Methane Abatement Costs in the Oil and Gas Industry: Survey and Synthesis

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EXECUTIVE SUMMARY JULY 2025

This paper critically reviews and synthesizes methodologies and findings related to the cost of reducing methane emissions from the oil and gas (O&G) sector. Given methane's extremely high global warming potential, recent estimates attribute about 30% of warming to anthropogenic methane emissions. The sector thus provides a major opportunity for "bending the curve" of near-term climate change by implementing cost-effective methane abatement measures as a bridge to longer-term strategies.

The literature identifies three principal methodologies for estimating methane abatement potential and costs. The first is the bottom-up engineering approach, which models the costs of implementing specific abatement technologies and processes. This method underlies analyses by the International Energy Agency (IEA) and the U.S. Environmental Protection Agency (EPA), which use it to generate marginal abatement cost curves and regulatory impact analyses. The second is an econometric, or retrospective, approach, which analyzes real-world market behavior and regulatory compliance to infer actual costs incurred by regulated entities. Recent studies, such as those by Marks (2022) and Lade and Rudik (2020), use variations in market conditions and regulation to derive these estimates. A third method involves examining the revealed costs of public policies—such as subsidies or emissions fees—by assessing firm participation.

A precise understanding of methane abatement costs is vital for effective policy design, regulatory standard development, anticipation of firm responses, and assessment of related trade measures, such as lifecycle emissions standards for liquefied natural gas (LNG) exports. This synthesis draws on a comprehensive review of published studies, reports, public comments, and expert communications.

Engineering cost models consistently indicate substantial potential for low-cost methane abatement. For example, the IEA (2024) estimates that over half of the 77 million metric tons of global O&G methane emissions in 2023 could be cut at no net cost, reflecting the value of captured methane. In North America, 25 percent of emissions could be eliminated at no net cost and roughly 74 percent at under \$10 per ton of CO_2-equivalent (tCO_2e). EPA analysis for its 2023 O&G methane rule suggests nearly 80 percent reductions are feasible at an average cost of about \$12/tCO_2e, after accounting for recovered methane. Canadian analyses yield similar results.

However, these engineering estimates have important limitations. They generally assume the ability to monetize all captured methane, which is not always realistic for every operator. They may also omit leak detection costs, ignore the wide variance in implementation costs across operators, and exclude management and administrative costs.

In contrast, retrospective analyses—by looking directly at observed behavior and compliance—implicitly incorporate many real-world costs overlooked by engineering models. Some studies indicate that, at lower levels of ambition, actual abatement can be achieved at even lower costs than engineering models project. For instance, Marks (2022) finds that a marginal price of about \$6.20/tCO_2e could motivate a 60 percent emissions cut for just \$60 million per year—far below engineering-based policy cost estimates. Lade and Rudik (2020) demonstrate significant cost differences among firms, and for

flaring-focused emissions, the average abatement cost of a 60 percent reduction is \$2.40/tCO_2e, rising to \$6.75/tCO_2e for an 80 percent reduction.

Overall, the synthesis finds substantial potential for low-cost methane abatement, typically at net costs much lower than those modeled for CO_2 reductions in the U.S. power sector under recent legislation. Yet, claims of widespread negative abatement costs should be treated cautiously. Notably, marginal costs rise steeply as abatement levels approach or exceed 70–80 percent. For example, adding just 6 percentage points beyond a 74 percent reduction in North America more than triples the incremental cost in engineering models, and similarly, costs for reducing flaring-related emissions escalate sharply beyond the initial gains.

Two additional findings have major policy implications. First, methane abatement costs vary significantly across firms, suggesting that market-based approaches could deliver substantial reductions more cost-effectively than uniform regulations. Second, technological innovation—especially in methane monitoring and remote sensing—has significant potential to lower detection and abatement costs further, improve cost estimates, and facilitate the extension of these methods to other methane sources.

Promoting Energy Conservation: A Field Experiment on Peer Comparisons and Rate Structures

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We compare the effectiveness of social comparison nudges on energy consumption when residents pay for electricity and when electricity is included in monthly rent. Using a randomized control trial, our intervention uses digital messages (text and emails) to provide residents with home energy reports comparing their recent electricity usage with similar households. Our design allows us to investigate the pecuniary and non-pecuniary impacts of a widely-used behavioral nudge. The average treatment effects suggest that peer comparison nudges are less effective for non-ratepaying customers, implying that cost-saving motives play an important role.

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Are Credit Rating Agencies Punishing Petrostates for Energy Transition Risks?

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EXECUTIVE SUMMARY

Motivations for the Research

The global shift toward renewable energy threatens countries whose economies depend heavily on oil exports. Nearly 25 countries rely on oil revenues for at least 10% of their national income, yet forecasts suggest oil demand could halve by 2050. This raises a critical question: are major credit rating agencies—Standard & Poor's, Moody's, and Fitch—already factoring these long-term risks into their assessments of oil-dependent countries?

Credit ratings determine borrowing costs for governments, making this question crucial for petrostate financing. Since ratings are forward-looking, they may signal economic pressures before current data reflects energy transition impacts. Understanding these dynamics provides insight into both the timeline and financial implications of moving away from fossil fuels.

Research Approach

This study analyzed 27 years of credit rating data from 1992 to 2019, covering 153 countries. Researchers defined petrostates as countries where oil income represents at least 10% of economic output or $300 per capita annually. Using statistical methods that controlled for traditional rating factors like economic growth and political stability, they compared how agencies treated petrostates versus other countries over time.

The analysis combined quantitative assessment of rating patterns with qualitative review of actual agency reports, providing comprehensive insight into both what agencies are doing and why they're doing it.

Main Findings

The research reveals that rating agencies are gradually adjusting their treatment of petrostates in three key ways, rather than implementing dramatic downgrades.

First, petrostate ratings have experienced modest but measurable declines since 2010. Oil-dependent countries saw average ratings drop by less than one-tenth of a grade, while oil-rich countries' ratings remained flat.

Second, petrostates receive less benefit from high oil prices than historically. Before the late 2000s, rising oil prices typically improved petrostate ratings. Since then, this positive relationship has largely disappeared, with ratings failing to improve even during strong oil price periods between 2010-2014 and 2018-2019.

Third, economic diversification has become increasingly critical. Countries with varied economies beyond oil receive better ratings, while those concentrated in oil face growing penalties. This

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effect has intensified over time, suggesting agencies view diversification as essential protection against transition risks.

Rating agency reports confirm these patterns while explicitly stating that energy transition concerns primarily affect future rather than current assessments. However, agencies are already incorporating these risks indirectly through greater emphasis on diversification and treating oil price increases as potentially temporary.

Policy Implications and Applications

These findings suggest economic diversification is becoming financially necessary for petrostates, not just economically prudent. Countries failing to develop alternative revenue sources may face progressively higher borrowing costs, creating challenges precisely when they need capital for economic transformation.

The gradual nature of current adjustments may signal more dramatic changes ahead. As energy transition timelines become clearer, petrostates could face sudden downgrades, potentially creating simultaneous revenue decline and reduced borrowing capacity.

For policymakers, these results highlight the importance of supporting petrostate diversification before rating pressures intensify. International financial institutions should prioritize helping oil-dependent countries build economic alternatives while they retain access to affordable capital.

The research also suggests rating agencies may need updated methodologies for handling unprecedented global transitions. Current approaches treating energy transition as distant, uncertain risk may leave markets unprepared for accelerating change.

From a broader perspective, these findings demonstrate that financial markets are already pricing climate-related risks without explicit regulatory requirements. This market-driven process may accelerate energy transition incentives while creating new challenges for fossil fuel-dependent economies. Understanding these dynamics is essential for designing transition policies that balance environmental goals with economic stability in affected regions.

Do Sustainable Operations through Energy Effectiveness Reduce Cost of Debt in Medium and High-tech Industries? Evidence from an Emerging Economy

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EXECUTIVE SUMMARY

1. Motivations underlying the research

Sustainable operational practices that prioritise energy efficiency are crucial in addressing greenhouse gas emissions, combating climate change, and promoting sustainable economic development. The manufacturing sector, as a significant energy consumer and contributor to emissions, can play a pivotal role in this context. Improving energy efficiency in manufacturing not only yields substantial environmental benefits but also offers significant economic and social advantages for present and future generations (Bai et al., 2021). Simultaneously, the availability of capital is vital in driving business

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operations, exerting significant influence on firms' behaviours and decision-making processes (Wang & Tang, 2023). The active engagement of capital providers in financing energy-efficient projects can unlock multiple benefits, including reduced environmental impact, enhanced operational efficiency, and improved long-term financial performance for businesses.

The incentive in terms of reduced cost of debt (COD) is a significant factor that impacts a firm's financial viability and ability to secure capital for future investments. It represents the interest rate a firm pays on borrowed funds and is influenced by various factors, including its creditworthiness, market conditions, macroeconomic factors and competitive landscape. The competitive landscape can have a notable influence on the interest rates charged by banks when lending, and there are several potential reasons for this relationship.

However, with the evolving business landscape, firms are increasingly focused on energy efficiency, which has captured the attention of investors. Firms increasingly recognise the importance of energy efficiency for environmental and societal reasons, as well as its profitability considerations. The growing awareness of environmental concerns and energy consumption patterns has heightened investors' focus on the reputational risks associated with energy-intensive firms. This measure, in turn, has motivated lenders to incorporate sustainability metrics in their credit assessments. On the other hand, a higher COD can indicate a higher risk, potentially negatively influencing investors' interest. Therefore, gaining insight into energy efficiency in the business that influences the COD is crucial for firms to make informed financing decisions and improve their financial performance. The theoretical foundation is based on the premise that enterprises using less or alternatives are more likely to address social and environmental concerns effectively. On the contrary, firms that consume substantial endure an additional risk for investors. Firms that engage in energy-intensive practices may participate in activities that increase liabilities and impact the cost of their borrowings.

2. A short account of the research performed

To explore the impact of energy efficiency on the cost of debt (COD), we use panel data from 2011 to 2021 for all listed firms on the Bombay Stock Exchange (BSE). We conducted a panel data analysis using 7,603 observations classified as high- and medium-tech from 2010 to 2022, employing two-stage least squares Tobit regression models. We categorise the firms into two groups, high-tech and medium-tech, based on the classification by the Organisation for Economic Co-operation and Development (OECD) (Sandven et al., 2005). We also address the possible issue of endogeneity. The lack of agreement in the empirical literature on the relation between energy efficiency and the cost of debt can be partly attributed to endogeneity. If firms with lower debt costs are more inclined to invest in energy efficiency, this could create a reverse causality issue. In other words, firms with already lower borrowing costs may have the financial resources and incentives to implement energy-efficient practices rather than energy efficiency directly influencing the cost of debt. We employ an instrumental variable (IV) Tobit model to address these concerns and provide more reliable estimates to examine the link between energy efficiency and COD. This model is particularly suitable for analysing right-censored data, where the dependent variable is truncated and only observable within a specific range. By applying the IV Tobit approach, as suggested by Chesher et al. (2023), we aim to overcome the limitations associated with endogeneity and enhance the coherence and robustness of our findings.

3. Main conclusions and policy implications of the work

This research presents empirical evidence for adopting sustainable operational practices, such as energy efficiency (reductions in the energy-output ratio) and COD when making a financing decision. The study offers significant theoretical, practical, and policy implications for firms, investors, and regulators in emerging economies such as India. First, the study identifies operational initiatives that firms can adopt to achieve both environmental sustainability and financial gain. The firm's sus-

tainability, measured through energy efficiency, reflects a summary metric of technology adoption and new investments in energy-saving measures. The research extends the analysis to explore the nature of this relationship across different industries and ownership structures. To demonstrate these linkages, we investigated the sample by splitting it into high-tech and medium-tech sectors. Distinctly studying these sectors enables policymakers to understand the unique dynamics and challenges that may develop regarding energy efficiency in each sector. The results suggest that the impact on COD varies depending on the degree of energy efficiency achieved (Fu et al., 2023). Although the influence is more pronounced in high-tech firms, it remains vital in medium-tech sectors. Medium-sized businesses must, therefore, carefully assess the investment size in energy-efficient technologies to achieve the intended economic benefit.

By recognising the financial benefits tied to energy efficiency, policymakers can create an ecosystem that fosters sustainable investment, enhances corporate creditworthiness, and ultimately stabilises the energy market by reducing dependency on fossil fuels. Policymakers in government can leverage this insight by introducing incentives, such as lowering taxes or subsidies, to firms that invest in energy-saving technology, potentially resulting in reduced greenhouse gas emissions and improved environmental performance. It also suggests that governments may strengthen regulatory frameworks to promote energy efficiency among businesses, thereby enhancing enterprises' environmental and financial performance. Since banks and financial institutions (FIs) are becoming more cautious of the reputational risks involved in lending decisions, especially to firms with inadequate environmental performance, regulators can mandate the inclusion of sustainable metrics in their lending processes. Further, FIs may be incentivised to foster sustainable business practices and possibly reduce financing costs for energy-efficient enterprises. Encouraging environmental regulations could potentially influence the sustainable business process and the resultant access to funding.

Settling the metric selection debate for assessing the energy efficiency of energy-intensive industries

Prashant Giri[1] and Tarun Sharma[1,2,]*

This study addresses recent calls to adopt multifactor efficiency measures in energy efficiency policymaking, moving beyond the traditional reliance on single-factor measures. Using firm-level panel data from 2003–04 to 2021–22, sourced from the Prowess database, we evaluate Total Factor Energy Efficiency (TFEE) and attainable energy-saving objectives for India's energy-intensive industries: aluminum, cement, fertilizer, pulp & paper, iron & steel, and textiles.

We applied Data Envelopment Analysis (DEA), including input-oriented Slack-Based Models with variable returns to scale, to determine energy efficiency potential. Our TFEE analysis reveals significant efficiency gains in iron & steel and textiles, contrasting with limited improvements observed in single-factor studies under the Perform Achieve and Trade (PAT) scheme. Despite a potential of 55.9% energy savings across industries, overall energy efficiency improved significantly during the period studied. The textile, iron and steel, and pulp and paper sectors show the greatest potential for improvements, at 65%, 61%, and 29%, respectively.

This manuscript offers a novel contribution by employing the Slack-Based Model in India's context and juxtaposing TFEE with single-factor measures, providing critical insights for policymaking. We

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confirm that the work has not been previously published, is not under consideration elsewhere, and complies with all ethical and publication standards.

Analyzing the Mechanism of Decentralized Energy Governance Strategy to Reduce Carbon Emissions: Evidence from China

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EXECUTIVE SUMMARY

1. Motivations underlying the research

Transitioning to renewable energy is crucial to reducing carbon emissions and achieving the Sustainable Development Goals, as renewable energy is cleaner, more efficient, and inexhaustible. However, due to heterogeneous regional development in energy transition, selecting appropriate governance strategies poses a complex challenge for central governments. Decentralized energy governance (DEG) strategies may provide a potential solution for this issue. A DEG strategy is a decentralized governance strategy in which the central government delegates the responsibility of environmental management to local governments.

Study on renewable energy governance contains several limitations and gaps that motivate our study. Current studies on renewable energy policies primarily focus on evaluating the effects of centralized energy policies. This approach, however, overlooks the impact of local renewable energy distribution on the development of renewable sources. Some studies examine the effect of China's DEG strategy on carbon emissions, although the mechanism of this strategy has not been comprehensively analyzed. Additionally, considering the heterogeneity of local government capacities at the regional level, the effects of the DEG strategy on local carbon emissions are not entirely clear.

To address this study gap, we examine two questions. First, what is the impact of the DEG strategy on reducing carbon emissions? Second, what are the mechanisms of impact of the DEG strategy? Specifically, we investigate how renewable energy innovation and energy transition mediate the impact of the DEG strategy on reducing carbon emissions. The DEG strategy facilitates renewable energy innovation by increasing the application of innovative knowledge, enhancing the flow and integration of innovative elements, and improving the efficiency of allocating innovative elements. Renewable energy innovation also reduces the cost of using renewable energy and enhances energy utilization efficiency, which is crucial in promoting industrial upgrading and reducing carbon emissions. Additionally, integrating distributed energy systems with local energy markets enables these markets to adapt more effectively to varying energy demands and supplies, improving the operational efficiency of the energy system. Within this framework, the energy transition from traditional to renewable sources provides a sustainable pathway for decarbonization.

This study makes three contributions to the existing literature. First, our study supports previous findings regarding the impact of China's DEG strategy on carbon emissions, thereby enriching the theory of environmental federalism. Second, we find that the specific channels of impact of the DEG

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strategy on carbon emissions are renewable energy innovation and energy transition. Third, we outline specific policy recommendations based on our empirical findings, emphasizing regional heterogeneity and encouraging technological innovation and the transition to new energy.

2. A short account of the research performed

We select China as the study context for the following reasons. First, China, as a major energy consumer, has an urgent need for energy transformation. Second, China is a significant global force in the development of renewable energy and has considerable potential to expand its application of renewable energy. In 2014, the China National Energy Administration implemented the New Energy Demonstration City (NEDC) policy, which added a distributed energy resource system to the Plan's assessment indicators, marking the beginning of the pilot policy for DEG. The NEDC policy provides a suitable quasi-natural experiment framework for this study. This study utilizes panel data from 283 cities and a Difference-in-Differences (DID) model to comprehensively and systematically analyses the direct effect and mechanism of impact of DEG on carbon emissions.

The results of this study suggest that the DEG strategy significantly reduces carbon emissions, primarily through innovations in renewable energy and energy transitions. Heterogeneity analysis further highlights that the policy's effectiveness is more pronounced in non-resource-based cities, R&D-intensive cities, and those with strong environmental regulations. These findings underline the importance of expanding DEG strategies and investing in resources to foster innovation and accelerate energy transitions, providing valuable policy recommendations for achieving carbon neutrality.

3. Main conclusions and policy implications of the work

The study draws the following three conclusions. First, our study supports previous findings that DEG is crucial in reducing urban carbon emissions. This study suggests that after the implementation of the pilot policy, the carbon emissions of pilot cities decreased by an average of 17.9%. Second, the mediating roles of technological innovation in renewable energy and energy transition are suggested as the channels through which DEG affects carbon emissions. Third, our study indicates that DEG has a stronger effect in non-resource-based cities, R&D-intensive cities, and cities with stronger environmental regulations than in their respective counterparts.

Building on these findings, we propose several policy recommendations. First, we suggest that the central government should further delegate energy governance authority to local governments. Second, we recommend that the government alleviate the R&D burdens on enterprises through targeted measures such as innovation subsidies and tax incentives. Third, the government should actively facilitate the transition to renewable energy by incentivizing new energy consumption, providing financial support, and strengthening renewable energy infrastructure to expand installed capacity. Fourth, it is essential to develop customized policies tailored to local conditions.

Does the Shale Gas Revolution Hinder Clean Energy Innovation?

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EXECUTIVE SUMMARY

This paper examines the impact of the U.S. shale gas revolution, after by the Energy Policy Act (EPAct) of 2005, on technological innovation in the electricity sector. Using a difference-in-differences methodology and a dataset of 337,009 patent applications from 134 countries spanning 1978 to 2018, the authors investigate shifts in innovation activity across green, renewable, and fossil-fuel technologies.

The study finds that the shale gas boom significantly redirected innovation away from clean energy technologies:

1. Decline in Green Innovation: The ratio of green to fossil-fuel electricity patents decreased by 1.60 in North America, with similar declines observed when compared to European countries and highly innovative "Top Green" nations. The share of green to total electricity innovation also showed a consistent, albeit smaller, decline.
2. Impact on Renewable Technologies: The ratio of renewable to fossil-fuel patents dropped significantly, though the effect on renewable technologies as a share of total innovation was less pronounced.
3. Rise in Fossil-Fuel Innovation: The share of fossil-fuel electricity patents increased, reflecting a shift in innovation in the energy sector.

These findings suggest that the shale gas revolution encouraged patenting in fossil-fuel-related electricity generation technologies relative to green-focused innovations. Robustness checks, including alternative samples and synthetic control analyses, support these conclusions.

The paper contributes to the literature on energy policy and innovation by demonstrating how major policy shifts can redirect technological development.

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