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Research on Negative Externalities and Internalization Strategies of the Coal Mine Power Generation Industry

Linzi Liang

Beijing Twenty-first Century School, Beijing, China
18237718888@163.com

Abstract. Coal-fired power generation is a pillar of the world's energy production system, but is beset with significant negative externalities. These costs are typically excluded from market pricing mechanisms. Existing literature on the topic lacks systematic analysis of the causes of these externalities and effective internalization methods. This research gap constitutes a key barrier to developing sustainable energy initiatives, particularly in coal-dependent regions. This paper examines the economic, environmental and regulatory causes of these negative externalities in the coal-fired power generation industry, aiming to identify viable internalization strategies. This aims to facilitate a balance between private costs and social impacts amid the implementation of sustainable energy programs. The research utilizes a hybrid approach, integrating a systematic literature review, case studies of coal-fired power generation systems, and econometric modelling to analyze externality drivers and effective internalization initiatives. Key findings reveal that while the causes of negative externalities can be clearly identified, successful internalization methods may not deliver the intended sustainable outcomes due to multiple barriers, such as high implementation costs and significant geographic variations. Ultimately, effective internalization methods can offer a robust framework for enhancing sustainability practices. provides a valuable reference for energy transition and offers a practical analytical tool for stakeholders addressing energy transition challenges in coal-dependent economies.

Keywords: Coal-fired power generation industry, negative externalities, internalization strategy, carbon pricing

1. Introduction

Coal-fired power generation remains a cornerstone of the global energy supply, especially in developing countries. However, this industry imposes considerable negative externalities including environmental degradation (e.g., air pollution, greenhouse gas emissions) and public health costs. These costs are not incorporated into production costs, leading to market inefficiencies and exacerbated environmental degradation [1]. This necessitates appropriate internalization measures to optimize the industry's sustainability [2]. While existing literature addresses externalities in the energy sector, no systematic research focuses on the negative externalities of coal-fired power generation or the diverse internalization approaches for its operation and regulation [3,4]. This literature gap highlights the need to clarify the negative externalities of coal-fired energy, investigate their causes and explore viable internalization approaches to mitigate them. The study's objective is to identify the causes of negative externalities in the coal-fired power generation industry and propose appropriate internalization measures based on theoretical frameworks, including Pigouvian Taxation and the Coase Theorem. This study investigates economic, environmental and regulatory issues of externalities, and conceptualizes how internalisation processes, such as carbon pricing and carbon emission trading, can align private and social opportunity costs more closely [5,6]. The research adopts a hybrid methodology, integrating a systematic literature review, case studies of coal-fired power generation across different regions, and econometric modelling. This models the monetized costs of negative externalities to analyze internalization effectiveness in mitigating them [7]. The study also analyzes data from peer-reviewed literature and industry reports to ensure the reliability of its conclusions [8,9]. The study's findings are highly relevant to countries reliant on coal-fired power generation for energy supply and can contribute meaningfully to the global transition toward sustainable energy.

2. Literature review

Two foundational theories underpin the analysis of negative externalities and their internalization: the Pigouvian Tax Theory and the Coase Theorem. These theories differ fundamentally in their views on market failure, property rights, and policy interventions.

Pigou argued that negative externalities arise from market failure—where the private cost of economic activities (e.g., coal-fired power generation) does not reflect their full social cost (e.g., environmental pollution and health damages). To correct this misalignment, he proposed government-led intervention through a "Pigouvian tax," which levies a fee on polluters equal to the marginal social cost of their externalities. This tax forces firms to internalize the previously uncompensated social costs, aligning private incentives with public welfare and reducing inefficient overproduction of externality-generating activities [10]. The core logic of Pigouvian theory relies on regulatory tools to remedy market imperfections, emphasizing the necessity of government involvement in correcting externalities. In contrast, the Coase Theorem posits that clearly defined property rights can resolve externalities through voluntary market transactions, even without government intervention—provided transaction costs are low. In the context of coal-fired power generation, this would entail defining and allocating property rights to affected parties (e.g., communities impacted by air pollution or ecosystems damaged by coal mining). With well-defined rights, polluters and affected parties can negotiate mutually beneficial agreements to internalize externalities, thereby achieving an efficient outcome irrespective of who initially holds the rights. The Coase Theorem shifts the focus away from government intervention towards reducing transaction costs and clarifying property rights, underscoring the potential for market mechanisms to self-correct externalities when institutional conditions are favorable.

The concept of negative externalities was coined by Pigou, to describe uncompensated social costs that economic activities impose on third parties. Within the energy sector, this analytical framework is widely used to understand the unintended consequences of power generation. Existing research generally categorized the negative externalities of coal-fired power generation into three dimensions: environment, health, and socioeconomics [1,2].

From an environmental perspective, literature reviews consistently confirm that coal-fired power generation is a major source of air pollutants and greenhouse gases. Silvia et al. quantified the association between power plant emissions and regional environmental degradation [2]. Additionally, life cycle analysis covering coal mining, transportation, and combustion identifies often-overlooked externalities such as water pollution and land subsidence, which are rarely

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included in operational analyses [4]. In terms of solutions, academic research distinguishes two approaches: market-based and command-and-control. Market-based tools such as carbon pricing and emission trading systems (ETS) are widely acknowledged for their cost-effectiveness and flexibility—independently select the most cost-efficient emission reduction pathways (e.g., fuel substitution, efficiency improvement, or clean energy transition) rather than being constrained by uniform regulatory mandates [5,6]. However, these tools have notable limitations: firstly, the risk of carbon leakage, where energy-intensive enterprises relocate production to regions with laxer environmental regulations to avoid compliance costs, undermining global emission reduction goals [8]; secondly, inequitable allowance allocation in ETS, which often favors large incumbent power plants and imposes disproportionate financial burdens on small and medium-sized enterprises (SMEs), exacerbating market inequities [5].

Command-and-control approaches, such as stringent emission standards and mandatory technology requirements, offer high certainty in emission reduction outcomes by setting clear, legally binding targets with little room for non-compliance [3,9]. Nevertheless, their drawbacks are prominent: on one hand, they impose substantial compliance costs on firms—retrofitting existing coal-fired power plants with mandatory pollution control technologies (e.g., flue-gas desulfurization systems) requires large upfront investment, which may strain the financial capacity of energy-intensive industries, especially in developing economies [3]; on the other hand, they risk technology lock-in—mandating specific control technologies can stifle innovation in more advanced, low-cost abatement solutions (e.g., CCUS), trapping the coal power industry in outdated technical pathways and impeding long-term sustainable transition [9]. Existing studies identify a critical research gap: the lack of integrated analysis of specific externality causation mechanisms in coal-fired power generation and comparisons of costs and benefits of internalization solutions under varying economic conditions. This study aims to develop a comprehensive analytical framework that links theory, causation, and solutions.

3. Causes of negative externalities in the coal power industry

The negative externalities of the coal-fired power generation industry stem from a complex interplay of environmental, economic, and regulatory factors. Analyzing these factors enables the development of targeted internalization strategies.

3.1. Environmental impacts

Environmental problems represent the primary source of negative externalities. Pollutant emissions can be quantified per unit of power generation.

Table 1. Comparison of pollutant emission intensities of coal-fired power in major global economies

Region/Year	CO_2 (kg/kWh)	SO_2 (g/kWh)	NO_x (g/kWh)	PM2.5 (g/kWh)	Data Source
China (2017)	0.843	0.26	0.25	0.06	National Energy Administration of China, 2018
U.S. (2023)	1.048	-	-	-	U.S. Energy Information Administration (EIA), 2024
UK (2024)	0.317 (CO_2e*)	-	-	-	Climatiq, 2025

These pollutants exert significant long-term impacts: they penetrate ecosystems and human respiratory systems, causing biodiversity loss (e.g., species extinction in acid rain-affected forests) and public health crises (e.g., chronic respiratory diseases) [1,6]. These air pollutants are primarily

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transported across regions through four pathways: monsoon advection, cold air advection, high-pressure system advection, and vertical mixing. External costs are concretely reflected in economic terms: global healthcare costs from air pollution are forecast to increase from 2B in 2020 to 176B by 2060. Labor productivity declines linearly with PM2.5 concentrations—productivity decreases by 5-25% as PM2.5 levels increase from 0 to 30 μg/m³ (see Figures 1 and 2).

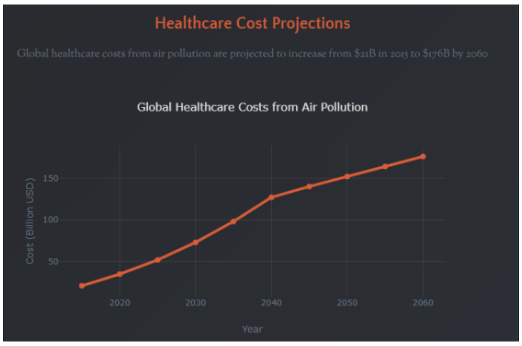

Figure 1. Healthcare cost projections

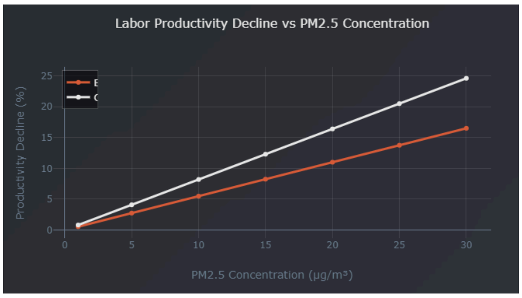

Figure 2. The relationship between labour productivity decline and PM2.5 concentration

Beyond air emissions, the coal supply chain generates substantial environmental externalities. Excessive coal mining causes land degradation, deforestation, and soil erosion. Furthermore, coal washing consumes significant volumes of water, and coal mining generates acidic wastewater, which results in freshwater pollution and depletion [4]. These externalities are typically intergenerational. Long-term environmental costs of resource depletion and ecological damage will be borne by future generations, a consequence not reflected in current coal prices.

3.2. Economic and regulatory factors

However, the environmental damage merely reflects underlying economic and regulatory failures. At its core is market failure rooted in the "tragedy of the commons"—where the atmosphere and waterbodies are treated as free waste disposal sinks. Since power plant operators do not have to pay for using these environmental sinks, the private cost of coal-fired power remains far lower than its true social cost. This mispricing creates distorted incentives, leading to excessive production and consumption of coal-fired power and disincentivizing investment in clean energy alternatives [2]. In many regions, particularly developing countries, environmental regulations are either insufficient, weakly enforced, or entirely absent, which exacerbates market failure. Lax emission standards, inconsistent approval processes, and weak enforcement systems create a low-accountability regulatory environment, allowing operators to externalize costs with minimal accountability [3,8]. Additionally, direct or indirect government subsidies for the coal industry widen the gap between

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private and social costs. They sustain the industry's political-economic dominance despite the negative consequences of coal-fired power generation. This combination of market and regulatory failure creates a "lock-in system," where coal production becomes politically entrenched, resisting policy intervention.

4. Internalization strategies

4.1. Market-based approaches

Market-based strategies use price signals to incentivize cost-effective emission reductions. Carbon Pricing and Taxes: These involve levying taxes directly on the carbon content of fuels such as coal. A carbon tax raises production costs for emitters, incorporating the social cost of carbon into business decisions. This creates ongoing financial incentives to switch to lower-carbon fuels, improve energy efficiency, and adopt cleaner production methods [5]. A key advantage is price certainty, enabling firms to pursue the most cost-efficient ways to comply. While carbon taxes provide price certainty by fixing the cost per unit of emissions, emissions trading systems (ETS) offer quantity certainty by capping total emissions. This trade-off between price and quantity control is a key design consideration for policymakers.

4.2. Regulatory and technological interventions

These measures, termed "command-and-control," prescribe specific performance standards or mandate the adoption of certain technologies.

Stricter Environmental Regulations: Governments can achieve internalization by imposing strict emission limits on pollutants such as SO_2, NOx, and PM2.5. These may be paired with requirements to install pollution control technologies, including flue-gas desulfurization (FGD) systems and electrostatic precipitators (ESPs). While such regulation reduces emissions, it may be inflexible and, in some cases, costlier than market-based mechanisms. This is because it denies firms the ability to adopt the least-cost compliance methods [3].

Technological Innovations: Stimulating or mandating technological advancements is a critical long-term strategy. This includes fostering Clean Coal Technologies (CCTs), such as supercritical and ultra-supercritical pulverized coal combustors, which have higher efficiency and lower emissions per kWh of electricity generated. Significant opportunities exist in Carbon Capture, Utilization, and Storage (CCUS), a technology whose development can enable continued fossil fuel use without releasing CO_2 into the atmosphere [4,9]. Additionally, policies promoting renewable energy integration into power grids will reduce coal use and its associated externalities.

4.3. Case studies

Real-world case studies provide insights into effective practices. The European Union exemplifies this multidimensional approach. The EU ETS forms the foundation of its climate policy, establishing a carbon price that drives power sector decarbonization [6]. This approach is supplemented by a rigorous legislative framework, for example through the Industrial Emissions Directive, which sets legally binding emission limits. The combination of market measures and regulation has accelerated the phase-out of inefficient coal-fired power plants, as well as increased investment in renewables and gas. In contrast, experiences in emerging economies with a high degree of coal dependence (e.g., India, South Africa) highlight challenges. In these contexts, the need for economic development and low-cost energy often conflicts with environmental objectives. While

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environmental standards may be defined in principle, implementation is hindered by weak institutional capacity and other political-economic factors [4]. This demonstrates that internalization strategies must be adapted to local economic and institutional realities and that international support and financing may be critical to success.

5. Evaluation of internalization effectiveness

A multi-dimensional measurement of their economic, social and environmental impacts is required for the evaluation of the effectiveness of internalisation strategies. This may involve quantitative modelling and multi-faceted performance metrics. From an environmental perspective, their effectiveness is measurable. Econometric and panel data analyses of production reveal clear causal links between carbon pricing implementation and reduced CO_2 emissions in the electricity sector. Studies of the EU ETS demonstrate significant emission reductions, particularly in later phases when the cap was tightened and carbon prices rose [5,6]. Similarly, stringent air quality regulations in the US, such as the Acid Rain programme, led to rapid SO_2 emission reductions at costs far lower than anticipated. This highlights how effective regulation can deliver positive outcomes.

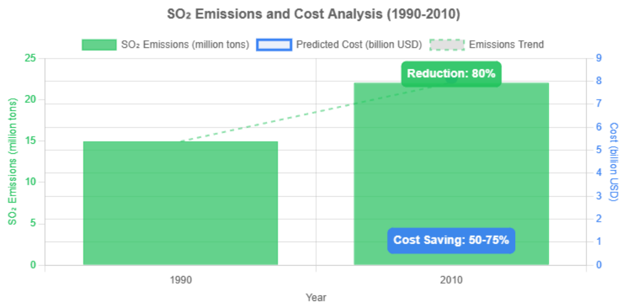

Figure 3. SO_2 emissions and cost analysis

Despite these significant environmental benefits, economic cost-benefit analysis reveals more nuanced trade-offs. Market mechanisms are advantageous because they reduce emissions at a lower aggregate social cost than uniform standards for equivalent emission reductions [7]. However they can lead to short-term electricity price increases, raising concerns about competitiveness and energy affordability. Regulatory measures, while providing certainty, impose high compliance costs on firms and may stifle innovation if overly prescriptive. Econometric models simulate these trade-offs by comparing abatement costs with avoided external costs (e.g., health care expenditure and environmental damage avoided) [7]. Results often show that long-term positive effects of internalisation, such as avoided climate damage and improved public health, far outweigh initial implementation costs [7]. Despite their potential, internalization strategies face several implementation challenges. High costs and political resistance are significant barriers, especially in regions where coal is a major employer and source of low-cost energy. Regional disparities in economic development, institutional capacity, and energy infrastructure make a one-size-fits-all policy impractical [8]. A policy successful in the technologically advanced, integrated EU market may fail in a fragmented grid in a developing nation.

6. Conclusion

This study indicates that negative externalities in the coal power industry, including air pollution, greenhouse gas emissions, and health costs, stem from market failures, resource depletion, and

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ineffective regulation. Internalization mechanisms such as carbon pricing, emissions trading systems, and stricter regulation of the environment effectively align private and social costs, reducing externalities and their environmental and social impacts. Case studies from the EU and emerging economies show that both market-based and regulatory interventions can foster sustainable energy practices, with carbon pricing exhibiting the greatest potential to drive emission reductions. These results illustrate the need to prioritize internalization measures in energy policies to mitigate the coal power industry's environmental impact and contribute to global sustainability efforts. The study has limitations, primarily due to challenges in quantifying externality costs across regions, varying data quality, and methodological differences, which complicate result interpretation. It focuses mainly on environmental and economic externalities, with less attention to social effects such as community displacement. Future research should improve accuracy by developing more sophisticated econometric models to quantify regional externality costs more precisely. It should also explore hybrid internalisation models, combining market-based and regulatory instruments to address implementation challenges. Additionally, investigating socio-economic consequences of internalization (e.g., impacts on coal-dependent communities) would provide a broader understanding of its effects. Longitudinal studies on the success of internalization strategies could further inform the design of scalable policies for sustainable energy transitions.

References

[1] Costa C R S, Ferreira P. A review on the internalization of externalities in electricity generation expansion planning [J]. Energies, 2023, 16(4): 1840.
[2] Silvia F, Talia V, Di Matteo M. Coal mining and policy responses: Are externalities appropriately addressed? A meta-analysis [J]. Environmental Science & Policy, 2021, 126: 39-47.
[3] Kudełko M. Are EU environmental regulations consistent with the concept of internalisation of externalities--the case of Polish electricity sector [J]. Economics and Environment, 2022, 81(2): 89-105.
[4] Pysmenna U Y, Trypolska G S. Sustainable energy transitions: Overcoming negative externalities [J]. 2020.
[5] Ziyaei S, Panahi M, Manzour D, et al. Impact analysis of internalizing environmental costs on technical, economic, and environmental performances for power plants [J]. International Journal of Environmental Research, 2023, 17(5): 54.
[6] Štreimikienė D. Externalities of power generation in Visegrad countries and their integration through support of renewables [J]. Economics and Sociology, 2021, 14(1): 89-102.
[7] Yu H, Dong S, Fei H, et al. Research on the Application of Econometric Model Parameters in Measuring the Internalization Degree of Industrial Positive Externalities [J]. Polish Journal of Environmental Studies, 2022, 31(1).
[8] Ghoddousi S, Talebi A F. The external cost of electricity generation: an applicable approach for environmental decision-making on electricity exportation strategy [J]. European Journal of Sustainable Development Research, 2021, 5(3): em0165.
[9] Pigou, A. C. (1920). The Economics of Welfare. London, UK: Macmillan.
[10] Li B, Chen S, Huang W, et al. Pricing of grid electricity of reservoir power plants based on quantification of the values of positive externality factors [J]. Water Policy, 2020, 22(3): 376-395.