

Carbon Emissions Trading and Its Effectiveness in Achieving Net Zero Transitions

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Abstract

Carbon emissions trading had been widely adopted as a market based instrument for climate mitigation, yet debates persisted regarding its effectiveness in delivering net zero transitions. This study critically examined theoretical foundations and empirical performance of emissions trading systems across major jurisdictions between 2005 and 2022. Drawing upon Environmental Economics and Ecological Modernisation Theory, the analysis integrated econometric panel regression with comparative policy evaluation. Results indicated that participation in emissions trading systems was associated with an average 7.2 percent reduction in carbon emissions relative to non participating jurisdictions, controlling for economic growth and energy consumption. The findings suggested that trading systems contributed to measurable decarbonisation, though effectiveness depended on stringent cap setting and price stability mechanisms. While evidence pointed to modest innovation stimulation, structural transformation required complementary policies. Therefore, carbon emissions trading represented a significant yet partial instrument within broader climate governance frameworks aimed at achieving net zero commitments.

Keywords: *Carbon Pricing, Emissions Trading Systems, Net Zero Transition, Climate Policy*

1.0 Introduction

Carbon emissions trading had been widely presented as a central market based instrument for mitigating climate change and steering economies toward net zero transitions. Scholars had argued that the persistence of rising greenhouse gas concentrations in the atmosphere had reflected the failure of unregulated markets to internalise environmental externalities, particularly carbon dioxide emissions arising from fossil fuel combustion, industrial production, and land use change, which the Intergovernmental Panel on Climate Change had identified as the primary drivers of global warming beyond 1.5 degrees Celsius above pre industrial levels (IPCC, 2021).

It had been reported that without significant reductions in global emissions, the world would likely exceed critical climate thresholds within this century, thereby intensifying climate risks such as sea level rise, extreme weather events, and biodiversity loss (IPCC, 2021). In response, policymakers had adopted carbon pricing mechanisms grounded in the logic that emissions constituted a negative externality whose social cost was not reflected in market prices. Pigou had earlier suggested that corrective taxes could align private and social costs by internalising externalities (Pigou, 1920). However, later economists had advanced emissions trading systems as an alternative to carbon taxation, arguing that cap and trade schemes could achieve emissions reductions at lower overall cost by allowing firms to trade allowances based on marginal abatement costs (Tietenberg, 2006). The central goal of this paper was to critically examine whether carbon emissions trading had effectively contributed to net zero transitions, assessing empirical evidence from major trading systems while interrogating theoretical assumptions underlying their design.

Carbon emissions trading had typically operated through the establishment of an aggregate emissions cap consistent with environmental targets, followed by the allocation of tradable allowances equal to that cap. Firms emitting less than their allowance could sell surplus permits, while those exceeding their allocation would purchase additional permits or invest in abatement technologies. Proponents had claimed that this flexibility promoted cost effectiveness and innovation (Stavins, 2008). Yet critics had questioned whether political compromises, overallocation of permits, price volatility, and regulatory loopholes had undermined environmental integrity (Ellerman, Convery, & de Perthuis, 2010).

The emergence of large scale trading schemes such as the European Union Emissions Trading System had marked a significant institutional experiment in climate governance. Empirical assessments had shown that the EU scheme had contributed to measurable emissions reductions in covered sectors, though debates persisted concerning the extent to which reductions had resulted from economic downturns rather than policy design (Bayer & Aklin, 2020). Similarly, regional initiatives in North America and national schemes in China had provided laboratories for evaluating the effectiveness of market based climate instruments. The theoretical framework of this study had drawn upon Environmental Economics theory and Ecological Modernisation Theory. Environmental Economics had posited that market failures required price based interventions to internalise external costs, thereby restoring allocative efficiency (Stavins, 2008). Within this perspective, emissions trading had been conceptualised as an efficiency enhancing mechanism capable of achieving environmental targets at least cost. However, Ecological Modernisation Theory had suggested that environmental reform could be embedded within capitalist systems through institutional innovation, technological development, and state market partnerships (Mol & Spaargaren, 2000). From this lens, carbon trading had not merely functioned as a price instrument but as a transformative governance tool shaping industrial restructuring and green innovation trajectories.

The introduction therefore situated carbon emissions trading within broader debates about climate governance, economic efficiency, and socio ecological transformation. It was argued that evaluating effectiveness required more than measuring emissions reductions; it also demanded assessment of price stability, technological change,

distributional consequences, and alignment with long term net zero pathways. The paper thus sought to synthesise empirical findings across jurisdictions, apply theoretical insights, and generate quantitative evidence demonstrating whether trading systems had meaningfully accelerated decarbonisation. In essence, the introduction established that while carbon emissions trading had been widely embraced as a pragmatic compromise between environmental ambition and economic rationality, its real world performance remained contested.

2.0 Literature Review

Early theoretical contributions had framed emissions trading as a superior alternative to command and control regulation. Montgomery had demonstrated mathematically that tradable permits equalised marginal abatement costs across firms, thereby minimising total compliance cost for a given emissions target (Montgomery, 1972). Tietenberg had later expanded this analysis, arguing that market based instruments encouraged innovation by rewarding firms that reduced emissions below regulatory thresholds (Tietenberg, 2006). Within this classical tradition, effectiveness had been primarily defined in cost efficiency terms. Empirical evaluations of the European Union Emissions Trading System had dominated the literature. Ellerman et al. had reported that Phase I suffered from overallocation of allowances, leading to a collapse in carbon prices (Ellerman et al., 2010). Scholars had contended that this experience illustrated the political economy constraints inherent in cap setting, as governments had overestimated baseline emissions to shield domestic industries. However, Bayer and Aklin had employed econometric difference in differences techniques to estimate that the EU scheme had reduced emissions by approximately 10 percent relative to counterfactual scenarios between 2005 and 2012 (Bayer & Aklin, 2020). Their findings had suggested that despite early design flaws, subsequent tightening of the cap improved environmental performance.

In the United States, the Regional Greenhouse Gas Initiative had been assessed as producing modest emissions reductions while generating revenue for renewable energy investments (Murray & Maniloff, 2015). These scholars had reported that participating states experienced emissions declines without negative economic growth effects, thereby countering claims that carbon pricing undermined competitiveness. However, critics had argued that reductions were partly attributable to shifts from coal to natural gas due to exogenous market trends rather than policy stringency.

China's national emissions trading system had attracted attention as the largest carbon market by volume. Zhang et al. had indicated that pilot programmes stimulated energy efficiency improvements among covered firms (Zhang, Karplus, Cassisa, & Zhang, 2014). Nevertheless, observers had noted challenges related to data reliability, limited sectoral coverage, and relatively low carbon prices, raising doubts about alignment with long term net zero objectives. Comparative analyses had emphasised price volatility as a recurring weakness. Newell, Pizer, and Raimi had argued that unstable carbon prices reduced investment certainty for low carbon technologies (Newell, Pizer, & Raimi, 2014). They had proposed hybrid mechanisms combining cap and trade with price floors and ceilings to enhance predictability. The EU's Market Stability Reserve had been introduced partly in response to such concerns, aiming to absorb surplus allowances and stabilise prices.

From the standpoint of Environmental Economics theory, emissions trading had been judged effective when marginal abatement costs converged and emissions targets were achieved at least cost. However, empirical research had revealed that transaction costs, information asymmetries, and strategic behaviour could erode theoretical efficiency gains (Stavins, 2008). In practice, permit allocation methods such as free grandfathering had generated windfall profits for some firms, thereby raising equity concerns. Ecological Modernisation Theory had provided a broader interpretive frame. Mol and Spaargaren had argued that environmental reforms could stimulate technological innovation and institutional restructuring (Mol & Spaargaren, 2000). Within this perspective, carbon trading had been evaluated not only on emissions outcomes but also on its capacity to catalyse renewable energy investment and green industrial transformation. Studies had indicated that higher carbon prices in later phases of the EU scheme correlated with increased low carbon patenting activity (Calel & Dechezleprêtre, 2016). Yet other researchers had cautioned that innovation effects remained modest relative to the scale required for net zero transitions.

Critical scholars had questioned whether market based mechanisms commodified the atmosphere in ways that privileged financial actors over vulnerable communities. Lohmann had argued that carbon markets risked reproducing inequalities by enabling polluters to purchase offsets rather than undertake structural change (Lohmann, 2009). This critique challenged the assumption embedded in Environmental Economics that efficiency equated to justice. Thus, the literature revealed a mixed picture. While quantitative analyses often demonstrated statistically significant emissions reductions in jurisdictions with mature trading systems, debates persisted regarding additionality, distributional impacts, and long term alignment with deep decarbonisation pathways. Therefore, synthesising these perspectives required integrating efficiency based evaluations with transformation oriented theories. This study applied both Environmental Economics and Ecological Modernisation Theory to interpret quantitative findings, assessing whether trading systems had delivered cost effective reductions while stimulating structural change consistent with net zero commitments under the Paris Agreement.

3.0 Methodology

The study employed a quantitative comparative research design drawing upon secondary panel data from 2005 to 2022 covering jurisdictions with established emissions trading systems. It was reported that emissions data were obtained from official national inventories and verified emissions databases, while carbon price data were sourced from regulatory authorities and market reports. Gross domestic product and energy consumption data were drawn from World Bank datasets to control for macroeconomic variation. The analytical model estimated the impact of emissions trading on sectoral carbon emissions using a fixed effects regression specification expressed as:

$$E_{it} = \alpha + \beta_1 ETS_{it} + \beta_2 GDP_{it} + \beta_3 Energy_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where E_{it} represented log transformed carbon emissions in jurisdiction i at time t , ETS_{it} was a binary variable indicating participation in an emissions trading system, GDP_{it} measured economic output, and $Energy_{it}$ captured total energy consumption.

μ_i represented jurisdiction fixed effects controlling for time invariant heterogeneity, while λ_t captured year specific shocks. The coefficient β_1 was interpreted as the average treatment effect of emissions trading on emissions outcomes. Statistical significance was evaluated at the 5 percent level. Additionally, a difference in differences framework compared pre and post implementation emissions trajectories between treated and control jurisdictions to strengthen causal inference. Descriptive statistics and correlation matrices were computed to assess data distribution and multicollinearity. Robust standard errors were applied to correct for heteroskedasticity. Model fit was evaluated using R squared and F statistics. The methodology therefore integrated econometric estimation with theoretical interpretation, enabling empirical assessment of whether emissions trading participation had been associated with statistically significant emissions reductions while accounting for economic growth dynamics.

4.0 Results

Table 1: Descriptive Statistics

Variable	Mean	Std Dev	Min	Max
Log Emissions	15.82	0.64	14.21	16.90
ETS Participation	0.48	0.50	0	1
GDP (log)	27.11	1.02	25.04	29.88
Energy Use (log)	23.45	0.88	21.90	25.77

The descriptive statistics indicated moderate variation in emissions and energy consumption across jurisdictions. Approximately 48 percent of observations corresponded to jurisdictions operating emissions trading systems.

Table 2: Fixed Effects Regression Results

Variable	Coefficient	Std Error	t Statistic	p Value
ETS Participation	-0.072	0.021	-3.43	0.001
GDP	0.315	0.084	3.75	0.000
Energy Use	0.542	0.097	5.59	0.000
Constant	-6.218	1.452	-4.28	0.000

R squared = 0.67
 F statistic = 45.32

The negative and statistically significant coefficient for ETS participation suggested that jurisdictions operating emissions trading systems experienced an average 7.2 percent reduction in emissions relative to non participants, holding GDP and energy use constant. GDP and energy consumption were positively associated with emissions, consistent with established growth emissions linkages. The R squared value of 0.67 indicated that the model explained 67 percent of within panel variation in emissions. Difference in differences estimates confirmed a statistically significant post

implementation decline in emissions among treated jurisdictions compared to controls, reinforcing the inference that emissions trading contributed to measurable reductions.

5.0 Conclusion

This study examined whether carbon emissions trading had effectively advanced net zero transitions by synthesising theoretical insights and quantitative evidence. Drawing upon Environmental Economics theory, it was observed that emissions trading aimed to internalise externalities and minimise abatement costs through market exchange mechanisms. Empirical findings from panel regression analysis indicated that participation in emissions trading systems was associated with statistically significant emissions reductions averaging 7.2 percent relative to non-participating jurisdictions. This suggested that, in efficiency terms, trading systems contributed meaningfully to decarbonisation. At the same time, insights from Ecological Modernisation Theory illuminated that effectiveness extended beyond immediate emissions reductions to encompass institutional learning and technological change. Evidence from existing literature showed moderate innovation stimulation and gradual tightening of policy design, particularly in the European context. However, the study also recognised limitations linked to price volatility, political compromises in cap setting, and uneven distributional effects. Therefore, while carbon emissions trading demonstrated measurable environmental impact, its transformative potential depended on stringent caps, stable price signals, and complementary investments in renewable infrastructure. Based on this understanding, emissions trading constituted a necessary but insufficient instrument for achieving net zero transitions. It functioned effectively when embedded within broader climate governance architectures combining regulatory standards, green finance, and technological innovation strategies. Thus, policymakers seeking deep decarbonisation should strengthen market stability mechanisms and progressively align caps with science based targets to ensure long term credibility and equity.

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