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REPORT

THE CARBON AT RISK MEASURE AND CARBON REMOVAL MARKETS

Photograph: Joshua Woroniecki, Unsplash

This paper addresses a central bottleneck in scaling carbon dioxide removal (CDR): how to measure, compare and manage the risks associated with different carbon removal approaches in a way that is credible to investors, policymakers and regulators. Existing carbon markets often rely on binary classifications such as 'permanent' versus 'non-permanent' or 'nature-based' versus 'engineered', which obscure meaningful differences in risk and discourage investment.

Authored by:

Lee et al. (2025), Working paper.

University of Exeter Business School

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The Carbon at Risk Measure and Carbon Removal Markets

Research and policy question

This paper addresses a central bottleneck in scaling carbon dioxide removal (CDR): how to measure, compare and manage the risks associated with different carbon removal approaches in a way that is credible to investors, policymakers and regulators. Existing carbon markets often rely on binary classifications such as 'permanent' versus 'non-permanent' or 'nature-based' versus 'engineered', which obscure meaningful differences in risk and discourage investment. The core policy question is how carbon removal risks can be quantified using a common, continuous metric that enables portfolio construction, risk management and large-scale finance while maintaining climate integrity.

Methodological approach

The authors introduce Carbon at Risk (CaR), a quantitative metric inspired by Value at Risk (VaR) in financial markets. CaR measures the maximum expected loss of carbon removal, relative to a target, at a given confidence level and time horizon. Formally, CaR answers the question: in X% of future states of the world, what is the maximum shortfall in carbon stored compared to what was promised? The framework operates in physical units (kg or tonnes of CO_2) rather than monetary values and can be applied consistently across diverse removal technologies. The paper demonstrates how CaR can be operationalised using probabilistic modelling, historical data, mechanistic models and Monte Carlo simulations, with examples spanning forest carbon projects and engineered geological storage.

Findings

The analysis shows that all carbon removal approaches involve both delivery risk (whether carbon is removed as planned) and storage risk (whether it remains stored over time), and that these risks differ substantially across technologies and locations. Using forest carbon as an example, the paper demonstrates how fire risk and regrowth dynamics generate widely varying CaR profiles across regions, and how risk accumulates over longer time horizons. For geological storage, modelling exercises show that CaR depends strongly on regulatory quality and site integrity. Importantly, the paper demonstrates that portfolio diversification—across projects and across technologies—can substantially reduce CaR, mirroring core insights from financial portfolio theory. Portfolios combining low-risk, high-cost technologies with higher-risk, lower-cost options can meet durability targets with high confidence while reducing overall costs.

Policy implications

Carbon at Risk provides a practical foundation for risk-based governance of carbon removals. By replacing binary notions of permanence with probabilistic risk assessment, CaR enables regulators to define acceptable risk thresholds while allowing flexibility in how risks are managed. This has direct applications for integrating removals into emissions trading systems, designing buffer pools, sizing financial reserves and pricing insurance against reversals. For investors and buyers, CaR enables transparent comparison of projects and construction of resilient carbon portfolios that balance cost, risk and expected climate impact. More broadly, the framework supports a transition from static certification towards dynamic, continuously updated risk tracking, improving accountability and supporting the scale-up of carbon removal finance needed to meet net-zero and net-negative targets.

The Carbon at Risk tool has been developed with the objective of allowing users to evaluate the risks associated with their portfolios of carbon removal technologies based on the latest understanding of the risks of these technologies. This can be seen at www.carbonatrisk.org.

Links and materials

Lee, B. et al. (2025). The Carbon at Risk measure can unlock financial markets for large-scale carbon removal: https://www.researchsquare.com/article/rs-7714530/v1

Carbon at Risk platform and tools:
https://www.carbonatrisk.org

Code and data repository:
https://github.com/BenGroom/CarbonAtRisk

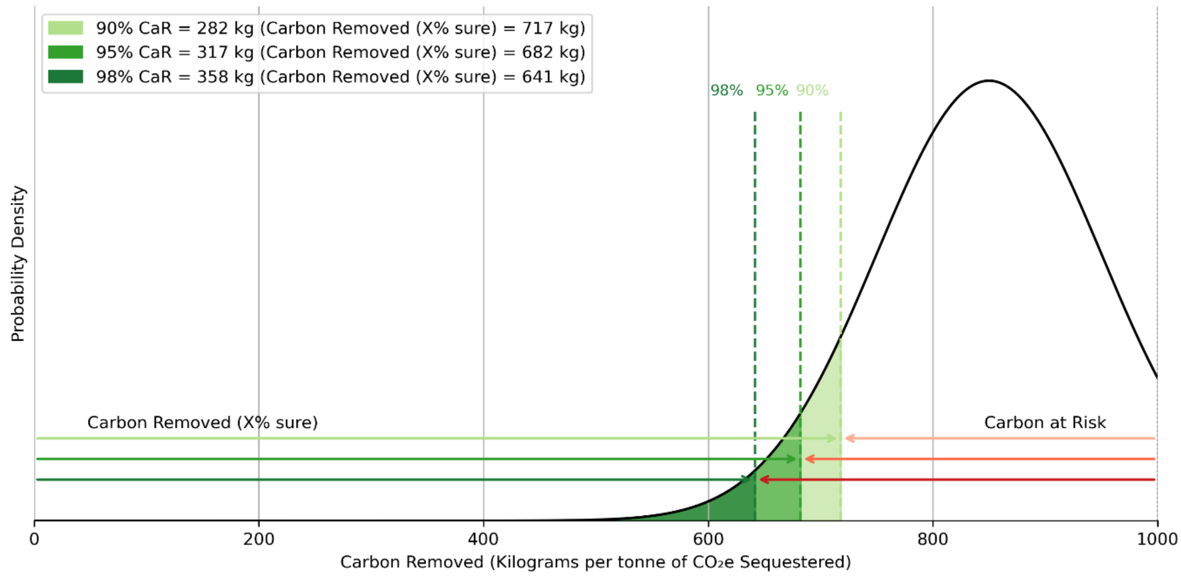

Figure 1. Financial Value at Risk (VaR) and physical Carbon at Risk (CaR) and its complement: X% sure Carbon Removed.

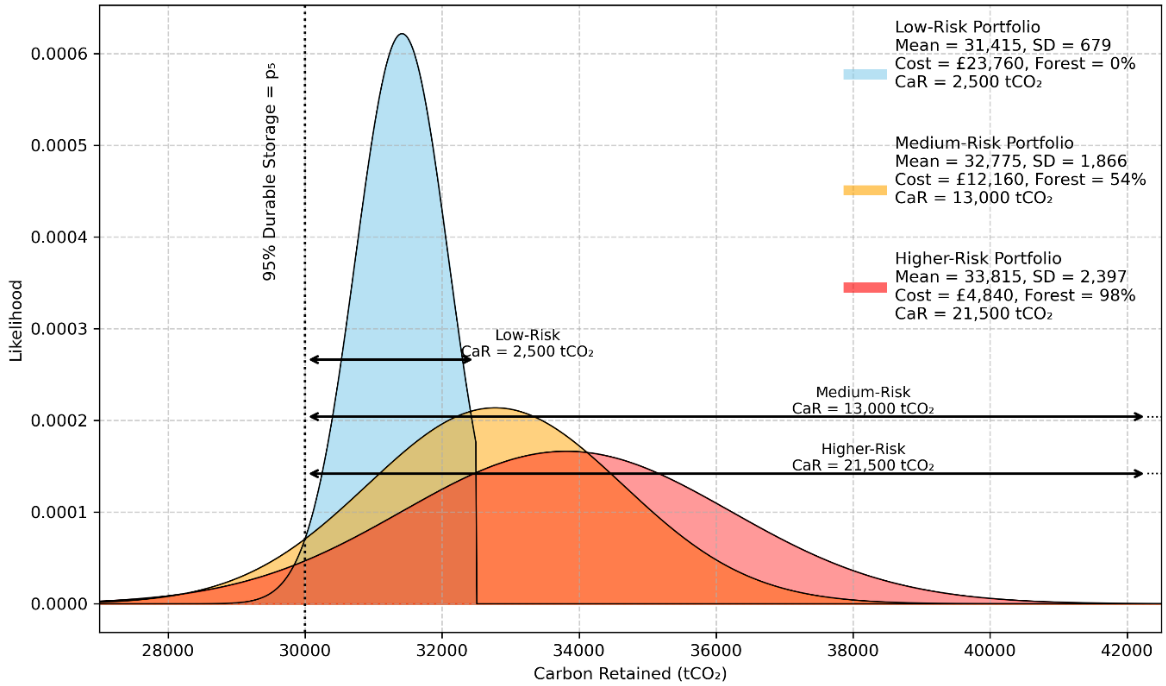

Figure 2. Three Portfolios with 95% durable carbon after 200 years of 30000 tonnes.

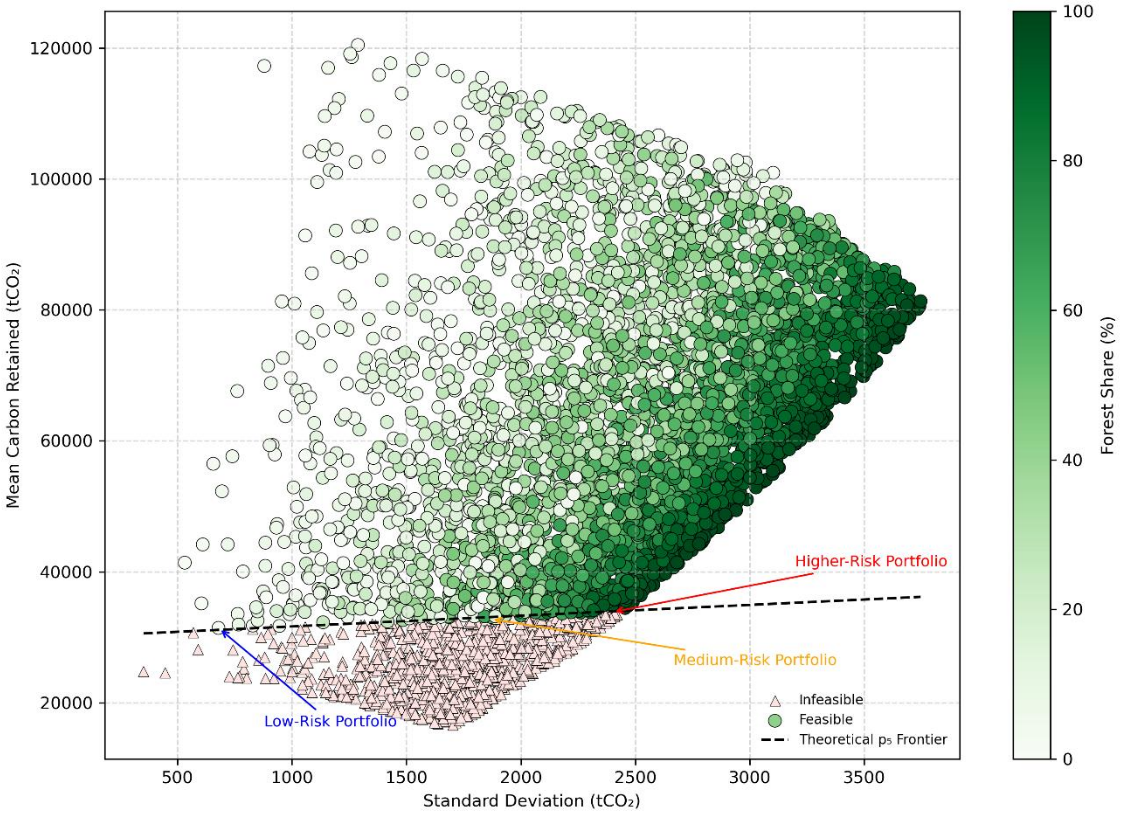

Figure 3. The universe of portfolios with 95% durable carbon after 200 years of 30000 tonnes.

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Economic Policy Decision Making for Biodiversity

Dragon Capital Chair
Xfi Building
University of Exeter Business School
Rennes Drive
Exeter
EX4 4PU

www.dragonchair.org.uk
b.d.groom@exeter.ac.uk

University of Exeter Business School

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