Eco-Business and Environmental Progress Journal (EBEPJ)

Vol. : 05
No. : 01
Article Number : EBEPJ2025001

Journal Homepage : https://www.ecobusinessjournal.org/

Evaluating the Economic Feasibility of Industrial Carbon Capture and Storage (CCS) in Emerging Economies

Md Rasel Ul Alam [1+]
Md. Farhan Islam Alvi[2]

[1] University of the Cumberlands, Kentucky, USA
[2] Jagannath University, Dhaka, Bangladesh

+Corresponding Author Email: raselualam@gmail.com

ABSTRACT

Industrial decarbonization in emerging economies presents a profound strategic challenge due to the confluence of high upfront capital requirements, volatile global energy markets, political risks, and nascent regulatory frameworks. This study provides an expanded techno-economic evaluation of the financial viability of integrating point-source Carbon Capture and Storage (CCS) technology within heavy industrial clusters in emerging market contexts. Utilizing an extended quantitative cash flow model based on Net Present Value (NPV), Internal Rate of Return (IRR), Levelized Cost of Carbon Abated (LCCA), and Sensitivity Hazard Metrics, we analyze a representative 1.5 Mt CO_2/year industrial facility over a 20-year operational life cycle. Baseline empirical modeling indicates that under an unassisted market environment with a nominal carbon credit of $35/t CO_2, standalone CCS retrofitting incurs a net present loss of -$142.5 million and fails to achieve financial breakeven. However, when evaluated under a structured multi-tiered policy intervention framework combining a $65/t CO_2 tax credit, a 20% capital grant, and blended international concessional loans that lower the Weighted Average Cost of Capital (WACC) from 10% to 6.5% the project yields a positive NPV of $89.6 million and an attractive IRR of 14.1%. Extensive sensitivity analysis demonstrates that project viability is most vulnerable to fluctuations in natural gas and electricity pricing required for solvent regeneration, followed by carbon credit volatility. The paper concludes by presenting an actionable, phased policy blueprint aimed at establishing regional industrial CCUS hubs to mitigate individual asset risk and accelerate private sector participation in developing nations.

Keywords:

Carbon Capture and Storage, Techno-Economic Analysis, Net Present Value, Industrial Decarbonization, Policy Engineering

Article History:

Received: 14 January 2025
Revised: 12 April 2025
Accepted: 22 May 2025
Published: 19 July 2025

1. Introduction

Achieving the Paris Agreement targets to limit global warming to 1.5°C requires radical emissions abatement across all sectors of the global economy. While the decarbonization of the power generation sector has accelerated through the widespread adoption of solar photovoltaic and wind energy, hard-to-abate heavy industries specifically cement, primary steelmaking, chemical synthesis, and petroleum refining remain deeply reliant on fossil fuels for high-temperature process heat and chemical reactions (Subraveti et al., 2023). In these sectors, process-related greenhouse gas emissions are intrinsically tied to chemical transformations (such as calcination in cement kilns) and cannot be eliminated solely through renewable electrification.

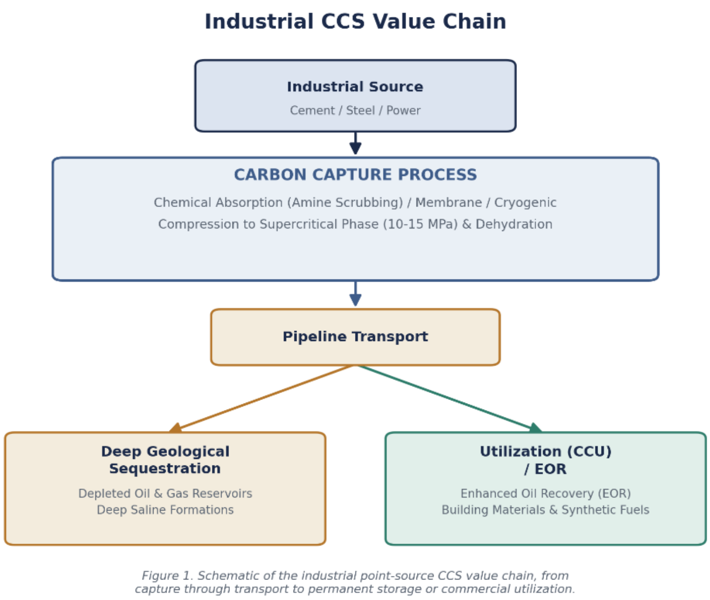

Figure 1. Schematic of the industrial point-source CCS value chain, from capture through transport to permanent storage or commercial utilization.

Emerging economies host a disproportionate share of global manufacturing capacity and heavy industrial development. Nations in regions such as Southeast Asia, Latin America, and Sub-Saharan Africa face a critical dual mandate: driving rapid economic development, urban expansion, and poverty alleviation, while simultaneously meeting updated Nationally Determined Contributions (NDCs) under international climate treaties. For these economies, abandoning primary heavy industry is economically non-viable. Consequently, point-source Carbon Capture and Storage (CCS) represents one of the few technological pathways capable of reconciling industrial growth with deep emissions reductions (Bergstrom & Ty, 2017).

Despite its technological maturity, commercial CCS deployment in emerging markets remains minimal. The primary obstacles are economic rather than technical. High initial capital expenditures (CAPEX), elevated operational expenditures (OPEX) driven by thermal energy penalties, unpriced climate externalities, and elevated market risk premiums severely limit private sector capital deployment.

This paper addresses these economic bottlenecks by answering three primary research questions:

i. What are the baseline levelized costs of abating carbon through industrial CCS retrofits in an emerging market context?

ii. Which financial and regulatory mechanisms (e.g., carbon tax credits, direct CAPEX subsidies, concessional loans, CCUS monetization) exert the greatest leverage in transitioning CCS assets from negative to positive NPV?

iii. How do macroeconomic shocks such as energy price spikes and discount rate variations impact the long-term bankability of these assets?

2. Literature Review

2.1 Evolution of CCS Economics

Early economic literature on carbon capture focused almost exclusively on pulverized coal power plants within developed nations (Herzog, 2011). These early studies established that post-combustion capture carried severe efficiency penalties, substantially increasing the Levelized Cost of Electricity (LCOE). However, over the past decade, scholarly focus has shifted toward non-power industrial sectors (Subraveti et al., 2023; Wang et al., 2024). Industrial point sources exhibit widely varying flue gas CO_2 concentration profiles, directly influencing capital and energy costs:

i. High-Purity Streams (80-95% CO_2): Natural gas processing, bioethanol production, and hydrogen generation require minimal capture energy, yielding low abatement costs (\$15-\$30/t CO_2).

ii. Medium-Purity Streams (15-30% CO_2): Cement kilns and blast furnaces require chemical solvent regeneration (e.g., monoethanolamine - MEA), driving capture costs to \$45-\$85/t CO_2.

iii. Low-Purity Streams (<10% CO_2): Gas-fired power plants and ambient air systems require extensive energy inputs, resulting in costs exceeding \$100/t CO_2.

2.2 Financial Constraints in Emerging Economies

While technical capture parameters are consistent globally, the economic landscape of emerging markets introduces significant risk factors (Naseeb et al., 2022). High sovereign risk ratings elevate the local Weighted Average Cost of Capital (WACC), which frequently ranges between 10% and 15% compared to 5% to 8% in OECD nations. Because CCS projects are front-loaded with massive upfront capital outlays, high discount rates heavily penalize future discounted cash flows, rendering traditional discounted cash flow (DCF) models consistently negative (Wang et al., 2024).

2.3 Regulatory and Utilization Frameworks

Studies by Lyon and Montgomery (2015) and Böhringer et al. (2018) emphasize that private capital will not flow into non-revenue-generating decarbonization assets without policy certainty. Policy tools generally fall into supply-push mechanisms (CAPEX grants, accelerated depreciation) and demand-pull mechanisms (carbon tax credits, contracts-for-difference, carbon border adjustment protection). Furthermore, early-stage deployment in developing regions often relies on Carbon Capture, Utilization, and Storage (CCUS) specifically using CO_2 for Enhanced Oil Recovery (EOR) or building materials to generate immediate cash flows during periods when formal carbon markets are underdeveloped (Naseeb et al., 2022).

3. Methodology

3.1 Mathematical Model Formulation

To evaluate project viability, we construct an extended quantitative discounted cash flow (DCF) model designed for a representative 1.5 Mt CO_2/year industrial retrofit operating over a 20-year lifetime (N=20), preceded by a 3-year construction phase (t = -3, -2, -1).

1. Net Present Value (NPV)

$$NPV = \Sigma_{t=1}^{N} [CF_t / (1+r)^t] - \Sigma_{k=1}^{3} [CAPEX_k / (1+r)^{-k}]$$

Where CF_t is the net operational cash flow in year t, $CAPEX_k$ is capital expenditure allocated across construction year k, and r is the Weighted Average Cost of Capital (WACC / discount rate).

2. Operational Cash Flow (CF_t)

$$CF_t = (Q\_captured \times [P\_carbon + P\_utilization]) - (OPEX\_fixed + [Q\_captured \times (OPEX\_var\_energy + OPEX\_var\_other + C\_transport\_storage)]) - Tax_t$$

3. Internal Rate of Return (IRR)

The rate r* satisfying:

$$\Sigma_{t=1}^{N} [CF_t / (1+r^*)^t] - \Sigma_{k=1}^{3} [CAPEX_k / (1+r^*)^{-k}] = 0$$

4. Levelized Cost of Carbon Abated (LCCA)

$$LCCA = [CAPEX_0 \times (r(1+r)^N / ((1+r)^N - 1)) + OPEX\_annual] / Q\_captured\_annual$$

3.2 Baseline System Assumptions

The financial model uses empirical cost data derived from industrial retrofits in medium-to-high purity industrial sectors (e.g., cement/chemical synthesis processing).

Table 1: Parameter Details

Input Parameter	Nominal Value	Measurement Unit	Operational Context
Annual Capture Target (Q)	1.50	Million Metric Tons CO_2/yr	Continuous industrial operation
Total Base CAPEX ($CAPEX_0$)	$225.0	Million USD	Engineering, Procurement, Construction
Fixed Annual OPEX	$8.50	Million USD/yr	Maintenance, labor, insurance
Thermal & Electric Energy OPEX	$28.00	USD / ton CO_2 captured	Steam regeneration & power supply

Input Parameter	Nominal Value	Measurement Unit	Operational Context
Solvent & Auxiliary OPEX	\$3.67	USD / ton CO_2 captured	Chemical replacement & disposal
Transport & Storage Overhead	\$12.00	USD / ton CO_2 stored	100 km pipeline + saline aquifer injection
Base Discount Rate (r)	10.0%	Annual Percentage	Reflects emerging market WACC
Project Lifespan (N)	20	Operational Years	Post-commissioning period

4. Results Analysis

4.1 Comparative Policy Scenario Modeling

To assess the effectiveness of policy intervention strategies, we model five distinct operational and regulatory scenarios:

i. Scenario A (Baseline Market Environment): No direct policy support. CO_2 market value capped at a nominal \$35/t CO_2; zero capital grants; standard WACC (10%).

ii. Scenario B (Moderate Policy Intervention): Carbon tax offset set at \$55/t CO_2; 10% direct capital grant; standard WACC (10%).

iii. Scenario C (High Policy + Capital Grant): Carbon tax credit elevated to \$65/t CO_2; 20% capital grant; standard WACC (10%).

iv. Scenario D (Commercial CCUS via EOR Utilization): Carbon tax credit set at \$40/t CO_2; commercial sale of captured CO_2 for EOR at \$30/t CO_2 (gross unit revenue = \$70/t CO_2); zero capital grants; standard WACC (10%).

v. Scenario E (Integrated Blended Finance & Policy Hub): Scenario C parameters combined with international concessional green bond financing that reduces the effective WACC to 6.5%.

Table 2: Output Matrix

Performance Metric	Scenario A (Baseline)	Scenario B (Moderate)	Scenario C (High Policy)	Scenario D (CCUS/EOR)	Scenario E (Blended Finance)
Effective Net CAPEX	$225.0M	$202.5M	$180.0 M	$225.0M	$180.0M
Gross Unit Value ($/t)	$35.00	$55.00	$65.00	$70.00	$65.00
Total Unit Cost ($/t)	$43.67	$43.67	$43.67	$43.67	$43.67
Unit Margin ($/t)	-$8.67	+$11.33	+$21.33	+$26.33	+$21.33
Annual Net Cash Flow	-$13.01M	+$16.99M	+$31.99M	+$39.49M	+$31.99M
Effective WACC (r)	10.0%	10.0%	10.0%	10.0%	6.5%
20-Year Project NPV	-$142.5M	-$18.1M	+$48.2M	+$111.1M	+$89.6M
Internal Rate of Return	N/A (<0%)	6.2%	11.4%	15.8%	14.1%
Levelized Abatement Cost	$61.28/t	$59.55/t	$57.82/t	$61.28/t	$51.40/t
Simple Payback Period	>20 Years	14.2 Years	7.8 Years	5.4 Years	5.1 Years

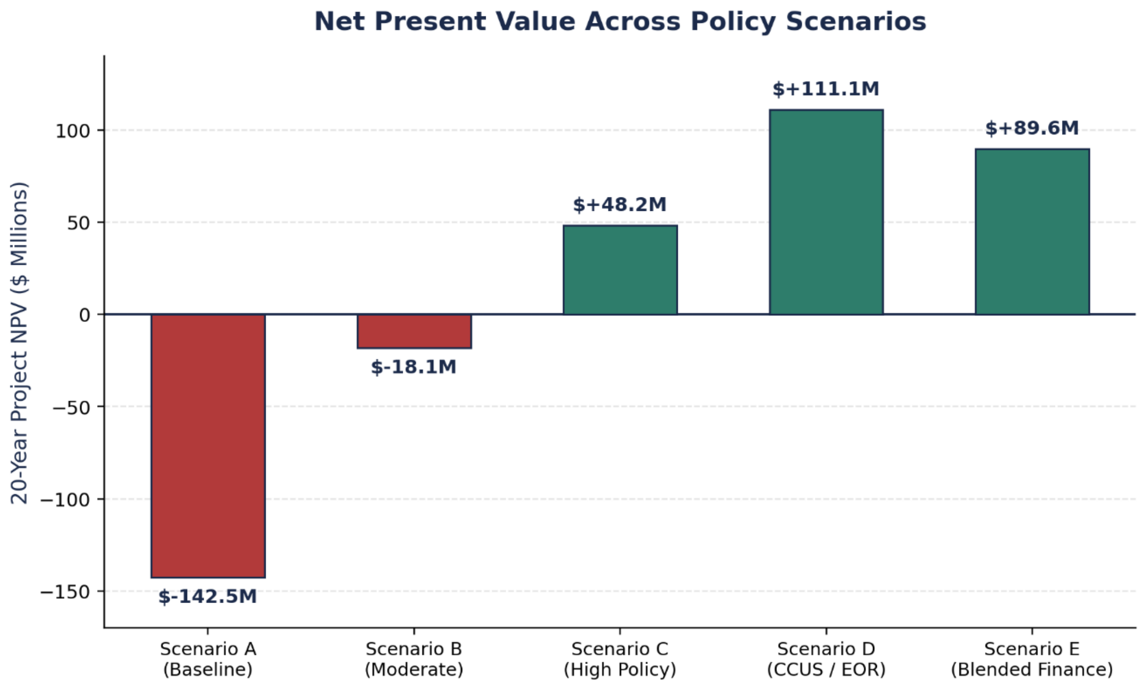

Figure 2. Net present value outcomes across the five modeled policy and finance scenarios, showing the transition from negative to positive project economics under intervention.

4.2 Economic Analysis and Breakeven Dynamics

The modeling yields several critical insights into project bankability:

1. Inadequacy of Baseline Carbon Pricing: Under Scenario A, operational expenditures exceeding gross revenues produce negative cash flows (-$13.01M annually). The facility cannot service capital debt, leading to project failure.
2. The Capital Grant Threshold: In Scenario B, despite achieving a positive operating margin (+$11.33/t), the net cash flow is insufficient to offset the $202.5 million capital outlay at a 10% discount rate, leaving the NPV negative (-$18.1M). This highlights that operating profitability alone does not ensure bankability under high WACC conditions.
3. WACC Reduction Leverage: Comparing Scenario C with Scenario E demonstrates the leverage of blended finance. Lowering the interest rate burden (WACC from 10.0% to 6.5%) nearly doubles the 20-year project NPV from $48.2M to $89.6M, while reducing the levelized cost of carbon abated to $51.40/t.

4.3 Multi-Factor Sensitivity and Risk Analysis

To determine project resilience against economic volatility, a multi-factor sensitivity matrix was evaluated against the baseline of Scenario C ($180M net CAPEX, $65/t carbon value, 10% WACC):

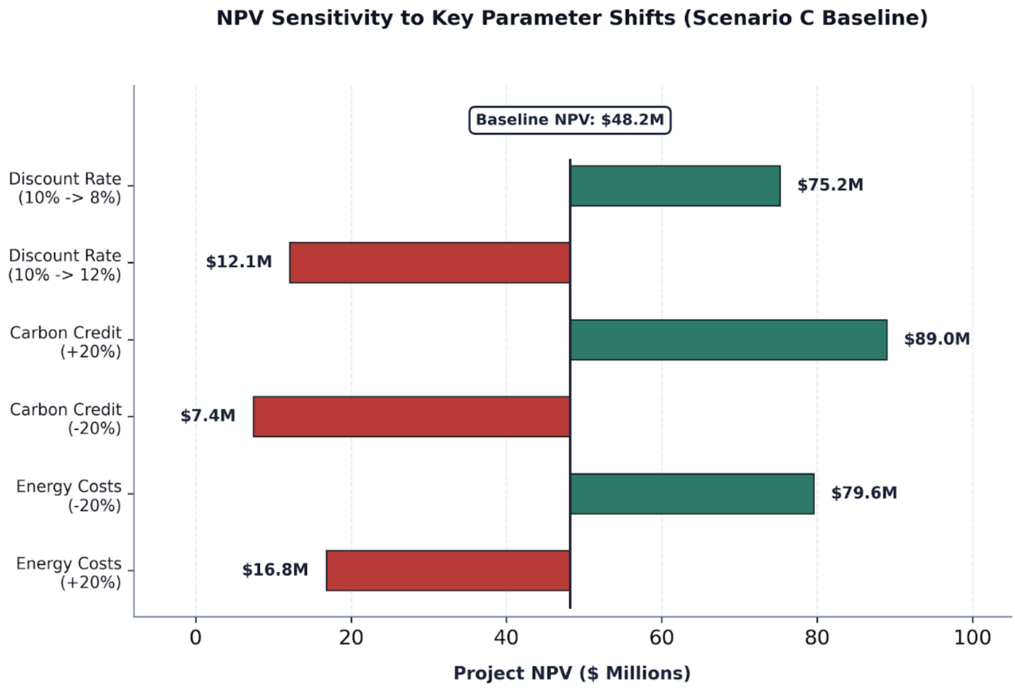

Figure 3. Tornado sensitivity chart showing the impact of a ±20% shift in energy costs and carbon credit values, and a ±2 percentage-point shift in discount rate, on Scenario C project NPV.

Sensitivity Drivers

i. Variable Thermal Energy Costs: A 20% increase in energy costs (steam and electricity required for amine regeneration) decreases project NPV from $48.2M to $16.8M, illustrating the high operational vulnerability to local energy market fluctuations.
ii. Carbon Credit Volatility: A 20% drop in carbon credit values (from $65/t to $52/t) reduces project NPV by 84.6% to $7.4M, approaching the financial breakeven margin.
iii. WACC Sensitivity: Increasing the hurdle rate from 10% to 12% reduces project NPV by 74.9% to $12.1M, emphasizing the sensitivity of capital-intensive assets to sovereign risk premiums.

5. Conclusion and Recommendations

Industrial Carbon Capture and Storage (CCS) deployment in emerging economies is constrained primarily by financial barriers rather than technical feasibility. Under prevailing market conditions characterized by low or nonexistent carbon pricing, high capital borrowing costs, and operational energy penalties industrial CCS retrofits are generally not financially viable without external support. However, the findings of this study demonstrate that financial viability can be achieved through well-designed risk-sharing mechanisms. Specifically, combining targeted carbon price floors of approximately $55–$65 per ton of CO_2, capital grants covering 10%–20% of project costs, and international blended finance can significantly reduce effective capital costs, improve project economics, and generate returns that are attractive to commercial investors. To accelerate industrial CCS deployment in emerging economies, policymakers and industry stakeholders should adopt integrated financial and infrastructure strategies that reduce investment risk while improving long-term project viability. Governments should establish stable, long-term carbon pricing mechanisms alongside upfront capital risk-sharing programs, such as matching grants or tax credits, to address early-stage financing barriers and encourage private investment. At the international level, multilateral climate finance institutions, including the Green Climate Fund and the Asian Development Bank, should prioritize blended finance initiatives through sovereign risk guarantees and concessional lending to reduce the weighted average cost of capital (WACC) to below 7% for industrial decarbonization projects. Furthermore, regional planners should promote the development of shared Carbon Capture, Utilization, and Storage (CCUS) infrastructure hubs instead of isolated plant-level retrofits. Shared CO_2 transport pipelines and geological storage facilities serving clusters of industrial emitters can achieve economies of scale, reduce per-ton transportation costs, optimize infrastructure utilization, and distribute storage risks across multiple participants, thereby enhancing the overall economic feasibility of CCS deployment.

References

Bergstrom, J. C., & Ty, D. (2017). Economics of carbon capture and storage. In Recent advances in carbon capture and storage (pp. 1–22). InTech. https://doi.org/10.5772/67000

Böhringer, C., Carbone, J. C., & Rutherford, T. F. (2018). The administrative and statistical burden of carbon border adjustments. The World Economy, 41(3), 738–753. https://doi.org/10.1111/twec.12586

Herzog, H. (2011). Scaling the policy mountain for carbon capture and storage. The Electricity Journal, 24(1), 7–14. https://doi.org/10.1016/j.tej.2010.12.001

Lyon, T. P., & Montgomery, A. W. (2015). The means and end of greenwash. Organization & Environment, 28(2), 223–249. https://doi.org/10.1177/1086026615575332

Naseeb, A., Ramadan, A., & Al-Salem, S. M. (2022). Economic feasibility study of a carbon capture and storage (CCS) integration project in an oil-driven economy: The case of the State of Kuwait. International Journal of Environmental Research and Public Health, 19(11), Article 6490. https://doi.org/10.3390/ijerph19116490

Subraveti, S. G., Rodríguez Angel, E., Ramírez, A., & Roussanaly, S. (2023). Is carbon capture and storage (CCS) really so expensive? An analysis of cascading costs and CO_2 emissions reduction of industrial CCS implementation on the construction of a bridge. Environmental Science & Technology, 57(7), 2595–2601. https://doi.org/10.1021/acs.est.2c05724

Wang, P., Robinson, A. J., & Papadokonstantakis, S. (2024). Prospective techno-economic and life cycle assessment: A review across established and emerging carbon capture, storage and utilization (CCS/CCU) technologies. Frontiers in Energy Research, 12, Article 1412770. https://doi.org/10.3389/fenrg.2024.1412770