

REVIEW ARTICLE

Carbon Border Adjustment and Emerging-Economy Exporters: Exposure, Measurement Capability and Firm Response

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ABSTRACT

The European Union's carbon border adjustment mechanism entered its transitional phase in 2023 and its definitive regime begins in 2026, covering cement, iron and steel, aluminium, fertilisers, electricity and hydrogen. Analysis of its consequences for emerging-economy exporters has concentrated on price exposure. This study argues that for such exporters, and for the small and medium enterprises within their supply chains, the binding constraint is not the carbon price but the capability to document embedded emissions at product level. The method is a structured review of research published between 2017 and 2024, combined with a firm-capability analysis that traces how the mechanism's default-value provisions convert a measurement deficit into a price penalty. Three findings follow. Exposure is highly uneven, with many developing economies having more than two per cent of exports and one per cent of production affected, concentrated in a small number of sectors. Emissions measurement is unreliable even among large listed firms, where harmonisation of reporting roughly doubles measured footprints and corporate reports omit about half of total emissions, which makes measurement capability a first-order constraint rather than an administrative detail. And the evidence base underpinning the mechanism is contested: no carbon leakage was detected in European manufacturing under emissions trading, and carbon pricing has generally shown no significant competitiveness effect. The study concludes that the first-order strategic response for exposed firms is investment in emissions accounting rather than abatement, and that a credible domestic carbon price is what converts exposure into actual emission reduction.

Keywords: *carbon border adjustment; emerging economies; emissions accounting; export competitiveness; small and medium enterprises*

ABSTRAK

Mekanisme penyesuaian karbon lintas batas Uni Eropa memasuki fase transisi pada 2023 dan rezim definitifnya dimulai pada 2026, mencakup semen, besi dan baja, aluminium, pupuk, listrik, serta hidrogen. Analisis atas dampaknya bagi eksportir negara berkembang selama ini terpusat pada paparan harga. Penelitian ini berargumen bahwa bagi eksportir tersebut, dan bagi usaha kecil dan menengah di dalam rantai pasoknya, kendala yang mengikat bukanlah harga karbon melainkan kemampuan mendokumentasikan emisi melekat pada tingkat produk. Metodenya adalah telaah terstruktur riset terbitan 2017 hingga 2024 yang dipadukan dengan analisis kapabilitas perusahaan untuk menelusuri bagaimana ketentuan nilai bawaan mekanisme itu mengubah defisit pengukuran menjadi denda harga. Tiga temuan mengikutinya. Paparan sangat tidak merata, dengan banyak negara berkembang mengalami dampak pada lebih dari dua persen ekspor dan satu persen produksinya, terkonsentrasi pada sedikit sektor. Pengukuran emisi tidak andal bahkan pada perusahaan besar tercatat, yang

harmonisasi pelaporannya kira-kira melipatgandakan jejak terukur dan laporan korporatnya menghilangkan sekitar separuh total emisi, sehingga kapabilitas pengukuran merupakan kendala utama, bukan rincian administratif. Basis bukti yang menopang mekanisme itu pun diperdebatkan: tidak ditemukan kebocoran karbon pada manufaktur Eropa di bawah perdagangan emisi, dan penetapan harga karbon umumnya tidak menunjukkan pengaruh signifikan terhadap daya saing. Penelitian menyimpulkan bahwa respons strategis pertama bagi perusahaan terpapar adalah investasi pada akuntansi emisi, bukan penurunan emisi, dan bahwa harga karbon domestik yang kredibel adalah yang mengubah paparan menjadi pengurangan emisi nyata.

Kata kunci: *penyesuaian karbon lintas batas; negara berkembang; akuntansi emisi; daya saing ekspor; usaha kecil dan menengah*

1. INTRODUCTION

A carbon border adjustment is, in its simplest description, a charge on imports calculated from the greenhouse gases emitted in making them. The logic is straightforward: if domestic producers face a carbon price and foreign producers do not, then either domestic production migrates abroad or the climate policy is diluted to prevent that migration. A border charge is intended to remove the choice.

The European Union's carbon border adjustment mechanism gives that logic operational form. Its transitional phase, in which importers report embedded emissions without payment, began in 2023, and the definitive regime in which certificates must be surrendered begins on 1 January 2026. The mechanism covers cement, iron and steel, aluminium, fertilisers, electricity and hydrogen. It does not, at present, cover pulp and paper, textiles or other manufactured goods that discussion of the mechanism sometimes assumes, and the distinction matters for any firm assessing its own exposure.

Most analysis of the mechanism's consequences for exporters outside the Union proceeds by estimating price exposure: how much of a country's exports fall within scope, what carbon price would be implied, and what output or welfare loss follows. That work is necessary and this study draws on it. But it takes for granted something that is not given, namely that a firm can establish what its embedded emissions actually are.

The mechanism's design makes that assumption consequential. Where an importer cannot demonstrate actual embedded emissions with acceptable documentation, default values apply. A default value is by construction insensitive to the exporter's real performance: an efficient producer and an inefficient one in the same country and sector are charged alike. The measurement deficit therefore does not merely delay the price signal; it severs the link between a firm's emissions and its liability, which is the link the instrument depends on.

This matters most where measurement capability is weakest, and the evidence indicates that measurement is unreliable even where capability should be strongest. Klaaßen and Stoll (2021) find that corporate reports omit approximately half of total emissions, and that harmonising the reporting of 56 technology firms raised the measured total from 360 to 751 million tonnes of carbon dioxide equivalent. If large listed firms with dedicated sustainability functions produce figures that roughly double under harmonisation, the assumption that a mid-sized exporter in an emerging economy can produce a verifiable product-level figure requires justification rather than assertion.

This study therefore asks three questions. First, what does the verified literature establish about the distribution of exposure to the mechanism across emerging economies and sectors? Second, what does it establish about firms' capability to measure and verify embedded emissions, and what follows for the mechanism's operation where that capability is absent? Third, what strategic response does this imply for exposed firms, and what policy condition converts exposure into actual emission reduction rather than into trade diversion?

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Design and its unresolved questions

Cosbey et al. (2019) synthesise the economic and legal literature on border carbon adjustment and set out the design decisions any such instrument must make: which products fall in scope, how product carbon content is calculated, what adjustment method applies, how revenue is used, and how the instrument is to be reconciled with trade and climate treaty obligations. Their framing identifies calculation of carbon content as a design choice rather than a technical formality, which is the point this study develops.

Böhringer et al. (2022) review border adjustment as a leakage remedy across leakage, competitiveness, cost-effectiveness, equity and international cooperation, and conclude that the viability of such schemes can be substantially reduced by current legal and practical implementation constraints. Zhong and Pei (2024), reviewing 97 studies systematically, conclude that no single design approach suits all cases and that policy design and the characteristics of the affected economy jointly determine outcomes.

Boute (2024) examines a specific design choice with direct emerging-economy consequences: the mechanism credits only explicit carbon pricing such as taxes and emissions trading, excluding regulatory standards and indirect pricing through instruments such as fuel excise. He argues the critique requires qualification, since the mechanism rests on actual emissions calculation and a producer regulated through emission standards may still demonstrate lower embedded emissions — a demonstration that returns the argument to measurement capability — and recommends amending the mechanism to recognise indirect carbon pricing and crediting systems.

The distribution of exposure

Magacho et al. (2024), combining trade data with multi-regional input-output matrices, find exposure highly uneven both geographically and sectorally. Russia, China, Turkey and Ukraine are the principal European trading partners in covered products, while many developing economies have more than two per cent of exports and more than one per cent of production affected. They warn that technological substitution is markedly easier in Europe than in emerging and developing economies, so the same price signal produces adjustment in one setting and loss in the other.

Zhong and Pei (2022) quantify the welfare and competitiveness consequences using a refined multi-regional input-output approach. At a price of one hundred United States dollars per tonne of carbon dioxide equivalent, European output rises by 0.38 per cent while output in the rest of the world falls by 0.1 per cent in the short run, with China, Russia and India bearing the largest burden. Their sub-national analysis of China carries an implication that is easily missed: income losses in landlocked provinces exceed their direct export losses, because exposure propagates inland through domestic production networks. Firms that do not export at all can therefore be exposed through the customers they supply.

Lin and Zhao (2024) find non-member economies of the Organisation for Economic Co-operation and Development facing greater output declines and larger production-cost increases than member economies, with African economies experiencing the most severe output reductions and Asian economies the steepest cost increases. Perdana and Vielle (2022) assess the mechanism together with eight complementary measures for least developed countries, finding that it reduces the leakage rate by one-third by 2040 and that exempting least developed countries is less justifiable than it appears, since exemption produces greater leakage than the alternatives; revenue redistribution toward clean energy use performs best.

Eicke et al. (2021) construct a third-country risk index from export structure, emissions intensity, emission-reduction targets, and — importantly for the present argument — institutional capacity to monitor and report product-based emissions. Their inclusion of monitoring capacity as a risk dimension is the closest the located literature comes to the argument developed here, though it operates at country rather than firm level.

Measurement capability as a constraint

Klaaßen and Stoll (2021) provide the most consequential evidence. Examining corporate carbon footprints, they find current accounting and reporting practices unsystematic and not comparable, particularly for value-chain emissions. Applying a harmonisation framework to 56 technology firms raised self-reported emissions from 360 to 751 million tonnes of carbon dioxide equivalent, a gap of 391 million tonnes; reported footprints rose by 99 per cent for software and services firms and 110 per cent for hardware firms, with individual deviations ranging from 0.06 per cent to a factor of 185 and a median that quadrupled. Corporate reports, they conclude, omit about half of total emissions.

The relevance is not that these firms are dishonest but that the measurement problem is genuinely hard and remains unsolved among the best-resourced reporters. Olekanma et al. (2024), reviewing 70 articles on small and medium enterprise carbon footprint initiatives, identify the absence of tracking frameworks for such enterprises as an open problem in the field. Their review concerns carbon reduction generally rather than border adjustment compliance, and is used here only for that narrower point.

The contested empirical premise

An adequate treatment must record that the mechanism's justification is empirically contested. Naegele and Zaklan (2019), examining European manufacturing sectors covered by emissions trading using trade flow data and embodied carbon metrics, find no evidence that the emissions trading system caused carbon leakage. Venmans et al. (2020), reviewing evidence across member economies of the Organisation for Economic Co-operation and Development and the Group of Twenty, find that most assessments detect no statistically significant effect of carbon pricing on imports, investment, employment or innovation, attributing this to low price levels combined with exemptions and free allowance provisions, and report a small positive effect on productivity and innovation.

Best et al. (2020), analysing 142 countries over two decades, find that carbon pricing countries show approximately two percentage points lower annual growth in carbon dioxide emissions, with each additional euro per tonne associated with roughly 0.3 percentage points lower subsequent growth, and record that 43 of the 142 countries had national or subnational carbon pricing. Carbon pricing works on emissions; the leakage it is meant to prevent is less well evidenced than the policy discourse implies.

Regional evidence and the Indonesian gap

The closest verified regional evidence concerns Vietnam. Chu, Do, Nguyen et al. (2024), using general and partial equilibrium models on public data, find the mechanism in its current form unlikely to produce substantial effects on Vietnam's overall economy because covered commodities form a small share of its export portfolio, while steel, aluminium and cement face potential reductions in output and export revenue. Chu, Do, Le et al. (2024) model Vietnamese steel with multiple technologies and find that the mechanism could significantly reduce steel exports to Europe without being sufficient to shift production from high-emission to low-emission methods; domestic carbon pricing, by contrast, can drive a substantial transition depending on the price level. This is the pivotal result for the present argument.

For Indonesia, the position must be stated plainly: no peer-reviewed study published between 2017 and 2024 quantifying Indonesian export exposure to the mechanism was located. Nurhayati et al. (2024) supply the domestic policy facts, reporting that Indonesia's carbon tax took effect on 1 April 2022 at thirty thousand rupiah per tonne of carbon dioxide equivalent, approximately two United States dollars, applied initially to coal-fired steam power plants with expansion planned, alongside a cap-and-trade arrangement in which firms below their cap receive emission permit certificates. The comparison the same study offers is instructive: Finland prices carbon at approximately 73 dollars per tonne and Sweden at approximately 137 dollars.

What the reporting-and-verification literature already establishes

The measurement capability this study identifies as the binding constraint has been examined directly in the adjacent literature on tax reporting, and the findings transfer with unusual precision because the underlying problem is identical: a firm must document a quantity that a distant authority will price. Bellon et al. (2022), examining a mandatory electronic invoicing rollout, find reported sales, purchases and tax liabilities rising by more than five per cent within the first year of adoption, concentrated among smaller firms and in sectors with weaker prior compliance. Requiring documentation changes what is reported, independently of what is produced.

Okunogbe and Pouliquen (2022) show that the effect is heterogeneous rather than uniform. In their experimental setting, electronic filing cut the time firms spent on tax by forty per cent, doubled tax paid among firms previously prone to evasion, and reduced tax paid among firms that were already compliant. Applied to embedded emissions, the parallel is direct: a documentation requirement redistributes measured liability according to the accuracy of prior reporting rather than lowering it for everyone, and firms whose actual performance is good but undocumented sit on the losing side of that redistribution.

Kochanova et al. (2020), examining electronic filing across a broad cross-section of economies, find it reducing the time firms spend preparing and paying taxes and the frequency of official visits, while modestly raising revenue as a share of output — and report no strong relationship between electronic government and corruption. The last point is worth carrying into the emissions context, where verification systems are frequently defended on integrity grounds that this evidence does not support.

Halling and Baekgaard (2024), reviewing 119 studies, establish administrative burden as a distinct construct from statutory compliance cost: burdens are consequential, distributive and constructed, and frontline delivery and communication shape what is actually experienced. Vincent (2023) adds that compliance responds to enforcement intensity, compliance costs and perceived legitimacy together rather than to any one of them. For an exporter facing a documentation requirement set in another jurisdiction,

legitimacy is the element least available to the authority imposing it, which is a design problem the border adjustment literature has not addressed.

Research gap

Three gaps follow. No verified study measures compliance cost for small and medium enterprises under this mechanism. No verified study within the review window quantifies Indonesian exposure. And no located work treats measurement capability as a firm-level strategic variable rather than as a country-level risk attribute. This study addresses the third directly, works within the first two by triangulation, and states where it is transferring evidence rather than reporting it.

3. METHOD

The study is a structured review combined with a capability analysis. It generates no primary firm data, makes no estimate of Indonesian export exposure, and does not model price effects.

Source identification and verification

Peer-reviewed studies published between 2017 and 2024 on border carbon adjustment, carbon leakage, corporate emissions accounting, carbon pricing in emerging economies and enterprise carbon management were identified and retained only where bibliographic details could be verified against a publisher page, a digital object identifier record, an indexing database record or an institutional repository. Works published by outlets without demonstrable peer review, and works whose metadata conflicted across sources, were excluded rather than qualified. Scope and timetable information for the mechanism itself was taken from the official European Commission publication.

Capability analysis

The capability component proceeds from the mechanism's default-value provision. Where actual embedded emissions cannot be documented, the liability is determined by a default rather than by performance. The analysis therefore traces what a firm must possess to produce a documented figure, classifies firms by which of those elements they hold, and derives the strategic response each class faces. The output is an analytical typology, not an empirical distribution: no claim is made about how many firms fall in each class, because no verified data on that distribution were located.

Treatment of quantities

All quantities reported are traced to a single identified source. Figures drawn from abstracts and publisher landing pages rather than full texts are reported as published and are not recombined or recalculated. Where two sources report different values for a related quantity, both are given with their sources. No figure circulating without an identifiable primary source is used, and no estimate of Indonesian sectoral exposure is offered, since none could be verified.

4. RESULTS AND DISCUSSION

Scope, timetable and the exposure it defines

Exposure begins with scope, and scope is narrower than general discussion implies.

Table 1. Mechanism scope and timetable

Source: European Commission publication on the carbon border adjustment mechanism; recognition of third-country pricing as analysed by Boute (2024). Pulp and paper, textiles and general manufactures are outside the initial scope.

Two consequences follow immediately for an exporting firm. A producer outside the six covered sectors has no direct liability, though it may have indirect exposure as a supplier to covered producers, which is the propagation Zhong and Pei (2022) detect in their sub-national Chinese analysis. And a producer within scope faces a liability determined by documentation as much as by emissions, because of the default-value provision in the fifth row.

Exposure is concentrated, not general

Table 2. Verified findings on exposure and effects

Source: compiled by the authors. Figures are reported as published in the cited sources and are not recalculated or combined. No verified estimate of Indonesian exposure exists within the review window.

Read together, these results describe an instrument whose aggregate effect is modest and whose distribution is sharply concentrated. An economy whose exports to Europe are diversified and largely outside the six sectors experiences little economy-wide effect, as the Vietnamese assessment finds, while the specific firms in covered sectors experience the full weight of it. Aggregate estimates and firm consequences are therefore not substitutes, and a national conclusion that exposure is manageable tells an individual steel or cement producer nothing about its own position.

The final row of Table 2 deserves particular attention because it sits uneasily with the rest. No leakage was detected in European manufacturing under emissions trading, and the broader competitiveness literature finds no significant effects of carbon pricing on trade or investment outcomes. The mechanism addresses a risk whose historical realisation is not well evidenced. This does not make the instrument unjustified — it may be preventing leakage that would arise at higher future carbon prices — but it means the case for it rests on projection rather than on observed harm, and an analysis that omits this is incomplete.

Measurement capability as the operative constraint

Figure 1. How a measurement deficit becomes a price penalty (authors' construction)

Figure 1 sets out the pathway that this study takes to be central. Where a firm cannot document actual embedded emissions, default values determine liability, and liability then bears no relation to the firm's actual performance. An efficient producer that cannot document its efficiency is charged as though it were inefficient. The instrument's price signal, in that case, does not reach the decision it was designed to influence.

The evidence that this is a real rather than a hypothetical constraint comes from the best-resourced end of the corporate spectrum. Klaaßen and Stoll (2021) find corporate reports omitting about half of total emissions, with harmonisation of 56 technology firms raising reported totals from 360 to 751 million tonnes and individual deviations reaching a factor of 185. These are large listed firms with dedicated reporting functions and external assurance. The inference for a mid-sized producer in an emerging economy is not that it will do somewhat worse but that product-level documentation adequate for a customs authority is a capability it must build, not a record it can retrieve.

Table 3. Firm classes by emissions documentation capability and their first-order response

Source: authors' typology, derived from the mechanism's default-value provision. The typology is analytical; no verified data exist on how firms are distributed across these classes.

The typology yields the study's central practical claim. For firms in classes B, C and D — which the measurement literature suggests are the majority — the first-order rational response to the mechanism is not to reduce emissions but to measure them. Abatement investment by an undocumented producer changes its actual emissions and not its liability, and is therefore unrewarded by the instrument until documentation exists. This is an uncomfortable conclusion for a climate policy, and it is a design consequence rather than a failure of firm intent.

Class D deserves separate emphasis because it is the class least likely to recognise itself. A supplier of inputs to a covered producer has no direct liability, yet its customer requires emissions data to avoid default values, and that requirement propagates down the supply chain. Zhong and Pei's (2022) finding that income losses in landlocked Chinese provinces exceed their export losses is the macroeconomic signature of exactly this propagation. Small and medium enterprises in this class face data requests they have no framework to answer, and Olekanma et al. (2024) identify the absence of such frameworks as an unresolved problem in the enterprise sustainability literature.

What converts exposure into abatement

If measurement rather than price is the first constraint, the question becomes what makes firms build measurement capability and then act on it. The Vietnamese steel evidence answers it directly. Chu, Do, Le et al. (2024) find that the mechanism alone could significantly reduce steel exports to Europe without shifting production toward lower-emission methods, whereas domestic carbon pricing can drive a substantial transition depending on the price level.

The reason is structural. A border adjustment prices only the exported fraction of output, and only that fraction destined for one market. A domestic carbon price applies to all output, which makes measurement worth building for the whole firm rather than for one export line, and makes abatement worth undertaking regardless of destination. Boute's (2024) analysis adds a second channel: because the mechanism credits explicit carbon pricing, a domestic price reduces the border liability directly, so the revenue is collected domestically rather than at the European frontier.

Figure 2. Carbon prices per tonne of carbon dioxide equivalent, three jurisdictions (source: Nurhayati et al., 2024)

Figure 2 shows the order of magnitude at issue. Indonesia's carbon tax of approximately two United States dollars per tonne, applied from April 2022 to coal-fired steam power plants, sits against roughly 73 dollars in Finland and 137 in Sweden. At two dollars the credit against a border liability is nominal and the incentive to build measurement capability is correspondingly weak. This is not an argument that the Indonesian rate should match the Nordic ones, whose fiscal and industrial contexts differ entirely; it is an observation that the domestic instrument is currently too small to perform the function the Vietnamese evidence assigns to it.

Two qualifications apply. Best et al. (2020) find carbon pricing associated with roughly two percentage points lower annual emissions growth, so the mechanism connecting price to abatement is evidenced. But Venmans et al. (2020) find no significant competitiveness cost from carbon pricing at observed levels, which cuts in an unexpected direction here: if a higher domestic price would not measurably damage competitiveness, the principal argument against raising it weakens, though that evidence is drawn from advanced economies and its transferability is not established.

Implications for firms and policy

Four implications follow. For firms in covered sectors, emissions accounting is a market-access investment with a fixed deadline rather than a sustainability reporting exercise, and it should be budgeted as such. For firms supplying covered producers, the same requirement arrives through customers rather than through regulators, and arrives with less warning. For industry associations, the measurement problem has strong economies of scale — a shared methodology, a common verification arrangement and sector default benchmarks are cheaper collectively than individually, and the small and medium enterprise literature indicates individual capability will not otherwise be built. For policy, the Vietnamese evidence indicates that a credible domestic carbon price is the instrument that converts external exposure into domestic abatement and retains the revenue.

Limitations

Four limitations qualify this analysis. First, no verified study within the review window quantifies Indonesian exposure, so the domestic argument transfers evidence from Vietnam and states that it is doing so. Second, the firm typology is analytical and no data on the distribution of firms across its classes were located. Third, the measurement evidence is drawn from large listed technology firms, and its extension to emerging-economy manufacturers is an inference from the difficulty of the task rather than a measured finding. Fourth, quantities drawn from abstracts and publisher pages are reported as published and were not verified against full texts.

5. CONCLUSION

The European carbon border adjustment mechanism will begin operating definitively in 2026 across six sectors, and analysis of what it means for emerging-economy exporters has largely been analysis of price. This study has argued that price is the second constraint and documentation the first. Where a firm cannot demonstrate its actual embedded emissions, default values determine its liability, and its efficiency — however real — becomes invisible to the instrument. The measurement literature indicates this is not a marginal case: corporate reports omit about half of total emissions even among large listed firms, whose reported footprints roughly double under harmonisation.

The consequence for firm strategy is direct and slightly perverse. For producers without product-level emissions accounting, and for the suppliers whose customers will demand such data, the first-order rational response is to invest in measurement rather than in abatement, because abatement without documentation changes emissions without changing liability. Exposure is also concentrated rather than general — the Vietnamese assessment finds no substantial economy-wide effect alongside real consequences for steel, aluminium and cement — so national reassurance and firm-level exposure are different questions with different answers.

What converts exposure into emission reduction is a domestic carbon price. The Vietnamese steel evidence finds the border mechanism alone capable of reducing exports without shifting production technology, while a domestic price can drive substantial transition; a domestic price also applies to all output rather than to one export line, and is credited against the border liability so the revenue stays at home. Indonesia's rate of approximately two dollars per tonne, applied from 2022 to coal-fired power generation, is presently too narrow and too low to perform that function. Finally, the mechanism's own empirical premise deserves to be stated honestly: no leakage was detected in European manufacturing under emissions trading, and carbon pricing has shown no significant competitiveness effect at observed levels. The instrument may still

be justified as insurance against leakage at future prices, but firms and governments responding to it should know that they are responding to a projection.

DECLARATIONS

Author contributions (CRediT)

Conceptualisation: Author 1. Methodology: Author 1. Formal analysis and investigation: Author 1. Writing — original draft preparation: Author 1. Writing — review and editing: Author 1. Supervision: Author 1. All named authors have read and approved the final manuscript and accept responsibility for its content.

Conflict of interest

The authors declare that they have no financial or non-financial conflict of interest in relation to the subject matter of this article. No author holds a position in, or receives support from, any organisation examined or evaluated in this study.

Data availability

This study generated no primary data. It draws exclusively on published peer-reviewed literature, publicly available legal instruments and publicly available official statistics, all of which are identified in the text and listed in the references. No confidential administrative record, individual taxpayer record, permit file or personal datum was accessed, and no individual person or business is identified. Every quantity reported was traced to a single identified public source and can be verified by any reader from that source.

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Declaration on the use of artificial intelligence

In accordance with COPE, ICMJE and WAME positions, and with the RCP AI Use Declaration requirement, the authors disclose that generative artificial intelligence tools were used in preparing this manuscript, specifically to assist with literature identification, synthesis of the reviewed sources, and language editing of the draft. Artificial intelligence was not used to generate data, results or citations. Every reference in this article was verified by the authors against the publisher's own record, a digital object identifier record or an indexing database record before inclusion, and sources whose bibliographic details or indexing status could not be confirmed were excluded. No artificial intelligence tool is listed as an author. The authors take full responsibility for the accuracy, integrity and originality of the entire content of this article.

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