Benjamin Amram, Yehuda Leibler, Romi Listenberg, and Dov Greenbaum[*]

SPECIAL SECTION

NAVIGATING COMPLIANCE AND ETHICAL CHALLENGES IN CARBON TRADING: STRENGTHENING GLOBAL FRAMEWORKS FOR MARKET INTEGRITY AND SUSTAINABILITY

Abstract

Anthropogenic climate change represents an unprecedented existential threat to global ecological systems and human civilisation, necessitating urgent and comprehensive mitigation strategies. This paper provides a critical analysis of specific regulatory, verification, and ethical challenges that currently undermine carbon trading markets as useful climate change mitigation mechanisms. We argue that current implementations of carbon trading systems largely fail to mitigate climate change. They often create the illusion of progress. Our examination focuses on documented issues in existing markets: regulatory inconsistencies that create enforcement gaps, verification deficiencies that compromise credit integrity, and persistent questions about additionality and double-counting. We identify how these structural flaws create problematic incentives that may discourage actual emissions reductions while enabling lower-quality credits to proliferate. The analysis further addresses the ethical dimension of carbon markets, documenting how the burden of emissions mitigation falls disproportionately on developing countries, particularly in the Global South, despite their historically minimal contributions to global emissions. We examine specific documented cases where political misalignment, energy injustices, and the prioritisation of carbon sequestration over development have undermined both climate goals and sustainable development. The paper concludes by evaluating how emerging technologies and governance approaches could potentially address these documented challenges, while acknowledging the limitations of technological solutions absent broader structural reforms.

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[*] Benjamin Amram - Zvi Meitar Institute for Legal Implications of Emerging Technologies, Reichman University; Yehuda Leibler - Zvi Meitar Institute for Legal Implications of Emerging Technologies, Reichman University; Romi Listenberg - Zvi Meitar Institute for Legal Implications of Emerging Technologies, Reichman University; Dov Greenbaum - Harry Radzyner School of Law Reichman University, Dina Recanati School of Medicine Reichman University, Zvi Meitar Institute for Legal Implications of Emerging Technologies, Reichman University; Biomedical Informatics and Data Science, Yale University.

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1 Introduction and background

1.1 Introduction

Carbon trading markets suffer from at least three critical structural flaws that significantly compromise their effectiveness as climate change mitigation mechanisms. Although market-based instruments have theoretical promise and have proliferated globally, they largely fail to deliver meaningful emissions reductions due to serious design deficiencies that require substantial reform. We argue that carbon markets are not inherently doomed to failure, but their current implementations reflect fundamental shortcomings that must be addressed through coordinated regulatory, technological, and ethical interventions. This paper provides a critical analysis of these interconnected challenges—misaligned incentive structures, verification deficiencies, and equity concerns—examining how they undermine both environmental outcomes and social justice. Moreover, the disproportionate policy focus on carbon market solutions represents significant opportunity costs. This diverts attention and resources from more direct and proven emissions reduction strategies such as regulatory standards, public infrastructure investment, and fundamental economic transformation.

Rather than abandoning market mechanisms entirely, we propose that comprehensive reforms across regulatory harmonisation, technological integration, and ethical reorientation could potentially transform these markets from potentially exploitative financial instruments into more effective tools for climate mitigation. The urgency of the climate crisis demands that we either fundamentally redesign carbon trading systems to eliminate their structural contradictions or significantly diminish their role in our collective climate response.

This paper analyses these interconnected challenges through an interdisciplinary lens that integrates legal, economic, and ethical perspectives. By examining documented cases of market dysfunction across varied jurisdictions, we demonstrate how these problems are not merely implementation difficulties but fundamental design flaws requiring structural reform.

We evaluate how emerging technologies, particularly distributed ledger systems like blockchain, might address transparency and verification challenges, while also acknowledging the limitations of technological solutions absent broader governance reforms. Our analysis reveals that effective carbon market reform requires coordinated intervention in at least three domains: regulatory harmonisation, technological integration, and ethical reorientation. By identifying specific pathways toward more transparent, effective, and equitable carbon trading mechanisms, this paper contributes to the urgent project of transforming these markets from structurally flawed market instruments into genuine tools for climate justice and environmental protection.

This paper adopts an interdisciplinary approach integrating legal analysis, economic literature, and ethical frameworks to examine structural flaws in global carbon trading markets. Drawing on case studies and documented examples from the European Union, United States, and voluntary markets in the Global South, we explore how carbon markets function not just as regulatory instruments but as emergent financial ecosystems marked by verification failures, regulatory fragmentation, and structural inequities. Our methodology employs documentary analysis, collecting evidence from regulatory frameworks, market implementation studies, and ethical impact assessments to systematically evaluate carbon trading across jurisdictional, operational, and ethical dimensions.

The analysis proceeds across three key dimensions: First, we establish the conceptual foundations of carbon credits, exploring their types and regulatory frameworks. Second, we identify critical market challenges including misaligned incentives that discourage actual emissions reductions, limited scalability, quality issues, governance gaps enabling market manipulation, and verification problems (examining additionality failures, leakage effects, and measurement inconsistencies through published case studies). Third, we evaluate both compliance dilemmas (greenwashing, verification failures) and ethical concerns regarding the disproportionate burden placed on developing nations, using an environmental justice framework to assess the implications of carbon offset projects in these regions. While emerging technologies such as digital Monitoring, Reporting, and Verification (MRV) systems, AI-powered verification, and distributed ledger technologies offer promising solutions, we argue that technical innovations alone are insufficient without parallel reforms in regulatory design and ethical accountability. The paper concludes with policy recommendations for transforming carbon markets into more transparent, effective, and equitable climate mitigation mechanisms, emphasising that market legitimacy and effectiveness require aligning market mechanisms with transparent verification, equitable burden-sharing, and enforceable legal standards.

1.2 Climate change and net zero

Climate change has become a pressing threat to the international community. Between 1880 and 1981, Earth's temperature rose by 0.08°C per decade; the pace of this increase accelerated to 0.18°C per decade in the 1980s.[1] Carbon credits, a form of tradable certificates that give entities a right to emit a preset amount of greenhouse gas (GHG), have emerged as potential solutions for addressing the emissions problem that has led in part to the temperature rise.[2] The popularity of these assets as a substitute for actual carbon reduction continues to increase dramatically.

Today, almost 200 nations have agreed to reduce their greenhouse gas emissions, aiming for zero emissions by 2050.[3] Furthermore, the number of companies with zero-emission pledges has increased from 500 to 1,000 during the period between 2019 and 2020.[4] However, the achievement of these ambitious goals remains a daunting task. Some emissions, such as those involving chemical reactions in the cement sector, cannot be completely eradicated.[5] Consequently, carbon credits have become an attractive strategy for offsetting emissions by funding sustainability projects.

1.3 The concept of carbon credits

Carbon markets attempt to correct market failures by pricing negative externalities associated with greenhouse gas emissions, but structural design flaws often undermine this theoretical promise.[6] By introducing a cap-and-trade mechanism—where regulators set an overall emissions limit (cap) and allow companies to buy and sell emission allowances (trade)—they create scarcity in emissions rights, thereby enabling market-based price discovery for carbon. Empirical studies have affirmed that emissions trading systems (ETSs), such as the EU ETS, function efficiently by allowing emitters to reallocate abatement efforts based on marginal cost differentials, reducing compliance costs while maintaining environmental targets.[7] Carbon allowances exhibit variable but often high tradability and liquidity—characteristics typically associated with mature commodity

[1] Rebecca Lindsey and Luann Dahlman, 'Climate Change: Global Temperature' (*Climate.gov*, 18 January 2023) <http://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature> accessed 15 November 2024.
[2] Justin D Macinante, *Effective Global Carbon Markets: Networked Emissions Trading Using Disruptive Technology* (Edward Elgar Publishing 2020).
[3] ibid.
[4] Geoff Bertram and Simon Terry, *The Carbon Challenge: New Zealand's Emissions Trading Scheme* (Bridget Williams Books 2021).
[5] Christopher Blaufelder, Charlotte Levy, Patrick Mannion, and Dickon Pinner, *A Blueprint for Scaling Voluntary Carbon Markets to Meet the Climate Challenge* (McKinsey Report 2021). <https://www.mckinsey.com/capabilities/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge> accessed 21 January 2025.
[6] Qingyang Wu, Siyu Ren, Yao Hou, Zaoli Yang, Congyu Zhao, and Xusheng Yao, 'Easing financial constraints through carbon trading' (2024) 67 Empirical Economics 655.
[7] Denny A Ellerman, Frank J Convery, and Christian De Perthuis, *Pricing carbon: the European Union emissions trading scheme* (Cambridge university press 2010); Lawrence H Goulder and Andrew Schein, "Carbon taxes vs. cap and trade: A critical review" [2013] NBER Working paper 19338.

markets—despite their regulatory origin.[8] In fact, trading volumes and market depth in the EU ETS rival those in traditional commodities like natural gas or electricity, reinforcing the argument that carbon credits constitute a "real" market.[9] And, like other commodities, carbon prices reflect supply-demand dynamics, but with added policy-driven volatility.[10] Nevertheless, price signals from carbon markets have demonstrably influenced investment in low-carbon technologies,[11] highlighting their function as instruments of both cost efficiency and long-term decarbonisation.[12]

The idea behind carbon trading can be traced back to the Kyoto Protocol, which established the national quotas for emitting carbon dioxide for each of the signatories.[13] The Kyoto Protocol imposes binding emission reduction obligations exclusively on Annex I Parties, with each assigned a quantified emissions limitation and reduction objective (QELRO) under Annex B. These legally binding commitments were enforced through a compliance mechanism including potential penalties for non-compliance, establishing Kyoto as a top-down legal instrument grounded in international treaty law.[14]

In contrast, the Paris Agreement's Article 6 establishes voluntary cooperative mechanisms: Article 6.2 facilitates bilateral transfers of mitigation outcomes (ITMOs), while Article 6.4 introduces a centralised crediting mechanism governed by the United Nations Framework Convention on Climate Change (UNFCCC); neither imposes mandatory participation or reduction targets. The legal obligation under Article 6 arises only upon a Party's decision to use these mechanisms, at which point it must adhere to the procedural rules agreed in the Article 6 rulebook.[15] This reflects a shift from the top-down compliance model of Kyoto to the bottom-up, facilitative architecture of Paris. Accordingly, references to carbon market "obligations" under Paris must distinguish between treaty-

[8] Boquiang Lin and Chenchen Huang, 'Analysis of emission reduction effects of carbon trading: Market mechanism or government intervention?' (2022) 33 Sustainable Production and Consumption 28, 37; Idris A Adediran and Raymond Swaray, 'Carbon trading amidst global uncertainty: The role of policy and geopolitical uncertainty' (2023) 123 Economic Modelling 1.

[9] Ralf Martin Mirabelle Muuls, Laure B de Preux and Ulrich J Wagner, 'Industry compensation under relocation risk: A firm-level analysis of the EU emissions trading scheme' (2014) 104 (8) American Economic Review 2482.

[10] Lin and Huang (n 8); Adediran and Swaray (n 8).

[11] Qianqian Hong, Linhao Cui and Penghui Hong, 'The impact of carbon emissions trading on energy efficiency: Evidence from quasi-experiment in China's carbon emissions trading pilot' (2022) 110(C) Energy Economics 106025; Wei Zhang, Guoxiang Li, and Fanyong Guo, 'Does carbon emissions trading promote green technology innovation in China?' (2022) 315 Applied Energy 1.

[12] Dazhi Linghu, Xinli Wu, Kee-Hung Lai, Fei Ye, Ajay Kumar, and Kim Hua Tan, 'Implementation strategy and emission reduction effectiveness of carbon cap-and-trade in heterogeneous enterprises' (2022) 248 International Journal of Production Economics 1.

[13] Jorge Gonçalves and Manuel Luís Costa, 'The political influence of ecological economics in the European Union applied to the cap-and-trade policy' (2022) 195 Ecological economics 1; John C Cole, 'Genesis of the CDM: The Original Policymaking Goals of the 1997 Brazilian Proposal and Their Evolution in the Kyoto Protocol Negotiations into the CDM' (2010) 12(1) International Environmental Agreements: Politics, Law and Economics 41.

[14] Daniel Bodansky, 'The History of the Global Climate Change Regime' in Urs Luterbacher and Detlef F Sprinz (eds), *International Relations and Global Climate Change* (MIT Press 2001) 23, 40.

[15] Lavanya Rajamani, Louise Jeffery, Niklas Höhne, Frederic Hans, Alyssa Glass, Gaurav Ganti, and Andreas Geiges, "National 'fair shares' in reducing greenhouse gas emissions within the principled framework of international environmental law" (2021) 21(8) Climate Policy 983, 1004; Michael A Mehling, Gilbert E Metcalf, and Robert N Stavins, 'Linking climate policies to advance global mitigation' (2018) 359(6379) Science 997, 998.

based participation and conditional procedural duties, ensuring legal terminology aligns with the instruments' formal status under international law.

Under Kyoto, countries that exceeded their quotas could buy carbon credits from those with surplus allowances. Over time, this instrument has expanded significantly, with regions like the European Union[16] and 11 US states having adopted the programme.[17]

A decision regarding the implementation of Article 6 of the Paris Agreement at COP26, which gave rise to a crediting mechanism, provided countries with a mechanism for buying voluntary carbon credits as well.[18] In this situation, the market of voluntary credits is expected to display dramatic growth in the near future. Voluntary carbon credits, driven by non-governmental and private organisations, form an increasingly important market due to their financial incentives. In 2020, voluntary carbon credits that were retired accounted for the reported offset of around 95 million tons of carbon dioxide, which indicates a more than 100% increase in comparison with the data from 2017.[19]

Having examined the fundamental principles and historical development of carbon credits, we now turn to the diverse typology of these instruments and how their various forms serve different market functions.

1.4 Types of carbon credits

Carbon credits can be divided into either mandatory or voluntary categories. Voluntary credits depend on particular projects and often involve either avoidance or removal projects. Avoidance projects focus on avoiding GHG emissions via varied efforts such as a large-scale wetland prevention programme or a local initiative aimed at changing diets for beef to reduce methane emissions.[20]

Removal projects seek to capture greenhouse gases and remove them from the atmosphere.[21] Considering that removal projects are believed to have a more significant impact on the environment, their credits are typically traded at a premium.[22]

Voluntary markets are often leveraged as part of broader corporate social responsibility (CSR) strategies, enabling firms to pursue carbon neutrality, enhance brand reputation,

[16] European Commission, 'EU Emissions Trading System (EU ETS)' (September 2022) <https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en> accessed 22 October 2024.
[17] Richard Schmalensee and Robert N Stavins, 'The Design of Environmental Markets: What Have We Learned from Experience with Cap and Trade?' (2017) 33(4) Oxford Review of Economic Policy 572.
[18] Lin Chen, Goodluck Msigwa, Mingyu Yang, Ahmed I Osman, Samer Fawzy, David W Rooney, and Pow-Seng Yap, 'Strategies to Achieve a Carbon Neutral Society: A Review', (2022) 20 (4) Environmental Chemistry Letters 2277, 2310.
[19] Chirstopher Blaufelder, Joshua Katz, Cindy Levy, Dickon Pinner, and Jop Weterings, 'How the Voluntary Carbon Market Can Help Address Climate Change' (McKinsey & Company 2020) <https://www.mckinsey.com/capabilities/sustainability/our-insights/how-the-voluntary-carbon-market-can-help-address-climate-change> accessed 19 February 2025.
[20] Michael Wara, 'Is the Global Carbon Market Working?' (2007) 445 Nature 595.
[21] Macinante (n 2).
[22] Blaufelder and others (n 5).

and meet growing consumer expectations for environmentally responsible practices.[23] Moreover, voluntary carbon markets play a critical role in financing climate resilience initiatives, particularly in regions and ecosystems vulnerable to the impacts of climate change.[24]

As described herein, despite their potential, voluntary markets are subject to ongoing scrutiny regarding the credibility and efficacy of carbon offsets in the absence of uniform regulatory oversight. Consequently, ensuring the legitimacy of voluntary carbon credits requires rigorous verification protocols and adherence to recognised standards.[25] Transparency, third-party certification, and long-term monitoring are thus essential to building and sustaining trust in the voluntary carbon market framework.[26]

In contrast, compliance carbon markets, or mandatory markets, are regulatory mechanisms established by governments to enforce greenhouse gas (GHG) emission reductions. These markets are embedded within legal frameworks that impose binding obligations, typically targeting high-emission sectors such as energy, manufacturing, and aviation. The European Union Emissions Trading System (EU ETS)[27] serves as a leading example, operating on a cap-and-trade basis: a fixed emissions cap is set, and companies must hold allowances equivalent to their emissions, either allocated or purchased. Surplus allowances can be traded, creating financial incentives to reduce emissions.

Other significant compliance schemes include California's Cap-and-Trade Program[28] and China's National Emissions Trading Scheme.[29] These systems aim to align industry behaviour with national or regional climate targets through enforceable limits and penalties for non-compliance.

The principal distinction between compliance and voluntary carbon markets lies in regulation. Compliance markets are mandatory for specific sectors, while voluntary markets are driven by corporate sustainability initiatives and offer participants greater flexibility in credit procurement. Cost structures differ as well—compliance markets

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[23] Andrea Von Avenarius, Thattekere Settygowda Devaraja, and Rüdiger Kiesel, 'An empirical comparison of carbon credit projects under the clean development mechanism and verified carbon standard' (2018) 6(49) Climate 1; Jianhu Cai and Feiying Jiang, 'Decision models of pricing and carbon emission reduction for low-carbon supply chain under cap-and-trade regulation' (2023) 264 International Journal of Production Economics 1.

[24] Andrei Marcu and Federico Cecchetti, 'The trading of carbon' in M Hafner and G Luciani (eds), *The Palgrave Handbook of International Energy Economics* (Palgrave Macmillan, Cham 2022) 439, 469; Rana Elkahwagy, Vandana Gyanchandani, and Dario Piselli, 'UNFCCC Nationally Determined Contributions: Climate Change and Trade' Working Paper 2017-02 (Center for Trade and Economic Integration 2017).

[25] Kenneth R Richards and Grant Eric Huebner, 'Evaluating protocols and standards for forest carbon-offset programs, Part B: leakage assessment, wood products, validation and verification' (2012) 3(4) Carbon Management 411, 425.

[26] Jianfu Wang, Shiping Jin, Weiguo Bai, Yongliang Li, and Yuhui Jin, 'Comparative analysis of the international carbon verification policies and systems' (2016) 84 Natural Hazards 381, 397.

[27] ibid 16.

[28] California's Cap-and-Trade Program site <https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program> accessed 20 June 2025.

[29] Progress Report of China's National Carbon Market (2024) <https://www.mee.gov.cn/ywdt/xwfb/202407/W020240722528850763859.pdf> accessed 20 June 2025.

typically involve higher expenses due to legal and administrative requirements, whereas voluntary credits are generally cheaper, though prices vary by project and location.[30]

Compliance markets tend to, albeit, sometimes inefficiently,[31] achieve more substantial environmental outcomes as they are central to binding climate commitments,[32] such as those under the Paris Agreement. They drive systemic change by placing a price on carbon and encouraging innovation in low-emission technologies.[33]

Nonetheless, challenges persist. Carbon pricing in these markets is sensitive to political and economic conditions, affecting market stability.[34] Regulatory complexity can burden companies, and cap-and-trade systems may enable continued emissions if entities can afford to purchase credits, potentially undermining climate objectives.[35]

Another classification groups carbon credit offsets into groups such as nature-based gas sequestration, actual reduction of emissions, technology-based removal of greenhouse gases from the atmosphere, and avoidance of nature loss.[36]

Carbon Credits that are offset by technology-based removal of greenhouse gases and removal of additional emissions have the potential for significant growth in supply over the next decades.[37] Nature-based sequestration and avoiding nature loss projects are also likely to increase dramatically in the near future, but their supply is expected to be concentrated in developed countries.[38]

While developing and least developed states might struggle with meeting the demand for these assets, the voluntary carbon credit market is likely to continue growing globally.[39]

1.5 The current regulatory landscape

Carbon credit markets operate under fragmented regulatory frameworks without a single governing body. This regulatory fragmentation creates significant challenges for market oversight, as inconsistencies between different jurisdictions' approaches can

[30] Zhijie Jia and Boqiang Lin, 'Rethinking the choice of carbon tax and carbon trading in China' (2020) 159 Technological Forecasting and Social Change 1.
[31] Yi-Fan Chen, 'Cap-and-trade system, firm selection, and emission intensity' (2025) 145 Energy Economics 1.
[32] Cameron Hepburn, 'Carbon trading: A review of the Kyoto mechanisms' (2007) 32 Annual Review of Environment and Resources 375, 393.
[33] Xing Chen and Boqiang Lin, 'Towards carbon neutrality by implementing carbon emissions trading scheme: Policy evaluation in China' (2021) 157 Energy Policy 1.
[34] Thomas D Jeitschko, Soo Jin Kim, and Pal Pallavi, 'Curbing price fluctuations in cap-and-trade auctions under changing demand expectations' (2024) 139 Energy Economics 1.
[35] Yonghong Zhao, Fu-Wei Huang, Ching-Hui Chang, and Jyh-Jiuan Lin, 'Domestic and foreign cap-and-trade regulations, carbon tariffs, and product tariffs during international trade conflicts: A multiproduct cost-efficiency analysis' (2024) 140 Energy Economics 1.
[36] Axel Michaelowa, Igor Shishlov, and Dario Brescia, 'Evolution of international carbon markets: lessons for the Paris Agreement' (2019) 10(6) Wiley Interdisciplinary Reviews: Climate Change 1.
[37] Blaufelder and others (n 5).
[38] Bertram and Terry (n 4).
[39] Hepburn (n 32).

create opportunities for regulatory arbitrage and undermine the environmental integrity of carbon trading

The European market of carbon credits, which is the largest cap-and-trade scheme in the world,[40] is regulated by the European Union Emissions Trading System (EU ETS) for EU states as well as Norway, Liechtenstein, and Iceland. The scheme covers 40% of GHG emissions in the European Union and limits emissions of approximately 10,000 installations in the manufacturing, aviation, and power sectors. The EU ETS is monitored by financial regulators, including ESMA, which recently found that the EU carbon market functioned without major deficiencies.[41] In the United Kingdom, the UK Emissions Trading Scheme (UK ETS) was adopted in 2021 to replace the EU ETS through the Greenhouse Gas Emissions Trading Scheme Order 2020.[42] In the United States, the White House, U.S. Department of Treasury, U.S. Department of Energy, and U.S. Department of Agriculture issued a joint policy statement in May 2024 that contains the principles for guiding voluntary market conduct.[43]

Additionally, the Carbon Border Adjustment Mechanism (CBAM) adopted by the European Union on October 1, 2023 forms yet another mechanism of regulating the carbon markets, particularly by imposing requirements on global manufacturers and exporters such as those in China.[44]

The United Nations Framework Convention on Climate Change (UNFCCC) operates a Carbon Offset Platform that allows companies and individuals to purchase carbon credits.[45] The organisation certifies environmentally friendly projects in developing countries using certified emission reductions. Following the landmark decision at COP26, the organisation was further tasked with regulating the trading of carbon credits by countries that aim at meeting their emission reduction goals.[46] COP26 also birthed the Article 6 rulebook that guides how countries trade carbon credits in efforts to reduce greenhouse gas emissions and meeting individual climate goals.[47]

[40] Cap and Trade is a market-based regulatory system designed to reduce greenhouse gas emissions. It sets a **"cap"** on the total amount of emissions that industries can produce, while allowing companies to **"trade"** emission allowances with each other.
[41] European Securities and Markets Authority, "ESMA Publishes Its Final Report on the EU Carbon Market" (ESMA 2022) https://www.esma.europa.eu/press-news/esma-news/esma-publishes-its-final-report-eu-carbon-market accessed 20 June 2025.
[42] Department for Energy Security & Net Zero and Department for Business, Energy & Industrial Strategy, "Participating in the UK ETS" (GOV.UK 2025) <https://www.gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets> accessed 20 June 2025.
[43] U.S. Dep't of the Treasury, "U.S. Department of the Treasury Releases Joint Policy Statement and Principles on Voluntary Carbon Markets" (U.S. DEP'T OF THE TREASURY 2024) <https://home.treasury.gov/news/press-releases/jy2372> accessed 20 June 2025.
[44] Jiezhong Chang, 'Implementation of the EU Carbon Border Adjustment Mechanism and China's Policy and Legal Responses' (2025) 110 Env't Impact Assessment Review 1.
[45] United Nations Online Platform for Voluntary Cancellation of Certified Emission Reductions (CERs), "United Nations Carbon Offset Platform" [2023] <https://offset.climateneutralnow.org/> accessed 20 June 2025.
[46] Chen and others (n 18).
[47] Michele Stua, Colin Nolden, and Michael Coulon, 'Climate Clubs Embedded in Article 6 of the Paris Agreement' (2022) 180 Resources, Conservation and Recycling 1.

UNFCCC also monitors compliance with the Kyoto Protocol and the Paris Agreement. Moreover, there are numerous bodies that verify the contributions of sustainability projects that sell carbon credits. For instance, S&P Global Platts collects data on projects that are certified by such standards as Verified Carbon Standard, Climate Action Reserve, and the Gold Standard.[48] Verified Carbon Standard (Verra) is currently the most widely used programme for certifying greenhouse gas credits. Verra is a non-government organisation specialising in providing certification for voluntary carbon markets. Despite its focus on voluntary credits, Verra's certifications are often acknowledged in some mandatory compliance markets, such as the carbon markets of Colombia and South Africa.[49]

This certification ecosystem raises important questions about accountability and governance in voluntary markets. Unlike compliance markets with clear regulatory oversight, the authority of voluntary certification bodies derives primarily from market acceptance rather than legal mandate. This hybrid public-private governance structure creates complex jurisdictional questions regarding the enforcement of standards, particularly in cross-border transactions.

While this regulatory patchwork represents earnest attempts to govern carbon markets, significant structural challenges have emerged that threaten both market integrity and environmental outcomes, as we explore in the following sections.

2 Challenges and concerns

This section examines four interconnected challenges that undermine carbon market effectiveness: misaligned incentives, limited scalability, quality issues, and market structure problems.

2.1 An incentive not to reduce

One of the major challenges associated with the carbon credit system is that it gives countries and entities an incentive not to actually reduce their GHG emissions in practice. This fundamental tension between financial incentives and environmental outcomes represents a classic principal-agent problem, where the objectives of market participants may not align with the ultimate goal of emissions reduction. The mechanism provides companies and individuals with an opportunity to offset rather than take practical measures to reduce emissions, as documented extensively in the literature.

[48] "Specifications Guide for Carbon Markets" (S&P Global, August 2023), <https://www.spglobal.com/commodityinsights/PlattsContent/_assets/_files/en/our-methodology/methodology-specifications/method_carbon_credits.pdf> accessed 20 June 2025.

[49] Verra, "Verified Carbon Standard" <https://verra.org/programs/verified-carbon-standard> accessed 8 March 2025.

For example, Cao and others discovered that there is a statistically significant relationship between the carbon trading price and carbon emission reduction levels.[50] Han and others[51] showed that a reduction in transaction costs resulted in a greater loss to residents, something that was not expected by the researchers. Song and Moura share a controversial opinion that carbon credits for forest preservation "may be worse than nothing".[52] Zhao and others[53] argue that introducing renewable energies is currently a much more expensive option for Chinese companies than buying carbon credits.

In some contexts, carbon trading, particularly when carbon prices are low or allowances are perceived as cheap relative to innovation costs, can create a "crowding-out effect" on corporate R&D investment in green technology. High-polluting enterprises may find it cheaper to purchase carbon quotas than to invest in higher-cost, riskier green technology innovation, especially in the short term or in early-stage markets with ample quotas. This diverts funds away from investments that could lead to deeper, technology-driven emission reductions towards simply purchasing the right to emit, potentially perpetuating less efficient practices.[54]

Despite this criticism, some researchers are optimistic that the price of offsetting will eventually increase over time such that the incentive to offset instead of practical reduction is reduced.[55] This assumption relies on the capability of the market to "fix itself". In line with many standard economic theories, the invisible hand of efficient markets self-corrects and self regulates to limit market failures, hence closing the gaps and correcting the key abnormalities.[56]

For example, research by BloombergNEF shows that the prices of carbon offsets could eventually reach a figure between $47 and $120 per ton.[57] The exact price of these assets will depend on numerous supply-related and demand-related factors. Alternatively, one possible scenario is that a significant increase in the price of carbon credits is unlikely in the future owing to the oversupplied nature of the market.[58] Another scenario views the

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[50] Kaiying Cao, Xiaoping Xu, Qiang Wu, and Quanpeng Zhang, 'Optimal Production and Carbon Emission Reduction Level under Cap-and-Trade and Low Carbon Subsidy Policies' (2017) 167 Journal of Cleaner Production 505.
[51] Jiayuan Han, Lingcheng Kong, Wenbin Wang, and Jiqing Xie, 'Motivating Individual Carbon Reduction with Saleable Carbon Credits: Policy Implications for Public Emission Reduction Projects' (2022) 122(5) Industrial Management & Data Systems 1268.
[52] Lisa Song and Paula Moura, 'An (Even More) Inconvenient Truth: Why Carbon Credits for Forest Preservation May Be Worse Than Nothing' (*ProPublica*, 22 May 2019) <https://features.propublica.org/brazil-carbon-offsets/inconvenient-truth-carbon-credits-dont-work-deforestation-redd-acre-cambodia/> accessed 20 June 2025.
[53] Fuquan Zhao, Feiqi Liu, Han Hao, and Zongwei Liu, 'Carbon Emission Reduction Strategy for Energy Users in China' (2020) 12(16) Sustainability 6498.
[54] Zhang and others (n 11).
[55] Rohit Jindal, Brent Swallow, and John Kerr, 'Forestry-Based Carbon Sequestration Projects in Africa: Potential Benefits and Challenges' (2008) 32 Natural Resources Forum 116.
[56] Evangelos Pournaras, Mark Yao, and Dirk Helbing, 'Self-Regulating Supply-Demand Systems' (2017) 76 Future Generation Computer Systems 73.
[57] BloombergNEF, "Global Carbon Market Outlook 2022: Bulls Trump Bears" (*Bloomberg*, 31 October 2022) <https://www.bloomberg.com/professional/blog/global-carbon-market-outlook-2022-bulls-trump-bears/> accessed 20 June 2025.
[58] Blaufelder and others (n 5).

possibility where markets will tighten their requirements towards these assets.[59] For example, regulatory measures like the Clean Development Mechanism requires parties to adhere to emission reductions requirements, hence limiting the types of acceptable offset credits.[60] Still, most voluntary markets lack rigid verification and validation procedures, resulting in criticisms of their accuracy and effectiveness of their validation methodologies.[61] While the introduction of stricter requirements may seem justifiable, it is likely to cause a further increase in project prices owing to higher project costs and their reduced number.

Beyond these problematic incentive structures, carbon markets face fundamental operational challenges. These limitations restrict market scalability despite growing demand and climate urgency.

2.2 Lack of scalability

Lack of scalability is a major challenge in carbon trading. The scalability challenge reflects broader issues in market design, as carbon markets must balance the competing demands of economic efficiency, environmental integrity, and administrative feasibility.

Scalability challenges arise from unpredictable supply and demand dynamics in carbon credit markets,[62] while at the same time ensuring that necessary market liquidity levels are attained for satisfying the needs of stakeholders. As such, companies are likely to shift to early purchases of carbon credits for their high-emission projects.[63] Rawuf believes that firms "will increasingly start offsetting their emissions as they begin work, rather than waiting until year-end".[64] It is currently unclear whether suppliers will be able to meet this growing demand.

The literature offers numerous insights into ways to ensure scalability in carbon trading. For example, a recent report by McKinsey proposes the use of digital verification and standardised standards for carbon credits definition, contracting, and trading infrastructure.[65] Still, the achievement of these goals remain challenging due to an absence of a consensus on terminologies of carbon credits as well as technical difficulties

[59] Marc N Conte and Matthew J Kotchen, 'Explaining the Price of Voluntary Carbon Offsets' (2010) 1(2) Climate Change Economics 93.
[60] United Nations Climate Change, "The Clean Development Mechanism" <https://unfccc.int/process-and-meetings/the-kyoto-protocol/mechanisms-under-the-kyoto-protocol/the-clean-development-mechanism> accessed 6 September 2023.
[61] Charlotte Streck, 'How Voluntary Carbon Markets Can Drive Climate Ambition' (2021) 39(3) Journal of Energy & Natural Resources Law 367.
[62] Jeitschko and others (n 34).
[63] Abdul Rawuf, "Transparency and Scalability: Two Keys to Unlocking Carbon Markets' Potential" (*Arabian Business*, 30 May 2022) <https://www.arabianbusiness.com/opinion/transparency-and-scalability-two-keys-to-unlocking-carbon-markets-potential> accessed 20 June 2025.
[64] ibid.
[65] Blaufelder and others (n 5).

related to the creation of such an ambitious solution.[66] Furthermore, shared principles and standardised protocols might be inconsistent with the current trading practices in most voluntary markets.[67] Despite the proposed enhancement measures, scalability remains challenging.

2.3 Incentivising lower credit quality

One of the most problematic features of existing carbon trading regimes is the presence of perverse incentive mechanisms that actively encourage the proliferation of low-quality credits.[68] This fundamental market design flaw undermines the environmental integrity that carbon markets are intended to promote. Typically, companies pursue ways to attain their corporate social responsibility (CSR) goals while maximising profits.[69] Such companies buy cheap carbon credits that confer a reputational gain without ensuring any real emission reduction in practice.[70] Furthermore, voluntary markets have very little regulation, so firms can buy practically useless credits regarding global warming with minimal scrutiny.[71] Solving this problem calls for a public awareness that discourages firms from buying low-quality credits, perhaps via shaming.[72] Additionally, building stricter validation and verification frameworks to make sure that carbon offsets are actually effective may help to ensure a sufficient quality of all the carbon credits in both voluntary and mandatory markets.[73] Still, some of the low-quality credits may be introduced via unethical actors, and therefore outright fraudulent.[74] Others may be used for money laundering rather than bona fide efforts to reduce emission.[75]

2.4 Issues with supply, demand and markets

The incentive model embedded in the carbon trading markets also faces challenges from mismatches between demand and supply. Buyers from different industries have

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[66] Enas Al Kawasmi, Edin Arnautovic, and Davor Svetinovic, 'Bitcoin-Based Decentralized Carbon Emissions Trading Infrastructure Model' (2014) 18(2) Systems Engineering 115.
[67] Fangyuan Zhao and Wai Kin (Victor) Chan, 'When Is Blockchain Worth It? A Case Study of Carbon Trading' (2020) 13(8) Energies 1980.
[68] Hepburn (n 32).
[69] Morteza Khojastehpour and Raechel Johns, 'The Effect of Environmental CSR Issues on Corporate/Brand Reputation and Corporate Profitability' (2014) 26(4) European Business Review 330.
[70] Matthew Lockwood, 'The economics of personal carbon trading' (2010) 10(4) Climate Policy 447.
[71] Blaufelder and others (n 5).
[72] Brilé Anderson and Thomas Bernauer, 'How Much Carbon Offsetting and Where? Implications of Efficiency, Effectiveness, and Ethicality Considerations for Public Opinion Formation' (2016) 94 Energy Policy 387.
[73] Tse-Lun Chen, Hui-Min Hsu, Shu-Yuan Pan, and Pen-Chi Chiang, 'Advances and Challenges of Implementing Carbon Offset Mechanism for a Low Carbon Economy: The Taiwanese Experience' (2019) 239 Journal of Cleaner Production 1.
[74] Deloitte, "Carbon Credit Fraud: The White Collar Crime of the Future" <https://tomaswell.files.wordpress.com/2015/02/carbon_credit_fraud.pdf> accessed 21 March 2025.
[75] Ed King, "Interpol Warns of Criminal Focus on $176 Billion Carbon Market" (*Climate Home News*, 8 May 2013) <https://www.climatechangenews.com/2013/08/05/interpol-warns-of-criminal-focus-on-176-billion-carbon-market/> accessed 20 June 2025.

unequal incentive structures for purchasing credits.[76] For example, high-emission industries such as mining rely more heavily on offsets than players in other sectors.[77] A significant challenge arises from the fragmentation of carbon trading across multiple marketplaces, resulting in inconsistent standards, verification practices, and pricing mechanisms. This regulatory patchwork creates opportunities for arbitrage and undermines market transparency, as different trading platforms may apply varying levels of scrutiny to similar carbon reduction projects.[78]

This multitude of voluntary markets also makes integration more complex, as new verification methods may increase costs and discourage participation.[79] Furthermore, some buyers could be confused by the rigid procedures of new markets and the unprecedentedly high level of competition that they will face. This information asymmetry between sophisticated market participants and newer entrants threatens market efficiency and potentially undermines the confidence necessary for robust trading

Another problem stems from the fact that carbon markets are based on controversial ideas such as the existence of a linear relationship between emissions and offsets. Thus, many projects cannot credibly measure their environmental impacts, and this makes the entire concept of offsetting questionable regarding their effectiveness.[80] As such, companies that are serious about their sustainable activities might stop the use of face-value offsetting credits and concentrate on reducing the emission of their greenhouse gases.

3 Compliance markets dilemmas: fraud, efficacy, efficiency & ethics

Inadequate verification systems compromise the fundamental integrity of carbon credits through persistent problems of additionality, leakage, and measurement inconsistency. Without robust standards to ensure emissions reductions are genuine, additional, and permanent, carbon trading becomes vulnerable to credits representing fictional or exaggerated climate benefits. This verification crisis threatens the environmental value proposition of the entire carbon market system.

New, unregulated markets often provide fertile ground for fraudulent activity. The legal literature has extensively documented how regulatory vacuums in novel markets create ideal conditions for various forms of manipulation, with carbon markets being

[76] Jonathan Otto, ‘Precarious Participation: Assessing Inequality and Risk in the Carbon Credit Commodity Chain’ (2018) 109(1) Annals of the American Association of Geographers 187.
[77] Song and Moura (n 52).
[78] Song Xu, Kannan Govindan, Wanru Wang, and Wenting Yang, "Supply chain management under cap-and-trade regulation: A literature review and research opportunities’ (2024) 271 International Journal of Production Economics 109199; Jeitschko and others (n 34); Xuelian Li, Wei Zhou, Tang-Yun Lo, and Jyh-Horng Lin, ‘International climate policy dilemmas: Examining effective carbon tariff and cap-and-trade regulation from a sustainable insurance perspective’ (2024) 134 Energy Economics 1.
[79] Al Kawasmi, Arnautovic and Svetinovic (n 66).
[80] Benjamin K Sovacool, ‘Four Problems with Global Carbon Markets: A Critical Review’ (2011) 22(6) Energy & Environment 681.

particularly vulnerable due to their intangible nature and complex verification requirements.[81] The nascent carbon trading market is still evolving and therefore lacks uniform standards of measurements and verification.[82] Since there is no standard measurement of a "high quality carbon credit" and some factors that are used such as: additionality, leakage, double counting, verification and transparency remain unregulated.[83] Fraud, money-laundering and criminal activity can heavily affect the efficiency and trust of the carbon market leading to reduced trading and increasing price per unit.[84] This imbalance led to an emissions market reliant on the integrity of countries and corporations to present accurate data of emissions levels.[85] As a result, organisations and countries are operating in the unregulated carbon market as America's old Wild West.

Among the most prevalent forms of market manipulation in carbon trading is greenwashing, which represents not merely a procedural concern but a fundamental threat to market credibility.

3.1 Greenwashing

Many regard the carbon market as a 'greenwashing scam' that enables polluters to avoid emissions restrictions. Greenwashing describes practices by organisations that falsely appear to be environmentally friendly rather than actually engaging in sustainable practices. "Corporations and even organised crime groups may purchase carbon offsets to finance "green" projects as fronts for other activities. These "green fronts" can apply to receive emission reduction credits which can then be sold directly to companies or traded on carbon markets generating large revenues.[86] At COP 27, The International Organization for Securities Commissions (IOSCO) has outlined the actions it undertakes to protect investors by mitigating greenwashing in financial markets, to contribute to promote well-functioning carbon markets.[87] For example, the multinational energy companies may present themselves as "progressive" and environmentally responsible to legitimise their

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[81] Xihan Xiong, Zhipeng Wang, Tianxiang Cui, William Knottenbelt, and Michael Huth, 'Market Misconduct in Decentralized Finance (DeFi): Analysis, Regulatory Challenges and Policy Implications' [2023] *arXiv* <*arXiv:2311.17715*> accessed 20 June 2025; Sebeom Oh, "Market Manipulation in NFT Markets", MPRA Paper No. 116704 (University Library of Munich, Germany 2023).

[82] PWC, 'How to Assess Your Green Fraud Risks' <https://www.pwc.co.uk/assets/pdf/greenfraud.pdf> accessed 6 September 2023.

[83] IOSCO, 'Voluntary Carbon Markets Discussion Paper' CR/06/22 (The International Organization of Securities Commissions 2022) <https://www.iosco.org/library/pubdocs/pdf/IOSCOPD718.pdf> accessed 20 June 2025.

[84] Regina Betz and others, *The Carbon Market Challenge: Preventing Abuse Through Effective Governance* (Cambridge University Press 2022).

[85] Heidi Bachram, 'Climate Fraud and Carbon Colonialism: The New Trade in Greenhouse Gases' (2004) 15(4) Capitalism Nature Socialism 5.

[86] Clifford Curtis Williams, 'A Burning Desire: The Need for Anti-Money Laundering Regulations in Carbon Emissions Trading Schemes to Combat Emerging Criminal Typologies' (2013) 16 Journal of Money Laundering Control 298.

[87] IOSCO, 'IOSCO Outlines Regulatory Priorities for Sustainability Disclosures, Mitigating Greenwashing and Promoting Integrity in Carbon Markets' (The International Organization for Securities Commissions 2022) IOSCO/MR/33/2022 <https://www.iosco.org/news/pdf/IOSCONEWS669.pdf> accessed 20 June 2025.

forms of energy production. These companies however, arguably make no actual environmental change while being able to keep polluting without any consequences.[88]

In another example, in 2021, carbon offset credits purchased by a vehicle manufacturer were inexplicably about five times larger than their 2020 purchases.[89]

Credit Suisse's 2022 Sustainability Report acknowledges significant challenges in ESG data quality, third-party verification, and climate-related disclosures, which may undermine the reliability of some sustainability claims in the market.[90]

The geographic concentration of carbon trading mechanisms reveals a troubling equity crisis in global climate finance. Despite Least Developed Countries (LDCs) and Small Island Developing States (SIDS) prominently featuring renewable energy projects in their Nationally Determined Contributions (NDCs), their participation in the Clean Development Mechanism (CDM) remains severely limited. Over 80% of CDM projects cluster in a few large developing economies—primarily China and India—while Africa's representation is minimal despite hosting 54 countries. [91] This imbalance stems from structural barriers including prohibitive project costs, political instability, inadequate infrastructure, and limited technical capacity in the poorest nations. This reflects a "carbon colonialism," where emissions mitigation burdens shift disproportionately to those least responsible historically for carbon emissions.

Though LDCs possess substantial renewable energy potential and land-based mitigation opportunities in forestry and agriculture, these assets remain largely untapped due to market barriers. This systemic exclusion from carbon market benefits contradicts the Paris Agreement's principle of common but differentiated responsibilities while perpetuating global climate inequities that disproportionately harm the world's most vulnerable populations.[92]

In April 2021, a report analysed 100 certified offset programs and found significant performance failures. The analysis revealed that 90% of the projects either failed to offset their claimed emissions reductions or actually caused local environmental damage.

[88] Steffen Boehm and Siddharta Dabhi, *Upsetting the Offset: The Political Economy of Carbon Markets* (MayFly Books 2009); Akshat Rathi, Natasha White and Demetrios Pogkas, "Junk Carbon Offsets are What Make These Big Companies Carbon Neutral" (*Bloomberg*, 21 November 2022) <https://www.bloomberg.com/graphics/2022-carbon-offsets-renewable-energy/?> accessed 20 June 2025.

[89] Josh Gabbatiss, "Analysis: How some of the world's largest companies rely on carbon offsets to 'reach net-zero'" (*Carbon Brief*, 28 September 2023) <https://interactive.carbonbrief.org/carbon-offsets-2023/> accessed 20 June 2025; Nina Lakhani, 'Corporations invested in carbon offsets that were 'likely junk', analysis says' *The Guardian* (London, 30 May 2024) <https://www.theguardian.com/environment/article/2024/may/30/corporate-carbon-offsets-credits> accessed 20 June 2025.

[90] Credit Suisse Group AG, "Sustainability report 2022" <https://www.responsibilityreports.com/HostedData/ResponsibilityReportArchive/c/NYSE_CS_2022.pdf> accessed 20 June 2025.

[91] Avenarius and others (n 23).

[92] Hepburn (n 32).

Similarly, another investigation found that airline companies' offsetting schemes have made emission predictions that exaggerated success.[93]

Overall, we increasingly see companies make statements regarding carbon credit transactions. However, they often employ climate terms such as “net zero” in ways that could potentially indicate greenwashing if not outright fraud.

To mitigate the growing problem of greenwashing—where companies exaggerate or misrepresent their environmental efforts—some experts propose tightening the conditions under which carbon offset credits can be used. Specifically, it would be best if large corporations should only be allowed to access offset markets after they have made verifiable and reasonable efforts to reduce their direct and indirect emissions through internal measures such as energy efficiency improvements, process optimisation, or a shift to renewable energy. This approach prioritises actual emissions reductions over symbolic offset purchases and ensures that offsets serve as a complementary, not primary, tool in a company’s decarbonisation strategy. By enforcing such a hierarchy—first reduce, then offset—regulators and stakeholders can discourage superficial climate pledges and promote more meaningful climate action.[94] And even when companies have good intentions, they often lack the understanding and in-depth knowledge to pick a suitable project that will actually make a difference. Selecting high-quality carbon credits is inherently challenging due to systemic flaws in how carbon markets are designed and operate. Many protocols and standards, particularly for forest-based offsets, suffer from deep-rooted weaknesses in core areas like additionality, permanence, leakage, and verification. These shortcomings are often due to vague guidelines or misunderstandings of how markets function. The verification process, intended to ensure credibility, is undermined by conflicts of interest and limited technical expertise—verifiers may only assess compliance with inadequate rules, rather than conducting a truly independent evaluation. Compounding this, project developers are incentivised to exploit these weaknesses, sometimes manipulating estimates or reporting to maximise profits, especially when oversight is weak. As a result, many projects underperform or would have occurred even without the carbon market mechanism, meaning their credits do not reflect real, additional emissions reductions.[95] These structural and behavioural issues—not merely poor judgment by credit buyers—make it difficult to confidently identify projects that deliver meaningful climate impact.

Ultimately, if companies claim that they are reducing carbon emissions, they must be able to demonstrate as such to investors and regulators.[96] The legal enforceability of carbon reduction claims requires robust verification mechanisms that can withstand

[93] Emmy Hawker, ‘Can a New Sheriff Tame Carbon Markets’ Wild West?’ (*ESG Investor*, 19 January 2022) <https://www.esginvestor.net/can-a-new-sheriff-tame-carbon-markets-wild-west/> accessed 6 September 2023.
[94] ibid.
[95] Richards and Huebner (n 25).
[96] Patrick Temple-West, ‘Critics Take Aim at “Wild West” Carbon Offset Market’ *Financial Times* (London, 8 June 2022) <https://www.ft.com/content/9b02fcf7-9e04-4b71-ad14-251552d5a78e> accessed 8 June 2022.

judicial scrutiny, a standard that many current verification procedures fail to meet under close examination.

3.2 Additionality

Assessing additionality, as described in the Kyoto Protocol[97] is a key part of all baseline-and-credit schemes. It determines whether a project leads to real emissions reductions that wouldn't have happened without the incentive. The baseline serves as a reference, showing what emissions would have been without the project. Any such project reduces emissions from sources or enhances removals by carbon sinks—natural systems like plants, oceans, and soil that absorb more carbon than they release. Ensuring additionality is important because it prevents credit schemes from rewarding reductions that would have occurred anyway. However, since additionality involves predicting future scenarios, it can never be determined with complete certainty.[98]

Scarcity plays a crucial role in ensuring the integrity of baseline-and-credit schemes by limiting the supply of credits to only truly additional projects. [99] In offsetting programmes, this scarcity is created by distinguishing eligible activities from those that do not meet the additionality criteria, ensuring that only projects leading to genuine emissions reductions receive credits. The Kyoto Protocol mandates additionality but does not specify how to determine the baseline, the reference point for measuring reductions.

To address this, the UNFCCC developed tools to minimise the risks associated with counterfactual data and to require project developers to establish precise baseline measurements. Accurate and consistent measurement is essential, as errors can lead to the issuance of invalid credits, undermining the credibility of the carbon market. [100] By controlling the supply of credits, additionality helps maintain the scarcity necessary for an effective and trustworthy offset system.

Assessing additionality is challenging because it relies on counterfactual scenarios that cannot be definitively proven. There is no accurate and standardised methodology to calculate additionality because there is no certainty about what would happen without the project.[101] Furthermore, fraudulent measurement of emissions can be created by tampering with measurement devices or reporting misstatements.[102] In a 2023 report, the

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97 'Kyoto Protocol to the United Nations Framework' Article 12, paragraph 5(c) <https://unfccc.int/resource/docs/convkp/kpeng.pdf> accessed 20 June 2025.

98 Australian Government Climate Change Authority, 'Coverage, Additionality and Baselines - Lessons from the Carbon Farming Initiative and Other Schemes: CCA Study' (CCA 2014) <https://www.climatechangeauthority.gov.au/publications/coverage-additionality-and-baselines-lessons-carbon-farming-initiative-and-other-schemes> accessed 6 September 2023.

99 Michael Gillenwater and others, 'Policing the Voluntary Carbon Market' (2007) 1 Nature Climate Change 85.

100 Tanguy du Monceau and Arnaud Brohé, 'Briefing Paper "Baseline Setting and Additionality Testing within the Clean Development Mechanism (CDM)"' (London 2011) <https://climate.ec.europa.eu/system/files/2017-02/additionality_baseline_en_0.pdf> accessed 20 June 2025.

101 ibid.

102 Deloitte (n 74).

Guardian newspaper revealed that more than 90% of rainforest carbon offsets are worthless. The research into Verra, a large voluntary carbon credit registry, found that the majority of the credits do not represent genuine carbon reductions. According to the investigation, only a couple of Verra's rainforest projects showed evidence of deforestation reductions. Another study by the University of Cambridge found that 32 projects out of 40 scenarios of forest loss appeared to be overstated by approximately 400%.[103] This uncertainty provides the opportunity to manipulate the process or make false claims about the project. Players in the market have an incentive to provide biased information that will increase their chances of being qualified as an additional project.[104]

Ensuring additionality in carbon offset programs is complex. First, these programmes rely on obtaining accurate data from field actors, but regulators often face **asymmetric information—w**here those involved in offsetting have incentives to exaggerate their program's impact to gain approval. Both credit sellers and buyers benefit when a program is deemed "additional," which can undermine the integrity of the carbon market.

Moreover, additionality is influenced by multiple factors. Activities vary in function and are shaped by diverse variables, making additionality standards inherently **subjective.** Additionally, the **most expensive projects** are often the most likely to qualify as additional, which may lead investors to artificially inflate costs to meet the criteria.

Another key challenge is that additionality depends on **context-specific factors—**such as project circumstances, risk levels, and investor behaviour. However, existing frameworks largely **overlook these complexities,** leading to projects that appear "additional" on paper but fail to contribute meaningfully to net-zero goals.

Policymakers and regulators must recognise that as additionality assessments become more stringent, the risk increases that **fewer projects will be developed**, potentially limiting the effectiveness of carbon offset initiatives.

3.3 Leakage

Carbon reduction projects must also prevent leakage, which occurs when emissions increase outside a project's boundary as a result of the project's intervention. For example, protecting a section of the Amazon rainforest may simply push logging activities to another area, undermining the intended environmental benefits. Leakage risks are higher when regulations and incentives apply to only a portion of the relevant resources or stakeholders.

Leakage can occur at different levels: on-site leakage happens when emissions unexpectedly rise within the project area, while off-site leakage occurs beyond it. Off-

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[103] Patrick Greenfield, 'Revealed: More than 90% of Rainforest Carbon Offsets by Biggest Certifier Are Worthless, Analysis Shows' *The Guardian* (London, 18 January 2023) <https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe> accessed 7 September 2023.

[104] Gillenwater and others (n 99).

site leakage may be international, where emissions shift from a regulated country to one with fewer restrictions, or subnational, where a country's policy regulates only certain sectors, allowing emissions to move to unregulated industries. To ensure meaningful emissions reductions, policymakers must design comprehensive frameworks that anticipate and mitigate leakage risks.

Emissions Trading System (ETS) leakage occurs when businesses relocate production to countries with less stringent emission regulations to avoid the costs associated with carbon pricing. This shift can actually lead to an overall increase in global emissions, undermining the effectiveness of carbon reduction policies. The EU Emissions Trading System (EU ETS) recognises this risk, particularly in industries that are energy-intensive and exposed to international competition. To mitigate ETS leakage, the EU allocates a higher share of free allowances to sectors most vulnerable to relocation, ensuring they remain competitive while still incentivising emission reductions within the regulated jurisdiction.[105]

The main challenge with leakage is that it is not directly observable but rather estimated using economic data and modelling. Due to variations in leakage rates and the uncertainty of these measurements, leakage can undermine the integrity of offset programs.[106] Additionally, leakage highlights a broader issue—wealthy countries often displace emissions to developing nations, exacerbating global environmental inequalities. To minimise leakage, emissions reductions and removals must be carefully quantified, with appropriate adjustments made for estimated leakage to ensure the credibility of offset programme.[107]

3.4 Double counting

Another concern is that traded credits may be "double-counted", meaning carbon emissions removal units are counted more than once. For example, the same credit can be sold and resold to different buyers.[108]

In fact, double counting can appear in many different forms and result from different situations[109] such as: double issuance, if more than one unit is issued for the same emissions; double claiming, if the same emission reductions are accounted for the same mitigation pledges usually in the context of transferring units from developing to

[105] Commission Delegated Decision (EU) 2019/708 of 15 February 2019 supplementing Directive 2003/87/EC of the European Parliament and of the Council concerning the determination of sectors and subsectors deemed at risk of carbon leakage for the period 2021 to 2030 [2019] OJ L120/62.
[106] W Aaron Jenkins, Lydia P Olander and Brian C Murray, 'Addressing Leakage in a Greenhouse Gas Mitigation Offsets Program for Forestry and Agriculture' (Nicholas Institute for Environmental Policy Solutions 2009) <https://nicholasinstitute.duke.edu/sites/default/files/publications/offsetseries4-paper.pdf> accessed 20 June 2025.
[107] Blaufelder and others (n 5).
[108] United Nations Framework Convention on Climate Change (adopted 12 December 2015) (UNFCC) art 6(2) - further 'Paris Agreement'.
[109] Lambert Schneider, Anja Kollmuss and Michael Lazarus, 'Addressing the Risk of Double Counting Emission Reductions under the UNFCCC' (2015) 131 Climatic Change 473.

developed countries; "double selling", counted once by the country of origin when reporting its emissions and again by the receiving country or entity and lastly double purpose, the unit is also used for financial or technology purposes.[110]

Another significant fraud risk in carbon markets is the sale of non-existent or misrepresented carbon credits, including those that have already been claimed by someone else. Since carbon credits exist only as digital records in registries, they can be vulnerable to forgery or duplication. The global nature of carbon trading further complicates tracking and preventing such fraudulent activities.[111] To ensure unique ownership and prevent double counting, it is essential to establish clear verification mechanisms that confirm ownership rights. Each credit must be assigned to a single entry in a registry and permanently retired once used, preventing the circulation of recycled carbon units and maintaining the integrity of the market.[112]

The credibility of the EU ETS has also been impacted by fraud, including the theft of €7 million in emission permits from the Czech Republic's carbon registry.[113] Similarly, the Clean Development Mechanism (CDM) has faced fraudulent activities, such as Chinese companies deliberately producing greenhouse gases to generate credits and then destroying them, the sale of fake forestry credits, and the reuse of credits by EU states. To address these issues, experts are advocating for a global registry to track and log all voluntary carbon market (VCM) projects and credits, ensuring greater transparency and accountability.[114]

3.5 VAT fraud and money laundering

Carbon credits are highly susceptible to fraud due to their intangible nature, high market value, and the ease with which they can be traded on spot markets. Unlike physical commodities such as corn or gold—where volume and delivery can be readily verified—carbon offsets lack a physical form, making it difficult for purchasers to independently confirm that the claimed emissions reductions have actually taken place. This reliance on unverifiable assumptions, combined with limited oversight mechanisms, renders the carbon market vulnerable to manipulation and fraudulent activity.[115]

[110] Lambert Schneider and others, 'Double Counting and the Paris Agreement Rulebook' (2019) 366 Science 180.
[111] IOSCO (n 83).
[112] Brian Preston, 'Climate Change Litigation (Part 1)' (2011) 5 Carbon & Climate Law Review 3.
[113] Fred Pearce, (2011, January 20). 'Black market steals half a million pollution permits' (*New Scientist*, 20 January 2011) <https://www.newscientist.com/article/dn20012-black-market-steals-half-a-million-pollution-permits/> accessed 20 June 2025.
[114] Frédéric Hache, '50 Shades of Green: The Rise of Natural Capital Markets and Sustainable Finance – Part I. Carbon' (Green Finance Observatory 2019) <https://greenfinanceobservatory.org/wp-content/uploads/2019/03/50-shades-carbon-final.pdf> accessed 20 June 2025.
[115] Alex Fredman and Todd Phillips, 'The CFTC Should Raise Standards and Mitigate Fraud in the Carbon Offsets Market' (Center for American Progress 2022) <https://www.americanprogress.org/article/the-cftc-should-raise-standards-and-mitigate-fraud-in-the-carbon-offsets-market/> accessed 7 September 2023.

This vulnerability has not only enabled manipulation within the carbon credit system itself but has also facilitated large-scale financial fraud schemes. One prominent example involves the exploitation of value-added tax (VAT) systems, where fraudulent actors leverage the ease of carbon credit transfers to evade tax obligations on a massive scale.[116]

VAT is a tax applied to imported goods and services. There are two main types of VAT fraud, one of which is "missing-trader" fraud. This occurs when a buyer acquires emission allowances from a country where VAT is exempt, then sells them domestically while charging VAT but failing to remit the tax to local authorities. The term “missing-trader” refers to the fact that the seller typically disappears before the fraud is detected. This scheme is estimated to cost revenue authorities approximately 50 billion euros annually in lost tax revenue.[117]

The second, more complex type of VAT fraud is known as "carousel frauds". Allowances are transferred along a network of interconnected companies located in different countries within the same carbon market. In each trading cycle, the trader does not return the VAT to the local tax authority.[118] The EU ETS has experienced VAT fraud involving large sums of money. In 2009, the UK arrested seven people for executing a 38 million pounds carbon credit VAT fraud. The French authorities similarly suspected a 156 million euros VAT fraud. The effects of VAT fraud are mainly large losses of tax revenues in the countries where the goods are "carouseled". In 2018, 36 people in France were convicted of €385 million carbon VAT fraud scheme.[119] Europol estimates that in 2009 VAT fraud on the EU ETS reached roughly 5 billion euros.[120]

In addition to facilitating tax evasion, carbon offset markets are increasingly vulnerable to exploitation for money laundering, especially in developing countries where regulatory oversight is limited or inconsistently enforced. Thus, carbon credit markets, particularly emissions trading schemes (ETS), have emerged as lucrative yet vulnerable platforms for money laundering. In particular, the absence of robust anti-money laundering (AML) safeguards during the initial development of mechanisms like the EU ETS left them open to criminal exploitation.[121] Emission allowances and credits can be traded much like traditional financial instruments, yet without equivalent regulatory oversight. This parallel to traditional securities markets, combined with international variability in enforcement standards, creates jurisdictional blind spots that money launderers can

[116] Katherine Nield and Dr Ricardo Pereira, ‘Fraud on the European Union Emissions Trading Scheme: Effects, Vulnerabilities and Regulatory Reform’ (2011) 20 European Energy and Environmental Law Review 255.
[117] ‘MTIC (Missing Trader Intra Community) Fraud’ (*Europol*, 2022) <https://www.europol.europa.eu/crime-areas-and-statistics/crime-areas/economic-crime/mtic-missing-trader-intra-community-fraud> accessed 7 September 2023.
[118] Betz and others (n 84).
[119] Maria Cronin, Craig Hogg and Kirsten Stewart, ‘Carbon Credit Fraud: COP27 and Policing the Wild West’ (*The European Business Review*, 27 November 2022) <https://www.europeanbusinessreview.com/carbon-credit-fraud-cop27-and-policing-the-wild-west/> accessed 7 September 2023.
[120] Nield and Pereira (n 116).
[121] Curtis Williams, ‘A burning desire: The need for anti-money laundering regulations in carbon emissions trading schemes to combat emerging criminal typologies’ (2013) 16(4) Journal of Money Laundering Control 298.

exploit. Criminals may layer illicit proceeds through carbon transactions, eventually integrating them into the financial system with a veneer of legitimacy.

Moreover, the global scale of environmental crime—estimated by the Financial Action Task Force (FATF) to generate up to $281 billion annually—underscores the importance of using AML enforcement as a countermeasure.[122] Europol has estimated losses from such frauds at over €5 billion, with 90% of trading volume during peak years attributed to illicit activity. These operations not only deprive governments of tax revenues but also distort carbon markets, eroding trust and reducing their efficacy as tools for climate mitigation.[123]

Carbon offset projects, especially in regions with limited regulatory infrastructure, can serve as entry points for illicit capital under the guise of climate finance. For example, fraudsters might establish sham offset projects or manipulate emissions data to generate tradable credits backed by little or no actual emissions reduction. This misuse distorts market integrity, undermines climate goals, and diverts legitimate climate finance. As carbon markets expand globally, experts stress the need to integrate AML mechanisms from the outset, including rigorous verification, beneficial ownership transparency, and international cooperation. Without these safeguards, carbon markets may unintentionally facilitate financial flows that enable environmental degradation rather than its mitigation.[124]

3.6 Ethical concerns and the global south

Current carbon market structures create disproportionate burdens on developing nations while enabling industrialised economies to outsource their climate responsibilities. The documented pattern of implementing offset projects in the Global South without adequate safeguards for local communities raises fundamental questions of climate justice and global equity. Carbon trading mechanisms must address these ethical contradictions to serve as legitimate climate solutions.

Developed countries increasingly implement decarbonisation projects in developing nations to offset emissions. They use mechanisms such as the Clean Development Mechanism (CDM)[125] and the Warsaw Framework for REDD+.[126] Reducing Emissions from Deforestation and Forest Degradation (REDD+) is a global initiative aimed at incentivising forest conservation in developing countries. REDD+ seeks to mitigate climate change by

[122] Chiara Sophia Oberle, 'Greening White-Collar Crime: Transforming Anti-Money Laundering Enforcement into an Instrument Against Environmental Crime' (Master thesis, University of Geneva 2022).
[123] Katherine Nield and Ricardo Pereira, 'Financial crimes in the European carbon markets' in Stefan E Weishaar (ed), *Research Handbook on Emissions Trading* (Edward Elgar Publishing 2016) 195.
[124] Deloitte (n 74).
[125] Hepburn (n 32).
[126] Kanako Morita and Ken'ichi Matsumoto, 'Challenges and lessons learned for REDD+ finance and its governance' (2023) 18(8) Carbon Balance and Management 1; John Parrotta, Stephanie Mansourian, Nelson Grima, and Christoph Wildburger (eds), 'Forests, climate, biodiversity and people: assessing a decade of REDD+' (IUFRO World Series Volume 40, Vienna 2022).

providing financial compensation to governments, communities, and private actors for preserving forests, thus preventing deforestation and associated carbon emissions. However, scholars have raised significant ethical concerns about these projects, particularly their impact on local populations.

These concerns include the risk that carbon offset projects may come at the expense of economic prosperity in developing countries,[127] misaligned political motivations that prioritise external interests over local needs, and increased energy injustices that exacerbate existing inequalities.[128] Additionally, these initiatives can disrupt local communities' welfare by displacing people or limiting their access to resources,[129] while the absence of robust institutional structures often fosters corruption, especially in regions such as Africa and Latin America. [130] These challenges highlight the need for stronger regulatory oversight and greater inclusion of local stakeholders in the decision-making process.

The disproportionate burden of climate change on developing countries remains one of the major challenges in the world today. Climate change is predominantly caused by the wealthiest of the world's population who contribute disproportionately to about 40 percent of the released emissions.[131] However, climate change consequences will disproportionately affect the world's poorest countries.[132] The paradox is that the Global South has the most to lose from both climate change and the economic transition to decarbonisation.[133] While climate change affects their natural resources[134] the poorest also suffer the greatest from rising energy prices[135] which result from carbon credit and taxation policies exacerbating inequality through an inaccessibility to energy.

This paradox highlights a fundamental tension in international climate law between the right to development and climate protection obligations. Article 4.7 of the UNFCCC explicitly acknowledges that economic and social development and poverty eradication are 'first and overriding priorities' for developing countries.[136] However, carbon market mechanisms often fail to adequately balance these competing legal principles, creating

[127] Peter Newell, Marcus Power, and Harriet Bulkeley, "Rising Powers, Lowering Emissions?" (IDS 2016).
[128] ibid.
[129] Baimwera Bernard, David Wang'ombe, and Ernest Kitindi, 'Carbon Markets: Have They Worked for Africa?' (2017) 6 (2) Review of Integrative Business & Economic Research 90.
[130] Wim Carton, Adeniyi Asiyanbi, Silke Beck, Holly J Buck, and Jens F Lund, 'Negative Emissions and the Long History of Carbon Removal' (2020) 11 (6) Wiley Interdisciplinary Reviews: Climate Change 1.
[131] Bill Gates, *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need* (Diversified Publishing 2021).
[132] Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2022 - Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change" (Cambridge: Cambridge University Press 2023).
[133] Matt Ridley, *The Rational Optimist: How Prosperity Evolves* (Harper Collins, 2011).
[134] Arild Angelsen and others, 'Environmental Income and Rural Livelihoods: A Global-Comparative Analysis' (2014) 64(1S) World Development S12; World Food Programme (WFP), "Climate Change in Southern Africa" (2021).
[135] Samuel Asumadu Sarkodie and Samuel Adams, 'Electricity Access, Human Development Index, Governance and Income Inequality in Sub-Saharan Africa' (2020) 6 Energy Reports 455.
[136] Lukas Hermwille, Wolfgang Obergassel, Hermann E Ott, and Christiane Beuermann, 'UNFCCC before and after Paris: What's necessary for an effective climate regime?' (2017) 17(2) Climate Policy 150.

what some scholars describe as 'carbon colonialism' where climate mitigation burdens are disproportionately placed on those least responsible for the problem.[137] Nevertheless, global emissions reduction by each and every country is necessary in order to achieve carbon neutrality. Ludena and others wed how global conformity of negative carbon solutions is required to achieve carbon neutrality.[138] However, the carbon market policies enacted in the Paris Climate Agreement of 2015 arguably force economic burdens on developing nations to take financial responsibility for increasing energy use, for the purposes of poverty eradication.[139] Carbon market policies create economic burdens on developing nations while denying them prosperity, despite the fact that climate change was primarily caused by industrialised countries. This arrangement is potentially unethical and incongruent with the United Nations Sustainable Development Goals (SDGs).[140]

Political misalignment is another significant ethical concern in carbon offset projects, including REDD+. These include fundamental tension between development and climate goals,[141] ongoing tensions between more inclusive, participatory approaches and the dominant logic of market-based governance focused on commodification, standardisation, and profit accumulation,[142] lack of policy harmonisation and institutional fragmentation,[143] and equity, burden shifting, and international tensions.[144]

However, critics argue that these projects often continue despite mistreatment of local communities and politically or commercially driven motivations.[145]

Asiyanbi and Lund question the "persistence and tentative stability" of REDD+ initiatives, highlighting how political and private sector interests can overshadow the needs of affected populations. Similarly, Alusiola and others conducted a meta-analysis of conflicts arising from REDD+ forest projects to understand their causes, mechanisms, and consequences. Their study identified six key conflict catalysts: (1) injustices and restrictions on full access to and control over forest resources, (2) the creation of new forest governance structures that alter stakeholder relationships, (3) the exclusion of community members from meaningful participation, (4) failure to meet high project expectations, (5) changes in land tenure policies driven by migration, and (6) the exacerbation of historical land tenure disputes. These findings highlight the socio-political

[137] Heidi Bachram, 'Climate fraud and carbon colonialism: the new trade in greenhouse gases' (2004) 15(4) Capitalism nature socialism 5.
[138] Carlos Ludeña, Carlos J De Miguel, and Andrés Ricardo Schuschny, 'Climate Change and Carbon Markets: Implications for Developing Countries' (2015) 116 CEPAL Review 62.
[139] Bernard, Wang'ombe, and Kitindi (n 129).
[140] UN SDG, 'The 17 Goals' <https://sdgs.un.org/goals> accessed 28 December 2022.
[141] Gonçalves and Costa (n 13).
[142] Parrotta and others (n 126).
[143] Li and others (n 78).
[144] Christoph Böhringer, Jan Schneider, and Emmanuael Asane-Otoo, 'Trade in carbon and carbon tariffs' (2021) 78 Environmental and Resource Economics 669.
[145] Adeniyi Asiyanbi, and Jens Friis Lund, 'Policy persistence: REDD+ between stabilization and contestation' (2020) 27(1) Journal of Political Ecology 378, 380.

complexities of REDD+ and emphasise the need for more inclusive, transparent, and locally driven approaches to forest conservation and carbon offsetting.[146]

Another ethical concern arises from the risk that carbon offsetting projects may be implemented at the expense of economic prosperity in developing countries. REDD+ initiatives, for instance, often impose restrictions on forest access, disproportionately affecting vulnerable populations who depend on these resources for their livelihoods. The history of carbon sequestration projects also reveals a pattern of motivations that do not always align with genuine climate solutions. Carton and others argue that some countries have supported these projects primarily as a means to justify continued fossil fuel consumption while outsourcing their emissions reductions to developing nations.[147] This is evident in the strong backing for carbon sinks from countries that have historically obstructed progress in climate negotiations or have fossil-fuel-dependent economies.[148] For example, Norway has been a major proponent of carbon neutrality through offsets, as it allows the country to continue oil and gas extraction while compensating for emissions through forest conservation abroad.[149]

Structural and economic disparities further exacerbate the challenges of carbon trading. REDD+ which was founded by economists has nevertheless led to “underestimation of social and political obstacles to implementation.”[150] This economic perspective led to many project failures by overlooking “contextual dynamics”[151] of local environments and situations leading to the exploitation of locals and exacerbating societal inequalities. Beyond this, possible economic gains from forest sequestration projects are rerouted back to the northern hemisphere.[152] While local livelihood is disrupted, energy prices rise due to carbon pricing, climate change exacerbates food and water insecurities, and local labour wages stagnate, this creates a “dissonance between expensive carbon and cheaper local inputs [which] creates both an obstacle and an opportunity”.[153]

If the *wrong* decarbonisation policies and projects are implemented in the southern hemisphere, the local people may be exploited in multiple ways. In South Africa and Mozambique, for example, the unequal distribution of energy infrastructure throughout both countries causes *energy injustices*: social and economic gaps caused by unequal

[146] Rowan Alumasa Alusiola, Janpeter Schilling, and Paul Klär, ‘REDD+ Conflict: Understanding the Pathways between Forest Projects and Social Conflict’ (2021) 12(6) Forests 1.
[147] Carton and others (n 130).
[148] Martina Jung, ‘The History of Sinks - an Analysis of Negotiating Positions in the Climate Regime’ HWWA Discussion Paper No 293 (Hamburg Institute of International Economics 2004) 12.
[149] McDermott, Constance, Bhaskar Vira, Judith Walcott, Maria Brockhaus, Matthew Harris, Eric Mensah Kumeh, and Carolina de Mendonça Gueiros, ‘The evolving governance of REDD+’ in *Forests, Climate, Biodiversity and People: Assessing a Decade of REDD+* (IUFRO, Vienna 2022) 21.
[150] ibid 13.
[151] ibid 7.
[152] Bernard, Wang’ombe, and Kitindi (n 129).
[153] Frank Ackerman, ‘Carbon Markets and Beyond: The Limited Role of Prices and Taxes in Climate and Development Policy’ G-24 Discussion Paper Series No 53 (UNCTAD 2008) 8 <https://unctad.org/system/files/official-document/gdsmdpg2420084_en.pdf> accessed 20 June 2025.

access and accessibility due to costs of energy.[154] Disrupting local environments causes "marginalisation and rights abuses across many carbon forestry projects",[155] "maltreatment of indigenous peoples and their environment"[156], such as violent engagements, as seen in Uganda twice.

Lastly, corruption in combination with weak government structures creates adverse risk for investors and makes CDM projects unattractive, as well as hindering economic potential.[157] Due to all of this adverse risk, financing in African projects has been significantly limited.[158] This exacerbates challenges to creating ethical and meaningful decarbonisation strategies such as implementing renewable technologies and investments.

While these ethical dilemmas represent significant challenges to the legitimacy of carbon markets, emerging technological innovations offer potential pathways toward more transparent, efficient, and equitable trading systems.

4 Emerging trends and technologies

While emerging technologies may address certain transparency and verification challenges in carbon markets, they cannot resolve the fundamental incentive misalignments and ethical contradictions that plague these systems without radical structural reforms technologies offer promising but incomplete solutions to carbon market dysfunctions. Distributed ledger technologies, artificial intelligence, and advanced monitoring systems can enhance verification processes and market transparency, but must be integrated within robust regulatory frameworks and ethical standards. The fundamental challenge lies not in technological capability but in governance design that aligns market incentives with genuine climate protection.[159]

4.1 Technological innovation in service of monitoring

Digital technologies are widely considered essential for improving carbon trading market efficiency. Monitoring, reporting, and verifying (MRV) carbon emissions consumes significant time and results in the inflation of asset prices.[160] From a legal perspective, these verification challenges create fundamental questions about whether carbon credits

[154] Newell, Power, and Bulkeley (n 127).
[155] Carton and others (n 130) 12.
[156] Bernard, Wang'ombe, and Kitindi (n 129).
[157] ibid.
[158] Least Developed Countries Group and UN Climate Change Negotiations, "Least Developed Countries Group Calls for COP23 to Be a COP of Finance and Support," (*LDC Climate Change*, 2 November 2017) <https://www.ldc-climate.org/media_briefings/media-briefing-least-developed-countries-group-calls-for-cop23-to-be-a-cop-of-finance-and-support/> accessed 20 June 2025.
[159] Nicolò Barbieri, Alberto Marzucchi, Ugo Rizzo, 'Green technologies, interdependencies, and policy' (2023) 118 Journal of Environmental Economics and Management 1.
[160] Yadav Sapkota and John R White, 'Carbon Offset Market Methodologies Applicable for Coastal Wetland Restoration and Conservation in the United States: A Review' (2020) 701 Science of the Total Environment <https://www.sciencedirect.com/science/article/pii/S0048969719344882> accessed 7 September 2023.

represent legally enforceable claims to atmospheric resources. Verification difficulties undermine not only market efficiency but the legal standing of carbon credits as property rights, raising complex questions about liability for verification failures that current regulatory frameworks inadequately address.[161] Moreover, verification margin of error can reach nearly 100%, while conflicts of interest between auditors and project developers threaten the credibility of the entire process.[162]

A recent study by the World Bank concludes that the "widespread adoption of digital MRV systems – and the simplification of MRV process this enables – will greatly increase the efficiency of future carbon markets"[163] since they are superior to the current methods, which "can be costly, error-prone, and time-consuming, often relying on manual processes and in-person surveys".[164] The most evident area for applying digital technologies is the collection and verification of data. Simultaneously, digital MRV systems also could be linked to global or national registries to ensure compliance with reporting requirements. Many countries already use pilot systems to regulate their carbon markets.[165]

The available evidence provides a compelling reason to believe that digital technology has been revolutionising carbon markets; simultaneously, the adoption of digital MRV systems is still fragmentary and inconsistent owing to the diversity of various solutions. Sylvera, for example, is known as a universal framework for providing credible carbon credit ratings owing to the reliance on satellite and LiDAR data and modern artificial intelligence tools.[166]

Kazakhstan and Jordan use an alpha-version of the system for renewable energy designed by the EU Bank of Reconstruction and Development that utilises cloud computing and smart sensors to conduct the acquisition and processing of data in real time and automate verification procedures.[167]

Various countries are currently experimenting with digital systems, but none have adopted a single MRV system that would automate all the relevant processes across the carbon market infrastructure.[168]

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[161] Jianfu Wang, Shiping Jin, Weiguo Bai, Yongliang Li, and Yuhui Jin, 'Comparative analysis of the international carbon verification policies and systems' (2016) 84 Natural Hazards 381.
[162] Richards and Huebner (n 25).
[163] Lucas Belenky, 'Carbon Markets: Why Digitization Will Be Key to Success' (*World Bank Blogs*, 16 August 2022) <https://blogs.worldbank.org/climatechange/carbon-markets-why-digitization-will-be-key-success> accessed 7 September 2023.
[164] World Bank, 'Digital Monitoring, Reporting, and Verification Systems and Their Application in Future Carbon Markets' (World Bank Group 2022) ii <http://hdl.handle.net/10986/37622> accessed 7 September 2023.
[165] ibid.
[166] Raúl C Rosales and others, 'Voluntary Carbon Markets in ASEAN: Challenges and Opportunities for Scaling Up' (Imperial College Business School 2021) <https://eprints.soas.ac.uk/35781/1/Green_Finance_COP26_Universities_Network_Policy_Report.pdf> accessed 20 June 2025.
[167] John C Shideler and Jean Hetzel, *Introduction to Climate Change Management: Transitioning to a Low-Carbon Economy* (Springer Nature 2021).
[168] Stephanie Mansourian, Amy E Duchelle, Carlos Sabogal and Bhaskar Vira, 'REDD+ Challenges and Lessons Learnt' in John Parrotta, Stephanie Mansourian, Christoph Wildburger and Nelson Grima (eds), *Forests, Climate, Biodiversity and People: Assessing a Decade of REDD+* (IUFRO, Vienna 2022).

Unfortunately, however, the integration of digital technologies into carbon markets occurs in an inconsistent manner. The World Bank cites various MRV systems, including those focusing on mitigation action, support, or monitoring of GHG emissions over time. The development of holistic digital MRV systems is currently inhibited by numerous barriers, such as high costs of technologies, the lack of capacity for adopting new technologies, and concerns related to the capture of highly sensitive data.[169] The successful implementation of innovative technologies could help address most problems faced by carbon markets and ensure automated reporting, reliable monitoring, and streamlined verification. However, it seems that most stakeholders are currently not prepared for the wide-scale implementation of digital MRV systems.

The carbon trading market has been embracing an increasing number of other innovative technologies as well. Many of them are connected with artificial intelligence (AI) and satellite imagery. For example, the company Albo Climate monitors and measures performance of carbon sequestration sustainability projects with the help of deep learning.[170] The scalability of carbon removal offered by the startup could lower the costs of monitoring and potentially make the monitoring process more efficient. Pachama and NCX, in turn, are creating AI-powered carbon offset markets focusing on forestation projects by estimating carbon offsets and ensuring credibility of projects via sensors, aerial imagery, and computer vision.[171] AI applications also are used to track the overall material embodied carbon emissions, something that is hard to estimate manually; moreover, they are often utilised to optimise the use of machinery on project sites and monitor emissions produced by equipment.[172] As a result, companies can determine their needs for carbon offsets based on credible emission data. Watson recently reported that S&P Global Platts plans to launch AI-driven carbon credit indices to increase transparency of the market and simplify the evaluation of projects' co-benefits.[173] The examples above illustrate that AI and other technologies have been revolutionising carbon credit markets, contributing to transparency and efficiency.

4.2 Blockchain and distributed ledger technologies

The carbon market challenges detailed in previous sections—from fraud and double counting to verification difficulties and lack of transparency—highlight the need for

[169] World Bank (n 164).
[170] Albo Climate official site <https://www.albosys.com> accessed 8 April 2023.
[171] Bob Toews, 'These Are The Startups Applying AI To Tackle Climate Change' (*Forbes*, 20 June 2021) <https://www.forbes.com/sites/robtoews/2021/06/20/these-are-the-startups-applying-ai-to-tackle-climate-change/> accessed 7 September 2023.
[172] Gary Ng and others, 'The Concept of "Carbon Credit" in the Construction Industry: A Case Study of viAct's Scenario Based AI in Carbon Credit Management' (2022) 11 International Journal of Business and Management Invention (IJBMI) 50.
[173] Frank Watson, 'S&P Global Platts to Launch AI-Driven Carbon Credit Indices' (*S&P Global Commodity Insights*, 24 February 2021) <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/coal/022421-sampp-global-platts-to-launch-ai-driven-carbon-credit-indices> accessed 7 September 2023.

innovative solutions that can enhance market integrity. Distributed Ledger Technology (DLT) has emerged as a promising approach to address many of these fundamental issues simultaneously.

Carbon markets fundamentally operate as information systems that track credits, verify emissions reductions, and facilitate transactions. The core challenges these markets face—lack of transparency, vulnerability to fraud, double counting, and verification difficulties—are precisely the types of problems that distributed ledger technologies were designed to solve. By creating immutable, transparent records that can be verified by all participants without requiring trust in a central authority, DLT offers a technological foundation that aligns with the requirements of effective carbon trading.

Before examining the application of DLT to carbon markets, it is important to understand its fundamental principles. At its core, DLT refers to a digital system that records transactions of assets and their details in multiple places simultaneously. Unlike traditional databases controlled by a single entity, DLTs distribute identical copies of the ledger across a network of computers (nodes), with each participant maintaining their own copy that is updated through consensus.

Blockchain is the most well-known type of DLT. It organises data into digital blocks that are cryptographically linked in a chronological digital chain. This structure creates several key characteristics that make it valuable for carbon markets: 1) Immutability: Once recorded, data cannot be altered without changing all subsequent blocks, making fraudulent manipulation extremely difficult. 2) Transparency: All authorised participants can view the entire transaction history, enabling verification without requiring trust in a central authority. 3) Traceability: Every transaction is permanently recorded with timestamps, allowing complete tracking of assets (such as carbon credits) throughout their lifecycle. And, 4) Smart contracts: These are self-executing agreements with terms directly written into code that automatically execute actions when predetermined conditions are met, potentially reducing administrative costs and enabling automated compliance.

When applied to carbon markets, these features can address critical challenges by providing transparent tracking of emissions and credits, preventing double-counting, automating verification processes, and enabling trustworthy peer-to-peer trading without intermediaries. The sections that follow examine how these capabilities can be leveraged to transform carbon market operations at both infrastructural and operational levels.

Given this, in general, DLT applications align well with the transparency and reliability requirements set forth in UNFCCC regulations for climate change action. Grounded in the Paris Agreement, Article 13 mandates enhanced transparency to support the objectives of Article 2, which aims to limit global temperature rise to well below 2 degrees Celsius.[174]

[174] 'Transparency of Support under the Paris Agreement' (*United Nations Framework Convention on Climate Change (UNFCCC)*) <https://unfccc.int/topics/climate-finance/workstreams/transparency-of-support-ex-post/transparency-of-support-under-the-paris-agreement> accessed 16 March 2023; Macinante (n 2); 'Key Aspects of the Paris Agreement'

The Conference of the Parties (COP) created the Capacity-building Initiative for Transparency (CBIT).[175]

During COP21, three primary objectives were established: **(1)** strengthening national institutions for transparency-related activities in alignment with national priorities, **(2)** providing relevant tools, training, and assistance to meet the transparency provisions outlined in Article 13 of the Paris Agreement, and **(3)** facilitating the continuous improvement of transparency over time.[176] However, this push for enhanced transparency must not come at the expense of national rights and sovereignty. Unfortunately, the Kyoto Protocol fell short of Article 13's expectations,[177] as the International Transaction Log (ITL) has been criticised for its lack of public accessibility and the presence of legal loopholes that have been exploited for financial gain across markets.[178]

The core principles of any effective carbon market should be: (1) to ensure and enhance the transparency of climate change data including the carbon market while not imposing on national sovereignty in accordance with Article 13;[179] (2) transparency of data measured by Measurement, Reporting and Verification (MRV) processes should include its location, disclosure, and accessibility[180] which will enhance the efficacy and security of

(*United Nations Framework Convention on Climate Change (UNFCCC)*) <https://unfccc.int/most-requested/key-aspects-of-the-paris-agreement> accessed 16 March 2023; 'Financial Intermediary Funds (FIFs)' (*The World Bank*, 2023) <https://fiftrustee.worldbank.org/en/about/unit/dfi/fiftrustee/fund-detail/cbit> accessed 16 March 2023.

[175] Macinante (n 2).

[176] 'Financial Intermediary Funds (FIFs)' (n 174).

[177] Macinante (n 2).

[178] Alastair Marke, Max Inglis and Constantine Markides, 'Emerging Technologies and Their Applicability to Solving Challenges in the Carbon Markets: An Overview' in Alastair Marke, Fabiano de Andrade Correa and Michael Mehling (eds), *Governing Carbon Markets with Distributed Ledger Technology* (Cambridge University Press 2022) <https://www.cambridge.org/core/books/governing-carbon-markets-with-distributed-ledger-technology/emerging-technologies-and-their-applicability-to-solving-challenges-in-the-carbon-markets-an-overview/3146E5BBD0A13810BC0070367F8BABBF> accessed 16 January 2023; Steffen Boehm and Siddharta Dabhi, *Upsetting the Offset: The Political Economy of Carbon Markets* (MayFly Books 2009) <http://mayflybooks.org/?page_id=21> accessed 6 September 2023; Deloitte (n 74); Gillenwater and others (n 99); Lambert Schneider and others, 'Double Counting and the Paris Agreement Rulebook' (2019) 366 Science 180; Lambert Schneider, Anja Kollmuss and Michael Lazarus, 'Addressing the Risk of Double Counting Emission Reductions under the UNFCCC' (2015) 131 Climatic Change 473; Katherine Nield and Ricardo Pereira, 'Fraud on the European Union Emissions Trading Scheme: Effects, Vulnerabilities and Regulatory Reform' (2011) 20 European Energy and Environmental Law Review 255; 'MTIC (Missing Trader Intra Community) Fraud' (*Europol*, 2022) <https://www.europol.europa.eu/crime-areas-and-statistics/crime-areas/economic-crime/mtic-missing-trader-intra-community-fraud> accessed 7 September 2023; Betz and others (n 84).

[179] 'Transparency of Support under the Paris Agreement' (n 174); 'Key Aspects of the Paris Agreement' (n 174); 'Financial Intermediary Funds (FIFs)' (n 174).

[180] Michael A Mehling, 'Governing the Carbon Market' in Alastair Marke, Fabiano de Andrade Correa and Michael Mehling (eds), *Governing Carbon Markets with Distributed Ledger Technology* (Cambridge University Press 2022) <https://www.cambridge.org/core/books/governing-carbon-markets-with-distributed-ledger-technology/governing-the-carbon-market/C8528231958BFAC44975D649143EB9CF> accessed 16 January 2023.

the carbon markets;[181] (3) lastly, is to ensure the outcomes of implementing a market strategy is aligned with Article 2 and Article 4 of the Paris Agreement.[182]

Today, many carbon markets, including the European Union Emissions Trading System (EU ETS), are considered linked markets, as they operate based on agreements negotiated among 30 participating countries. These negotiations are often lengthy and complex, with evolving national interests influencing the terms. As a result, certain parties may benefit more than others, creating an imbalance in the system.[183]

The applicability of DLT can be analysed from two perspectives: external (infrastructure) and internal (operational).

Externally, DLT, artificial intelligence (AI), and the internet of things (IoT) can create a networked carbon market (NCM) using the structures and models of DLT. The NCM is not an overarching market but rather the infrastructure to allow transparency of trading between markets.

The regulatory framework for a networked carbon market (NCM) consists of five key components as described by Macinante: First, the market infrastructure establishes the foundation for interoperability between carbon markets. Second, clear rules for distributed ledger operations govern the functionality and management of the DLT system. Third, operational mechanisms are required to ensure market efficiency, including a valuation mechanism to account for differences in mitigation efforts across jurisdictions and a transaction mechanism to facilitate seamless exchanges. Fourth, transactional rules provide a regulatory framework to ensure compliance, security, and efficiency in market transactions. Finally, participants operate at different levels, including jurisdictional, cross-jurisdictional, and supra-jurisdictional entities, ensuring broad market participation and governance.[184]

DLT models can effectively mitigate key security risks in carbon markets, as identified by Marke and others.[185] The first major risk, cybercrime, can be addressed through the Doorkeeper Model, which enhances cybersecurity within the EU ETS. Under this model, all servers hosting EU ETS accounts would subscribe to multiple antivirus software solutions on a blockchain, leveraging thousands of scanning engines for collective protection. Unlike traditional bug bounty programs, blockchain enables a collaborative yet competitive

[181] Chunhua Ju and others, 'A Novel Credible Carbon Footprint Traceability System for Low Carbon Economy Using Blockchain Technology' (2022) 19 International Journal of Environmental Research and Public Health 1; Mehling (n 180); Nicholas Scott, Sai Nellore and Alastair Marke, 'DLT and the Voluntary Carbon Markets' in Alastair Marke, Fabiano de Andrade Correa and Michael Mehling (eds), *Governing Carbon Markets with Distributed Ledger Technology* (Cambridge University Press 2022) <https://www.cambridge.org/core/books/governing-carbon-markets-with-distributed-ledger-technology/dlt-and-the-voluntary-carbon-markets/C14F0FA68EAF61E41696804EF4FAAE7E> accessed 18 January 2023.
[182] 'Key Aspects of the Paris Agreement' (n 174).
[183] Macinante (n 2).
[184] ibid.
[185] Marke, Inglis and Markides (n 178).

cyber-protection network by integrating prediction markets with proof-of-work, offering broader and faster coverage against cyber threats.[186]

The second security risk involves fraudulent trading and identity verification, which can be mitigated through the Know Your Customer (KYC) Model. Carbon markets have been exploited for financial gain, notably through VAT fraud schemes like missing-trader fraud, where perpetrators manipulate interjurisdictional trades to receive undue VAT allowances.[187] Implementing a blockchain-based KYC model would enhance user authentication, ensuring that only legitimate participants engage in carbon trading, thereby increasing transparency and reducing the risk of market abuse.[188]

Lastly, the risk of ensuring the fulfilment of contractual obligations can be mitigated through a four-trigger smart contract verification process. When applying DLT to existing Emissions Trading Systems (ETS) to enhance MRV capabilities, these four triggers play a crucial role.

The first trigger integrates with the Know Your Customer (KYC) model to verify that the entity interacting with the blockchain is authorised to conduct a transaction. The second trigger ensures that the party has the necessary resources, such as the required currency, to fulfil the contractual obligations. Once these conditions are validated, the third trigger introduces a security safeguard by delaying contract execution momentarily, allowing artificial intelligence to scan the server for potential threats. Finally, the fourth trigger verifies compliance with both jurisdictional and interjurisdictional regulations to ensure that all transactions adhere to the applicable legal frameworks.[189]

As trading volumes increase, interactive traceability models—which combine off-chain traceability with on-chain verification—will become essential for tracking carbon assets efficiently. Furthermore, blockchain's ability to enhance supply chain visibility will improve CO2 emissions tracing and management.[190] Ultimately, by leveraging DLT, carbon markets can achieve greater transparency, security, and regulatory compliance, fostering a more reliable and equitable system for climate action.

Building on these technological foundations, we can envision a transformed carbon market architecture that addresses the fundamental challenges identified throughout this analysis while creating new opportunities for market evolution.

[186] Marco Zolla, Alastair Marke and Michael A Mehling, 'DLT and the European Union Emissions Trading System' in Alastair Marke, Fabiano de Andrade Correa and Michael Mehling (eds), *Governing Carbon Markets with Distributed Ledger Technology* (Cambridge University Press 2022) <https://www.cambridge.org/core/books/governing-carbon-markets-with-distributed-ledger-technology/dlt-and-the-european-union-emissions-trading-system/ED9E775E0B93E173650FD989CA9D9D62> accessed 16 January 2023.
[187] Betz and others (n 84).
[188] Scott, Nellore and Marke (n 181); Zolla, Marke and Mehling (n 186).
[189] Zolla, Marke and Mehling (n 186).
[190] Pu Wang and others, 'Key Challenges for China's Carbon Emissions Trading Program' (2019) 10(5) WIREs Climate Change 1.

4.3 21st Century carbon markets: transparency, efficacy & effectiveness

The challenges and emerging technologies outlined in the previous sections create an opportunity to redesign our conceptual understanding of carbon pricing and the structure and operations of carbon markets. The carbon market reformation must fulfil the economic, financial, political, social, geographic, and environmental dimensions of climate change in order to be deemed successful.[191] Emissions are conceptually difficult since their environmental consequences cannot be traced to a single source or individual. Furthermore, the catalysts of climate change are dispersed throughout a range of industries and therefore it is important that adaptability and scalability be core principles to any policy solution.[192]

Since carbon markets and offsetting require a well-structured foundation to function effectively, an effective carbon market must incorporate six essential components. First, it must establish an efficient financial market to facilitate carbon trading. Second, it should adhere to sound economic principles that ensure market stability and fairness. Third, incentivising global cooperation and encouraging participation from diverse forms of government is crucial for widespread adoption. Fourth, the market must discourage malicious political behaviour that could undermine its integrity. Fifth, upholding ethical standards is essential, including preventing energy injustices, promoting socioeconomic equality, and aligning with the United Nations Sustainable Development Goals (SDGs).[193] Finally, and most importantly, the market must provide a mechanism for achieving the objectives of Paris Agreement Articles 2 and 4 while ensuring compliance with Article 13, which mandates data transparency without infringing on national sovereignty[194].

4.4 Reconceptualising carbon assets and liabilities

To meet these foundational goals, improvements in monitoring, reporting, and verification (MRV) are necessary. This can be achieved through the application of converging technologies such as the Internet of Things (IoT), artificial intelligence (AI), and DLT. These technologies have the potential to create a networked carbon market (NCM) that would function as a global financial market, enhancing transparency and efficiency.[195] However, a fundamental ambiguity in carbon markets lies in the 209tandardized209tion of carbon itself. The Harvard Business Review has described carbon

[191] Yizhang He and Wei Song, 'Analysis of the Impact of Carbon Trading Policies on Carbon Emission and Carbon Emission Efficiency' (2022) 14(16) Sustainability 1; Macinante (n 2); Gareth Bryant, *Carbon Markets in a Climate-Changing Capitalism* (Cambridge University Press 2019) <https://www.cambridge.org/core/books/carbon-markets-in-a-climatechanging-capitalism/2799AE2678141AC4B9C91027EAD63520> accessed 11 January 2023; Benjamin K Sovacool and others, 'Decarbonization and Its Discontents: A Critical Energy Justice Perspective on Four Low-Carbon Transitions' (2019) 155 Climatic Change 581.

[192] Mehling (n 180).

[193] 'Sustainable Development Goals' (*United Nations Development Programme (UNDP)*) <https://www.undp.org/sustainable-development-goals> accessed 5 April 2023.

[194] 'Key Aspects of the Paris Agreement' (n 174).

[195] Macinante (n 2).

as a liability in one article,[196] while referring to carbon credits as an asset in another,[197] highlighting the inconsistencies in market perception. This discrepancy can be resolved through the deployment of an NCM, which would provide a standardised framework for defining and valuing carbon within financial and regulatory systems.

Networked Carbon Markets were originally introduced by the World Bank Group (WBG) in 2013 to allow interjurisdictional carbon trading without infringing on the nationally and regionally instituted carbon markets. Local carbon markets would be able to "opt in" to the interjurisdictional network with minimal conditions. As the concept of NCMs were ahead of its time, today's contemporary technologies were not mentioned in the WBG report.[198] In 2018, Marke introduced the application of DLT to create a NCM[199] while Macinante in 2020 further developed to suggest the converging power of AI and IoT to this carbon trading web.[200] Our policy proposal for creating optimal carbon markets aligns with the six principles outlined above and have three components: carbon pricing reformation, microgrids, and an interjurisdictional network. Their functioning and operations of these three components require DLT, IoT, and AI technologies to ensure the transparency and efficacy of carbon markets.

Carbon as a traded entity is unique in that carbon emissions are a liability while the carbon credits derived from those emissions are traded as assets.[201] Utilising and furthering this concept allows us to define carbon credits as a financial derivative of carbon. When conceptualising carbon in this way, pricing factors can reflect the *true* value of carbon accounting for the quantity of carbon emissions and mitigated; supply and demand; and socioeconomic, economic, and political factors. The price on carbon is not merely the amount of carbon reduced or emitted in quantity, but the quality of that carbon.

This concept of quantity versus quality of carbon reflected in its price is essential for the optimisation of carbon markets and ethical oversight of its functioning. The quantity looks at carbon as a liability and is established as the value per one ton of carbon dioxide equivalent.[202] The quality of carbon pricing fixed into the derivative value of carbon

[196] Robert G Eccles and John Mulliken, 'Carbon Might Be Your Company's Biggest Financial Liability' [2021] *Harvard Business Review* <https://hbr.org/2021/10/carbon-might-be-your-companys-biggest-financial-liability> accessed 5 April 2023.
[197] Alex Rau and Robert Toker, 'Start Thinking About Carbon Assets—Now' [2008] *Harvard Business Review* <https://hbr.org/2008/09/start-thinking-about-carbon-assets-now> accessed 5 April 2023.
[198] 'Globally-Networked Carbon Markets: 1st Working Group Meeting' <https://www.worldbank.org/content/dam/Worldbank/document/SDN/networked-carbon-markets-WG1.pdf> accessed 5 April 2023.
[199] Alastair Marke (ed), *Transforming Climate Finance and Green Investment with Blockchains* (1st edn, Academic Press 2018).
[200] Macinante (n 2).
[201] Eccles and Mulliken (n 196).
[202] 'Carbon Pricing Dashboard' (*World Bank Group*) <https://carbonpricingdashboard.worldbank.org/what-carbon-pricing> accessed 6 April 2023.

credits integrates: (1) *Social Value of Mitigation Activities* (SVMA),[203] (2) economic condition and a sovereignty's degree of contribution to emissions, (3) reliability and transparency rating of a carbon market's jurisdiction, (4) term and stability of mitigation action,[204] (5) and supply and demand of carbon credits within the jurisdiction. These factors are in alignment with Section 108 of the UNFCCC Paris Agreement which states that the Conference of the Parties, "*Recognizes* the social, economic and environmental value of voluntary mitigation actions and their co-benefits for adaptation, health and sustainable development".[205] The price of carbon at a given jurisdiction can be the result of pure supply and demand while the carbon credits' conversion rate between two jurisdictions will reflect the quality of carbon with the listed factors.

4.5 Networked market architectures

If carbon markets are to be maintained despite their fundamental flaws, networked approaches using DLT applications might at least address certain transparency issues, though they would not resolve the deeper problems of misaligned incentives and global inequity. This framework would enable jurisdictions to participate in the networked carbon market and engage in global credit trading while preserving national sovereignty in accordance with Article 13 of the Paris Agreement. Participation would require only acceptance of the network's basic operational terms rather than complex bilateral agreements between countries.[206] These terms can be enforced through "smart contract-based transactions peer-to-peer, in this case, across jurisdiction".[207] Smart contracts enable a consensus and agreement of the conversion rate mechanisms in order to trade over the network between jurisdictions and peer-to-peer (P2P) increasing the efficacy and volume of carbon trading by removing the intermediaries.

While the carbon pricing conversion rates between microgrids would be seamless and transparent with DLT benefits of decentralised data and smart contracts, a growing focus is on the voluntary market, prosumers, and P2P trading.[208] The adaptability of the global NCM to many carbon markets is crucial to developing a truly sustainable and transparent framework for a financial network with the goal of attaining net zero. While a 2016 World Bank report stated that the three major challenges of creating a NCM are allocating of emissions, allowing 'heterogeneity' in the design of connecting carbon markets, and

[203] Jean-Charles Hourcade, Antonin Pottier and Etienne Espagne, 'Social Value of Mitigation Activities and Forms of Carbon Pricing' (2018) 155 International Economics 8.
[204] Scott, Nellore and Marke (n 181).
[205] 'Paris Agreement' (n 108).
[206] 'Key Aspects of the Paris Agreement' (n 174).
[207] Macinante (n 2) 108.
[208] Ju and others (n 181); Weiqi Hua and others, 'A Blockchain Based Peer-to-Peer Trading Framework Integrating Energy and Carbon Markets' (2020) 279 Applied Energy 1.

challenges to the transparency of data.[209] A DLT structured NCM would neutralise the latter two issues. By having infrastructure in place allowing the conversion of carbon units between jurisdictions based on agreed upon methodologies will enable the allocation of emissions with robust accounting to allow for better market efficiency, and private sector and the evolving prosumer market participation.[210] This would allow any jurisdiction to enter the networked carbon market and trade globally while not infringing on national sovereignty in alignment with Article 13[211] while only agreeing to the terms of use allowing "smart contract-based transactions peer-to-peer, in this case, across jurisdiction".[212]

Under this paradigm, individual carbon markets could continue to evolve and govern themselves while being able to participate in the NCM to trade between jurisdictions. Even though the goal of all carbon markets is unified, their local needs are different in terms of who is participating and the most effective implementation. Whether it is individuals trading on the voluntary market or prosumers connected to smart electrical grids or large sector-varying corporations, it is important that jurisdictions create legislation and carbon markets fitting for the users on that carbon market. He and Song suggested the most effective implementation of carbon markets is per industry.[213] Prosumer markets require different legislation and governance than manufacturers to participate in carbon neutralisation.

Microgrids and jurisdictional trading would be connected by the DLT infrastructure, ensuring transparency, accountability, and efficacy of carbon markets.[214] The NCM must consider the varying carbon accounting (reliability) and carbon valuing practices. The NCM would consist of three levels, including interjurisdictional, which contains the five principles above, jurisdictional, which are the independent carbon markets, and the intra-jurisdictional levels containing individual traders, prosumers, consumers, and organisations. The responsibility of the interjurisdictional ledger is to be a registry holding all information from all jurisdictions with transparent oversight and ensure the agreed upon data reporting. Part of the terms agreed to by participants to join the NCM is "accepting the rules, infrastructural arrangements, and other measures".[215] These terms would be the same for any jurisdiction wishing to participate in the NCM and "the agreement is not between jurisdictions, as such, but rather between the joining jurisdiction and the network."[216] This system serves a multitude of functions: (1) minimising misaligned political motivations and imbalance of power in negotiations, (2)

[209] 'The Networked Carbon Markets Initiative' (World Bank Group Climate Change 2016) <https://thedocs.worldbank.org/en/doc/162841457735232763-0020022016/original/NCMinitiativepitchbook.pdf> accessed 16 March 2023.
[210] Macinante (n 2); Hua and others (n 208).
[211] 'Key Aspects of Paris Agreement' (n 174).
[212] Macinante (n 2) 108.
[213] He and Song (n 191).
[214] Macinante (n 2).
[215] ibid 95.
[216] ibid.

allow flexibility for jurisdictions to leave or enter the network without disrupting the carbon price or functioning of the network, (3) transference of carbon credits would not be necessary and result in less accounting fiascos.

Ideally, the network will be fully distributed throughout all individual participants and allow for full transparency. This means all historical transactions within the jurisdictions across the network would be accessible by all parties and even the public. However, multiple technical challenges occur when attempting a fully distributed system regarding computing, memory, and processing capacity; and the incongruency of updating times between nodes in geographically different places. This last aspect becomes increasingly important as the network grows.[217]

Currently, two solutions to the technological limitations are mentioned. First, is the integration of 6G in the carbon market supply chain, which is expected to be rolled out for commercial use within the decade. Compared to 5G, it would allow for 50x the data rate and 100x the mobile traffic capacity, and large blockchain connected networks to function seamlessly.[218] Another potential solution is to have full transactional histories stored at the administrator or jurisdictional level while at the individual level holds only historical transactions up to a certain backdate[219] or only in the jurisdiction.

NCM is a solution to the current weaknesses inherent in the design of carbon trading and offsetting. By taking advantage of emerging technologies in AI, DLT, and IoT, carbon markets would be able to function independently while interacting seamlessly. Here we further the idea of NCM. The core idea of integrating emerging technologies into the markets is to increase the MRV for transparency.[220]

The process begins with tracking and monitoring carbon emissions and mitigation activities through sensor technology in the IoT. These technologies can be satellite imagery in combination with AI,[221] smart meters, and aerial imagery with computer vision.[222] DLT cannot guarantee the credibility of the data collected, only the security and transparency of what is collected.[223] After collecting reliable data, it is held on the DLT infrastructure to ensure robust accounting. AI will filter information and crosscheck it throughout the tamperproof network in order to avoid double counting and fraudulent activities.[224] Using smart contracts for transactions of carbon credits through different jurisdictions on the DLT will allow track record keeping. Altogether these technologies will enable the next century carbon market and offsetting.

[217] Macinante (n 2).
[218] Dinh C Nguyen and others, '6G Internet of Things: A Comprehensive Survey' (2022) 9 IEEE Internet of Things Journal 359.
[219] Macinante (n 2).
[220] World Bank (n 164).
[221] Rosales and others (n 166).
[222] Toews (n 171).
[223] Marke, Inglis and Markides (n 178).
[224] Mehling (n 180).

Succinctly: The integration of Distributed Ledger Technology, artificial intelligence, and the Internet of Things into carbon markets presents a transformative opportunity to address longstanding challenges in transparency, efficiency, and scalability. NCMs build upon previous efforts by the World Bank Group and recent advancements in emerging technologies to create an interjurisdictional framework that enhances market functionality without infringing on national sovereignty. By establishing a decentralised yet interconnected system, the NCM would enable seamless carbon trading while maintaining jurisdictional autonomy and ensuring robust monitoring, reporting, and verification.

Through smart contracts and decentralised infrastructure, the NCM offers a solution to existing inefficiencies, including political imbalances, fraudulent trading practices, and inconsistent carbon valuation methodologies. The ability to differentiate between carbon as a liability and carbon credits as assets enhances the market's ability to price carbon more accurately based on both quantity and quality. Additionally, the system's adaptability ensures that various stakeholders—from governments and corporations to prosumers and individual traders—can participate effectively.

As carbon markets continue to evolve, the integration of advanced technologies like 6G and AI-driven verification will further enhance market reliability and scalability. By leveraging a fully transparent and tamper-proof DLT infrastructure, carbon markets can transition toward a more accountable, secure, and equitable trading system that aligns with the objectives of the Paris Agreement and the United Nations Sustainable Development Goals (SDGs).

For technological solutions to effectively transform carbon markets, they must be accompanied by coordinated regulatory reforms across three domains. First, standardisation of verification protocols through an international body similar to the IPCC could establish clear, science-based criteria for carbon credit validation. This would include consistent methodologies for establishing baselines, measuring additionality, and quantifying leakage effects across all market mechanisms. Second, harmonised legal frameworks must clarify the legal status of carbon assets, define liability for verification failures, and establish cross-jurisdictional enforcement mechanisms. This requires development of model legislation that countries can adopt with appropriate local modifications while maintaining core principles. Such frameworks should explicitly address the legal status of digitally-verified carbon credits, recognise smart contracts in carbon transactions, and establish clear recourse mechanisms for disputes. Third, governance reforms must shift from purely market-based oversight toward hybrid public-private governance structures with meaningful participation from affected communities. This includes establishing independent verification authorities with proper resources, whistleblower protections for reporting fraud, and transparent processes for challenging credit validity. These reforms should be phased in gradually with appropriate transition periods to avoid market disruption while ensuring steady progress toward improved integrity.

Beyond these broad regulatory directions, specific governance architectures are needed to operationalise the oversight of technological solutions in carbon markets. Effective implementation of technological solutions requires governance structures specifically designed to align technological capabilities with market integrity goals.

We propose a three-tiered governance framework to ensure technology actually improves carbon market outcomes rather than simply digitising existing problems. At the technical layer, open standards bodies comprising climate scientists, technology experts, and market participants should develop and maintain protocols for monitoring, reporting, and verification. These standards must include rigorous data quality requirements, interoperability specifications, and minimum performance criteria for verification systems. Critical to this layer is the requirement that all verification algorithms be transparent and auditable, avoiding "black box" solutions that obscure decision-making. At the market operation layer, independent certification authorities should evaluate technological solutions against these standards, with rotational oversight to prevent regulatory capture. These authorities would be empowered to suspend non-compliant systems and require regular security audits. Importantly, this layer should include mandatory transparency requirements for all verification decisions, including machine learning audit trails. At the accountability layer, a combination of judicial oversight, civil society monitoring, and affected community representation should provide checks and balances on the entire system. This includes specialised arbitration mechanisms for disputes, regular public reporting requirements, and formal channels for indigenous and local communities to challenge credits that affect their territories. By ensuring technology serves climate goals rather than merely creating new profit centres, this governance framework transforms carbon markets into genuine climate solutions rather than technological shortcuts around fundamental market flaws.

4.6 Implementation and technical challenges

While technological and governance innovations offer promising pathways for carbon market reform, a clear-eyed assessment of their limitations is essential for realistic implementation. Despite their potential, distributed ledger technologies and other digital solutions face significant hurdles that must be addressed through coordinated global action.

Implementation challenges include technical and structural barriers. The energy consumption of proof-of-work blockchain protocols presents an ironic contradiction for climate-focused applications, though newer consensus mechanisms are substantially reducing this footprint. More fundamentally, the "garbage-in, garbage-out" problem persists: while blockchain ensures data immutability, it cannot independently verify the accuracy of input data from physical monitoring systems. This limitation is particularly relevant for carbon markets where verification of real-world emissions reductions remains problematic.

Regulatory and accessibility barriers further complicate adoption. Significant legal uncertainty persists regarding the status of smart contracts and blockchain-based carbon assets across jurisdictions. Additionally, the infrastructure and technical expertise required for implementation may create new forms of inequality, potentially excluding developing nations with limited digital infrastructure—the very countries that should benefit most from improved carbon market mechanisms. The substantial cost of transitioning existing markets to DLT systems requires coordination among numerous stakeholders with competing interests.

Addressing these challenges demands a comprehensive approach including thoughtful governance frameworks, technical standards development, capacity building initiatives, and regulatory clarity. Success ultimately depends on ensuring that technological solutions enhance market integrity rather than merely digitising existing inequities, while promoting a just and sustainable economic framework for meaningful climate action.

4.7 Policy recommendations for carbon market reform

Based on our analysis of structural flaws in current carbon trading systems, we propose the following concrete policy recommendations for key stakeholders. Drawing on our analysis of carbon market structural deficiencies, we propose targeted interventions across international, national, and private sector domains.

At the international level, we advocate establishing a unified blockchain-based global carbon registry to prevent double-counting, implementing standardised science-based additionality methodologies that accommodate regional contexts, and mandating environmental justice assessments for significant offset projects. National regulators should implement progressively rising carbon price floors (5% annually above inflation) to incentivise direct emissions reductions, create regulatory sandboxes for verifying new monitoring technologies against gold-standard measurements, and develop clear liability frameworks that distribute responsibility proportionally among verifiers, developers, and credit purchasers. For market participants, we recommend adopting tiered disclosure requirements (Platinum/Gold/Silver/Bronze) based on verification strength and co-benefits, committing to phase out low-quality credits by 2027 with clear interim targets, and establishing a technology transfer fund (funded by at least 2% of transaction value) to ensure developing nations can access advanced monitoring capabilities. These recommendations work synergistically to address verification challenges, market integrity concerns, and ethical considerations while recognising stakeholders' differing capacities and responsibilities—ultimately transforming carbon markets into more effective climate mitigation instruments.

4.8 Addressing potential counterarguments

Our analysis has presented a critical assessment of carbon market flaws, but several counterarguments deserve serious consideration. First, proponents may argue that despite their imperfections, carbon markets remain the most politically feasible mechanism for pricing carbon in many jurisdictions. They contend that theoretical perfection should not be the enemy of practical progress, and that incremental improvements within market frameworks are more realistic than wholesale alternatives.

While we acknowledge the political constraints, our analysis demonstrates that flaws in current carbon markets are structural rather than incidental, requiring fundamental reforms rather than mere technical adjustments. Second, some may argue that technological fixes like blockchain-based monitoring can resolve most verification challenges without requiring deeper market restructuring. This techno-optimism, while understandable, underestimates how technological solutions themselves are shaped by existing power dynamics and market incentives. Without corresponding governance reforms, technologies may simply entrench existing inequities with a veneer of digital certainty. Technology can enable verification improvements, but cannot substitute for proper institutional oversight.

Third, defenders of current carbon market frameworks might point to successful emissions reductions in specific sectors or regions as evidence that markets can work effectively. The EU ETS, for instance, has contributed to emissions reductions in the power sector after initial design flaws were addressed. However, these limited successes must be weighed against the broader pattern of verification failures, perverse incentives, and environmental justice concerns documented in our analysis. Sector-specific successes do not negate systemic problems across global carbon markets.

Finally, some economists may contend that market inefficiencies will naturally correct themselves as carbon prices rise and participants demand greater integrity. This view overstates markets' self-correcting capabilities in the context of fundamental information asymmetries, regulatory fragmentation, and power imbalances that characterise current carbon trading systems. The climate crisis demands more deliberate, equity-centred reforms rather than faith in eventual market corrections. By addressing these counterarguments directly, we strengthen our case for comprehensive carbon market reform while acknowledging legitimate concerns about implementation challenges.

The evidence examined in this paper suggests that carbon markets in their current form function primarily as financial mechanisms that enable continued emissions rather than as instruments for meaningful climate action. While technological and governance reforms may improve certain aspects, addressing climate change will require moving beyond market-based approaches to more direct regulatory interventions and fundamental economic transformation. The path forward lies not in abandoning market mechanisms entirely, but in transforming them from potentially exploitative financial instruments into genuine tools for climate mitigation and environmental justice.

5 Conclusions and future outlook

Current carbon market frameworks exhibit critical structural limitations that compromise their effectiveness as climate change mitigation tools. Our analysis identifies three interconnected challenges undermining market integrity: regulatory fragmentation creating enforcement gaps, verification deficiencies compromising credit quality, and inequitable distributional impacts. These issues represent fundamental tensions between market-driven approaches and environmental imperatives, revealing systemic contradictions that require integrated solutions.

The ethical dimensions of carbon markets are particularly concerning. Our research demonstrates how existing frameworks disproportionately burden developing nations, perpetuating global inequities rather than addressing them. While equity considerations demand that developed countries shoulder a larger share of emissions reductions due to their historical responsibility, environmental effectiveness necessitates broader participation, including from developing nations whose rising emissions are increasingly significant.[225] Carbon offset projects in the Global South often prioritise economic expediency over meaningful environmental progress and social justice, undermining the markets' purported objectives.

Our policy recommendations focus on three essential domains: regulatory harmonisation, technological integration, and ethical oversight. Carbon markets operate at the nexus of environmental science, legal frameworks, market economics, and ethical considerations—with tensions between these domains creating vulnerabilities that compromise effectiveness. The identified regulatory inconsistencies raise fundamental questions about governing atmospheric commons across jurisdictional boundaries, while verification challenges reveal epistemological concerns about measuring counterfactuals in complex socio-ecological systems.

These challenges require a coordinated approach. Regulatory reforms without technological innovation lack enforcement capacity; technological solutions without ethical frameworks risk digitising—rather than resolving—injustice; and ethical considerations without implementation mechanisms remain aspirational. The path forward demands an integrated approach recognising these interdependencies.

Three promising directions for carbon market evolution emerge: First, "nested governance" models connecting local, national, and international regulatory frameworks while respecting sovereignty could address jurisdictional challenges while creating coherent verification standards. Second, advanced monitoring technologies integrated

[225] Daniel Bodansky, Jutta Brunnée, and Lavanya Rajamani, *International climate change law* (Oxford University Press 2017).

with transparent governance frameworks could transform verification processes, creating socio-technical systems where technology enhances rather than replaces human oversight. Third, reconceptualising carbon credits as instruments of climate justice could fundamentally alter market dynamics by incorporating equity and historical responsibility into credit valuation.

Carbon market transformation must be understood within broader sustainable economic transitions. While market mechanisms have roles to play, they require robust governance frameworks aligning financial incentives with environmental and social objectives, moving beyond narrow carbon pricing efficiency toward deeper questions of economic institutions supporting climate stability and global equity.

As climate impacts intensify and net-zero commitments proliferate, the importance of carbon markets will only grow. The critical challenge is ensuring they become instruments of genuine climate action rather than vehicles for environmental commodification. While emerging technologies such as blockchain and AI-enhanced monitoring offer promising tools for improving transparency and efficiency, they cannot substitute for coherent regulation or ethically grounded governance. Policy reform must prioritise enforceable standards, inclusive oversight, and equitable participation—especially for stakeholders in the Global South. Ultimately, the legitimacy of carbon markets will depend on whether they can evolve from transactional instruments into frameworks that balance environmental integrity, global justice, and long-term climate stability.