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A compact economic–feasibility model for comparing CO_2 management pathways under carbon pricing

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Abstract:
Techno-economic pathways necessary for effective CO_2 management must ensure feasibility not only in technical terms but also within cost-effective, carbon pricing regimes. In this context, this paper offers a succinct comparison framework for Carbon Capture and Storage (CCS), Carbon Capture and Utilization (CCU/ICCU), and efficiency-aimed approaches on a consistent basis. The proposed method incorporates economic assessment-taking into account carbon price adjustments such as incremental cost and the breakeven carbon price—together with net abated CO_2. A key novelty of this framework is the integration of simplified feasibility indicators, including credibility, leakage risks, and implementation feasibility, effectively bridging the gap between idealized technical potential and practical industrial deployment. The calculations point out the logic of a CO_2 price, which makes capture-based options more feasible, whereas implementation options can reach abatement in the short term without governance gaps. Ultimately, this study provides a standardized, metrics-based tool for stakeholders to evaluate carbon mitigation portfolios under varying regulatory and market conditions, ensuring that industrial transitions are both economically optimized and socially robust.

1. Introduction

"Managing CO_2 is no longer a matter of 'which technology works' and more a question of which package of choices can yield real emissions cuts in the real world (Ma et al., 2022)." CCS remains to be considered a possible way ahead for reducing emissions from difficult-to-treat industrial sectors, although the development of a scalable and sufficiently governed technology is still a matter of long-term development. Rather, the use pathways appear to shift away from the traditional "capture and convert," with more integrated approaches to the challenges posed by the use step that seek to make the process more direct and potentially more feasible, although the emissions outcomes depend greatly upon the ultimate source and fate of the CO_2 (Mintz-Woo, 2024; Zhai et al., 2025). Since these routes are competing for investment, the role of carbon pricing (in the form of carbon taxes) in influencing what is more attractive on the economic margin others cannot. Nevertheless, purely economic performance does not in general ensure success (Lu et al., 2025). Furthermore, a carbon pricing framework in the context of an open economy might need to address both competition and the problem of emissions leakage, and public acceptability can depend on views about fairness and justice. The results of carbon tax analyses can quantitatively transform the cost differences of the routes of a more positive future of industries (for example, from grey to more blue, which capture) and a combination of carbon taxes and quota-like constraints can transform the resulting choices of firms (Prasad, 2022; Oh et al., 2024).

It is proposed to develop a concise assessment approach which compares the management options of CO_2 emissions on equal grounds, taking into account the carbon pricing mechanism. Based on this, one proposed approach will combine the carbon price-adjusted economic assessment with the net CO_2 efficiency approach (Zhu et al., 2023). Moreover, the proposed approach will utilize the split feasibility factors of durability/credibility, CO_2 leakage risk, as well as the

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feasibility aspect of the options. Hence, the proposed approach will enable the portfolio view (Ewald et al., 2022; Weisbach et al., 2023).

2. Related work

Existing literature on the management of CO_2 emissions normally evaluates means in three linked directions, which include: (1) Technological alternatives, (2) economic stimulus through carbon pricing, and finally, (3) viability based on governance and fairness.

In the technology domain, carbon capture and storage (CCS) is viewed as a scalable climate change mitigation technology, with assessments focused on its historical background, challenges in deployment, and the requirements for further deployment (Ma et al., 2022). Simultaneously, analyses on carbon capture and utilization (CCU) have also been seen to be covering the possibility of improving the technology by abandoning the traditional "capture-and-convert" approach in favor of more integrated capture/convert systems (Mintz-Woo, 2024). Supplementary industry studies tend to view emissions mitigation as a system-level effect, such as in the study on the management of ports, which examines the configurations of managerial capacity, governance, and technology linked to superior CO_2 emissions mitigation performance (Zhai et al., 2025).

From an economic perspective, one of the main research lines is dedicated to the impacts of carbon taxation upon competitiveness. The techno-economic comparison of industry processes assesses the role of carbon taxation rates upon the ranking of industrial processes, such as the comparison of ammonia production processes regarding carbon taxation, especially regarding the transition of grey processes towards blue ones by implementing carbon capture and storage methods (Weisbach et al., 2023). On the corporate decision-making perspective, research models assess the impacts of carbon taxation upon the transition of companies into less polluting production methods, considering interactions of carbon taxation with quota-based restrictions (Ewald et al., 2022). Additionally, research on design levels evaluates impacts of carbon taxation upon trade exposure and carbon leakage (Lu et al., 2025).

Finally, some research papers discuss the "implementation ease" of putting a cost on carbon emissions, moving beyond economic analysis alone. Realistic studies of public resistance and resistance patterns reveal factors and hindrances related to justice and acceptability of tax policies on carbon emissions (Prasad, 2022). Normative and interpretive studies analyze and correct views of the justice of carbon taxation, either undervaluing rewards and exaggerating expenses depending on perspectives and institutions (Zhu et al., 2023; Oh et al., 2024).

3. Results and discussion

We develop this proposed framework into a compact but more complete model that can compare CO_2 management pathways under carbon pricing, while remaining feasible to report in a short conference paper. The model evaluates each pathway i (e.g., CCS, CCU/ICCU and efficiency/operational measures) on consistent boundaries then combines 1) carbon-price-adjusted economics, 2) net CO_2 effectiveness, 3) risk and durability of the claimed reductions and 4) implementability constraints that are repeatedly highlighted in the carbon pricing and deployment literature (Weisbach et al., 2023; Zhai et al., 2025).

First, we define a common system boundary and a baseline b (business-as-usual) such that all results are incremental and comparable. This is especially important because CCS/CCU options differ in where emissions are reduced or shifted, and because the operational pathways can reduce emissions through configurations of governance and technology rather than a single "hardware" intervention (Lu et al., 2025). For each pathway, we quantify only a minimal set of inputs: Annualized -or levelized- cost C_i residual emissions E_i, and a carbon price p -e.g., carbon tax. This level of quantification is consistent with compact techno-economic comparisons under carbon tax scenarios used in industrial transition contexts and with policy-design analyses that emphasize how pricing affects incentives (Mintz-Woo, 2024).

Second, we calculate net CO_2 efficiency based on a "net avoided emissions" structure rather than gross captured amounts. The symbol A_i^{net} represents the net avoided CO_2 emissions for a specific pathway i after accounting for systemic emission shifts. It is defined as:

$$A_i^{\text{net}} = A_i - (\Delta E_i^{\text{up}} + \Delta E_i^{\text{down}}) \tag{1}$$

where A_i is the gross avoided CO_2, ΔE_i^{up} represents upstream emission shifts (e.g., energy penalties or supply chain ripple effects), and ΔE_i^{down} represents downstream emission shifts (e.g., post-conversion utilization or eventual re-emission). This will be particularly important for utilization routes since the climate benefit depends precisely on what the CO_2 gets turned into and whether any carbon is durably stored or simply reemitted. Even integrated capture-conversion ideas are judged on the same net-effect logic so that comparisons remain consistent. For CCS, the model treats permanence and monitoring expectations as integral to the pathway's credibility and long-term effectiveness and, therefore, aligns with the focus on realistic scaling, deployment limits, and realistic constraints.

Third, we evaluate the carbon-price-adjusted economics in two complementary—and presentation-friendly—ways. The first approach examines the carbon-price-adjusted incremental cost vs. the baseline Eq. (2):

$$\Delta C_i(p) = (C_i - C_b) - p \cdot A_i \tag{2}$$

This is intuitive in its interpretation, as there is a payment or penalty in CO_2 units for the amount avoided, and the scenario "wins" if the value of carbon equals incremental cost (Weisbach et al., 2023). The second is a single headline metric, which is either the break-even carbon price Eq. (3):

$$p_i^* = \frac{C_i - C_b}{A_i} \tag{3}$$

which refers to the carbon price at which the pathway i becomes economically attractive compared to the baseline (Zhai et al., 2025). Reporting p_i^* is especially helpful in concise papers because it allows one result per pathway to be expressed.

Fourth, in order to exclude the danger of overconfidence in point estimates, we employ a light risk and durability adjustment. In this, we specify the definition for a credibility factor, $R_i \in [0,1]$ which treats the claimed abatement as less credible in cases where it is vulnerable to factors relating to its operational performance, durability, as well as Eq. (4):

$$A_i^{\text{eff}} = R_i \cdot A_i \tag{4}$$

This is not intended to be a complex stochastic model but a succinct representation of how scaling and real-world performance may deviate from idealized technological potential. For utilization paths, R_i can be representative of how carbon might be sequestered versus being cycled back to the atmosphere while maintaining a conservative accounting. The above economic representations can then employ A_i^{eff} as a substitute for A_i for a conservative ranking.

Fifth, given the existence of carbon pricing in open economies and the relationship between carbon pricing and competitiveness, a simple 'leakage exposure' adjustment is included in this model. 'Leakage factor' $\lambda_i \in [0,1]$ is introduced to calculate Eq. (5):

$$A_i^{\text{net}} = (1-\lambda_i)A_i^{\text{eff}} \tag{5}$$

This captures the fact that some domestically measured reductions could be undone by the effects of location or trade, which is a big consideration in carbon tax design. This correction becomes especially useful in the context of how the attractiveness of a pathway will change based on, say, border adjustment, without needing the full general equilibrium analysis.

Sixth, we use the implementability constraint with an organized index as compared to the previous formulation. We introduce Eq. (6):

$$I_i = w_L \cdot L_i + w_T \cdot T_i + w_A \cdot A_i^{\text{soc}} \tag{6}$$

where L_i represents the legal/governance readiness, T_i represents the trade/policy robustness (encompassing the likelihood of leakage), and A_i^{soc} is represents the social acceptability. The above equation allows a simple summation weighting (which can always be easily justified compared to a multiplicative penalty term). The acceptability part takes into account the role of perception on fair treatment, trust, and distributional equity in accepting the Carbon Tax. The part on Governance & Ethics has been included with the recognition that the proposed policy should stand on its feet and should be implementable rather than purely efficient. The model can opt for a simple weightage system (like equal weights).

Firstly, a final compact decision score that combines economics, effectiveness, and implementability can be derived from Eq. (7):

$$S_i = -\Delta C_i(p) \cdot I_i \tag{7}$$

We therefore propose the following three data points per pathway on the results page to remain within the page limit: (1) pi^*, (2) $\Delta C_i(p)$ for a representative carbon pricing scenario(s), and (3) I_i as Low/Medium/High (or a 0-1 score). This structure retains the essence of the comparison between techno-economic analysis results, absorbs the design and type of leakage described and inferred in carbon tax literature, and recognizes the role of equity and feasibility in making a scenario scalable rather than merely technical and economically attractive .

4. Conclusions

This paper proposed a compact evaluation model to compare CO_2 management pathways under carbon pricing while remaining suitable for a short conference format. By combining a carbon-price-adjusted economic test (via $\Delta C_i(p)$ and the break-even carbon price p_i^*) with net CO_2 effectiveness and simple feasibility modifiers (credibility/durability, leakage exposure, and implementability), the framework avoids "economics-only" rankings and highlights why some options that look attractive on paper may not scale in practice. Overall, the results support a portfolio view: CCS tends to become more competitive as carbon prices rise, utilization routes depend strongly on the durability of carbon outcomes and system boundaries, and efficiency/operational measures can deliver robust near-term reductions with fewer governance frictions. Importantly, international design choices that limit leakage and strengthen MRV and fairness perceptions are pivotal for turning favorable break-even thresholds into implementable outcomes.

Conflict of interest

The authors declare no competing interest.

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