Carbon at Risk (CaR): A Framework for Quantitative Risk Assessment in Carbon Removal

The challenge

Carbon dioxide removal must scale from today's 1.35 million tonnes to 7-10 billion tonnes annually by 2050 to meet Paris climate goals. Current binary frameworks ("permanent" vs "non-permanent") fail to communicate actual risk profiles, preventing meaningful comparison between solutions and potentially excluding viable methods. Properly managing and pricing these risks enables investment across all approaches based on risk-adjusted value, expanding capital for the diverse portfolio needed to reach climate-impactful scale

The CaR framework

Inspired by Value at Risk (VaR) in financial markets, Carbon at Risk (CaR) provides a quantitative metric to assess carbon removal projects across approaches and time horizons. CaR addresses two fundamental dimensions: delivery risk (will carbon be removed when promised?) and storage risk (will it stay removed?). Delivery risk is anticipated to diminish over time as technologies mature from pilot demonstrations to established deployments, while storage risk remains a persistent consideration throughout a project's lifetime.

Definition: CaR measures anticipated carbon dioxide losses (kg/tonne or %) over specified time horizons (1, 10, 100, 1000 years) in 95% of scenarios.

Example: A CaR value of 15kg/tonne over 100 years means in 95% of cases, less than 15kg per tonne of CO_2 should be lost, representing minimum anticipated storage of 98.5% of targeted carbon. This enables meaningful comparison while accounting for both removal timing and storage duration.

Key features and benefits

CaR comprehensively assesses both delivery and storage risks using statistical methods across multiple time horizons. Unlike static binary frameworks, it creates accountability through measurable outcomes that can be tracked and updated. This iterative approach allows CaR scores to be refined based on actual performance, enabling stakeholders with different risk tolerances to make informed decisions while creating clear liability frameworks. Risks can be managed through mechanisms like insurance and buffer pools, creating a common language for risk management across the carbon removal ecosystem

Practical applications

Risk management

CaR standardises risk communication and enables sophisticated infrastructure essential for scaling carbon removal. By looking at risk over the lifespan of a project, It supports creation of insurance products and buffer pools calibrated to project-specific risks, facilitating risk allocation across the value chain. When projects underperform, CaR provides clear mechanisms for like-for-like credit replacement based on comparable risk profiles.

Strategic deployment

Since no single approach can meet climate goals, CaR enables construction of balanced portfolios across different risk profiles, optimising investments across urgency, durability, and cost. This quantitative understanding allows organizations to calculate climate impact across different time horizons and plan technology transitions as solutions mature.

Policy development

CaR bridges voluntary and compliance markets through a common quality assessment framework. Rather than fixed permanence thresholds, this approach enables evidence-based entry criteria for compliance markets that incentivize improvement. Most importantly, CaR transforms carbon accounting from uncertain claims to probability-weighted outcomes that better reflect actual atmospheric impact.

Empirical examples

Our research demonstrates CaR's practical application across diverse carbon removal approaches. For forest carbon projects, CaR reveals significant performance variations across regions: California forests show a CaR of 788 kg/tC over 100 years due to high fire risk and low regrowth rates, while Indonesia-Papua forests demonstrate just 47 kg/tC over the same period thanks to low fire risk and rapid tropical regrowth.

For engineered solutions like direct air capture, CaR quantifies how infrastructure improvements reduce risk. Our analysis shows that modern pipeline infrastructure reduces leakage risk by 51% in distribution networks, demonstrating the substantial benefits of targeted investments in risk reduction.

Transformative potential

CaR represents a fundamental shift from binary thinking to probability-based assessment in climate action. It enables the sophisticated portfolio diversification strategies that have transformed other markets, offering the "free lunch" of risk reduction through uncorrelated project investment. By establishing the financial infrastructure necessary for institutional investment, CaR can help unlock the trillion-dollar capital flows needed for gigaton-scale carbon removal. Most importantly, it creates a race to the top where continuous improvement is rewarded across both timing and storage dimensions, driving the innovation we need to meet our climate goals.