling and substitution (Neuhoff et al., 2022).[2] Studies that conduct a comprehensive modeling of the mechanism include Böhringer et al. (2017, 2021).

As with global carbon pricing and full auctioning applied to all industrial sectors, at €75/t CO_2, this would increase costs for consumers by 0.4% (low-income households) and 0.5% (higher-income households) relative to their total expenditure (Stede et al., 2021). As an integrated environmental policy instrument, the reform could be implemented through qualified majority voting in the EU (Ismer and Haussner, 2016). Combined with CCfDs, it would remain WTO-compliant (Ismer et al., 2023).

In a comprehensive assessment conducted as a support study for the Directorate-General for Taxation and Customs Union (DG TAXUD), the approach of using adjustments with a standardized liability was positively evaluated across most dimensions, including leakage prevention and emission reductions (European Commission, 2021). However, at the time it was not pursued because standardized values do not directly incentivize more carbon-efficient material production or carbon pricing in third countries.

[1] Based on emissions attributed in EU ETS registry to production of coke, pig iron or steel, ferrous metals, primary aluminium, bulk chemicals, hydrogen and synthesis gas and 16% of emissions from refinery sector (Larsen and Tilsted, 2024).In principle, investments in clean processes could also be supported by the provision of the same level of free allocation as conventional producers (Venmans, 2016). However, the combined demand for free allowances by conventional and clen producers would soon exceed the declining emissions cap.

[2] There is one limitation: As the liability is waived on exported products, it does not create incentives for material efficiency improvements of exported products.

3.3. International effect

The current CBAM has helped to revive international debate on carbon pricing. By contrast, adjustments based on standardized values do not create direct international incentives for carbon pricing or clean material production in third countries: like domestic producers, importers would face the same liability per ton of product, irrespective of the production process.

However, the limitations of the CBAM Regulation imply that Europe's economic success would depend on other jurisdictions implementing of effective carbon pricing. This dependence could encourage other countries to delay carbon pricing to gain a competitive advantage through carbon leakage. A shift to border adjustments based on standardized values would remove such incentives and instead make the ETS environmentally robust and economically resilient to carbon price differences. This would strengthen Europe's credibility and leverage in global climate negotiations and could also place greater emphasis on complementary initiatives such as product labeling schemes and standards. It also underscores the role of bilateral and multilateral cooperation among progressive countries, backed by carbon pricing revenue and instruments such as international CCfDs.

Border adjustments based on standardized values would also create a dedicated revenue stream, of which a fraction (e.g. 20%) could be used to support the transition to climate-neutral production in partner countries from the Global South. Such support would focus on measures to strengthen domestic production and use of climate neutral materials in those countries rather than exports to the EU, ensuring that all countries can prepare their industries so they can meet future demand for climate-neutral materials.

4. Conclusion and outlook

An effective carbon price remains central to achieving Europe's climate and industrial policy objectives. Yet the current CBAM design, based on production-specific emission intensities, leaves significant carbon leakage channels unaddressed, particularly for materials with complex value chains. Extending free allowance allocation, while politically expedient, would weaken carbon pricing incentives, reduce revenues, and undermine the investment framework needed for industrial transformation.

Border adjustments based on standardized values offer a practical and WTO-compliant alternative. By combining the EU ETS with a standardized liability subject to border adjustment, this approach would deliver three key benefits. First, it would provide more effective protection against carbon leakage compared to the current CBAM design. Because liability is independent of production process or location, it can be applied along the full value chain, including through export relief, without the circumvention and resource shuffling risks associated with production-specific values.

Second, it would preserve carbon pricing revenue. Unlike an extension of free allowance allocation, this reform would ensure that the ETS generates sufficient revenue to finance industrial decarbonization and modernization through instruments such as Carbon Contracts for Difference, while keeping European industry competitive and well-positioned in the global transition to climate-neutral production.

Third, it would protect incentives for a circular and material-efficient economy. By ensuring a carbon price signal on material use, the reform would discourage the use of carbon-intensive materials, reducing emissions and energy use in raw material extraction and processing. It would also improve overall value chain resilience, while generating co-benefits for biodiversity and resource security.

A further strategic advantage concerns policy resilience. Currently, the success of the EU's ETS and CBAM is contingent on external progress in global carbon pricing, exposing European climate and industrial policy to international uncertainty. Border adjustments based on standardized values would reduce this vulnerability by providing a domestically controlled instrument that enhances policy stability and protects long-term industrial investment. If progress towards global carbon pricing is slower than expected, the clean investment framework provided by the ETS would not be jeopardized. Enhancing the resilience of regional climate policy against global development would ensure that European climate action remains credible and consistent.

In summary, reforming the ETS and CBAM to use standardized values presents a credible and pragmatic approach to strengthen carbon leakage protection, support industrial investment, while also enhancing Europe's resilience to geopolitical uncertainty. Such a reform would ensure that the continent can pursue a low-carbon industrial transition even in a fragmented global policy environment.

CRediT authorship contribution statement

Karsten Neuhoff: Conceptualization, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Misato Sato:** Conceptualization, Writing – original draft, Writing – review & editing. **Fernanda Ballesteros:** Writing – original draft, Writing – review & editing. **Christoph Böhringer:** Conceptualization, Writing – original draft, Writing – review & editing. **Simone Borghesi:** Conceptualization, Writing – original draft, Writing – review & editing. **Aaron Cosbey:** Conceptualization, Writing – original draft, Writing – review & editing. **Thibault Deletombe:** Writing – review & editing. **Balázs Felsmann:** Writing – review & editing. **Roland Ismer:** Conceptualization, Writing – original draft, Writing – review & editing. **Angus Johnston:** Conceptualization, Writing – original draft, Writing – review & editing. **Pedro Linares:** Conceptualization, Writing – original draft, Writing – review & editing. **Sini Matikainen:** Conceptualization, Writing – original draft, Writing – review & editing. **Stefan Pauliuk:** Conceptualization, Writing – original draft, Writing – review & editing. **Alice Pirlot:** Conceptualization, Writing – original draft, Writing – review & editing. **Philippe Quirion:** Conceptualization, Writing – original draft, Writing – review & editing. **Knut Einar Rosendahl:** Conceptualization, Writing – original draft, Writing – review & editing. **Aleksander Sniegocki:** Conceptualization, Writing – original draft, Writing – review & editing. **Harro van Asselt:** Conceptualization, Writing – original draft, Writing – review & editing. **Lars Zetterberg:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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