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REVIEW

Economic Cost-Benefit Analysis and Environmental Resource Management Performance Evaluation under the Carbon Trading Market

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ABSTRACT

The carbon trading markets have emerged as a key policy tool to achieve climate mitigation with economic flexibility. Current research, however, tends to examine their impacts from either an economic or an environmental perspective, yielding mixed results regarding market performance. This review is developing an integrated framework for the analysis of economic cost-benefit effects and environmental resource management performance under carbon trading markets. It first summarizes the theoretical basis of carbon trading, including internalizing externalities, property rights allocation, the cap-and-trade system, and carbon price formation. It then reviews key economic costs, such as compliance costs, transaction costs, administrative costs, and costs of low-carbon investment, and key economic benefits, which include abatement-cost savings, increasing energy efficiency, green innovation, and auction revenue. The review also examines aspects of environmental performance, including emission reduction, carbon productivity, resource-use efficiency, pollution-control co-benefits, green innovation, and governance capacity. The article proposes to consider carbon trading as a dynamic governance system, rather than a single trading system, by connecting these facets. The results indicate that well-designed carbon markets require credible price signals, adequate caps, robust monitoring, sufficient liquidity, and policy support. Future research should focus on dynamic assessment, causal analysis, sectoral and regional differences, firm-level dynamics, digital governance, and distributional justice. This holistic view offers insights into theory and practice for the design of carbon markets and the sustainable management of resources.

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1. Introduction

The mitigation of climate change has become not only a policy ambition but a fundamental economic development, industrial restructuring, and environmental resource management limitation. Carbon trading markets are among the most influential market-based policy instruments for internalizing greenhouse-gas externalities [1]. Carbon trading makes emission reduction an economic choice, rather than an administrative one, by giving a value to carbon-emission rights that can be traded in the market for allocation, abatement investment, technological innovation, and optimization of resources [2]. Today, the institutional significance of carbon pricing is growing: carbon pricing instruments now cover approximately 28% of global emissions, and in 2024, more than USD 100 billion was collected in public revenues from carbon pricing. Additionally, emissions trading systems play a significant role in newly established and planned carbon pricing instruments [3].

Carbon trading markets have engendered a new research area that lies at the intersection of environmental economics, resource management, public policy and corporate sustainability [4]. In 2025, there were 38 emissions trading systems (ETS) globally, and 20 ETS were under development or consideration, reflecting carbon trading moving beyond the few pioneering jurisdictions to become a mainstream tool of climate governance. It is still, to date, the world's first international emissions trading system, the European Union Emissions Trading System, which is in its fourth phase since 2005 [5]. It establishes a decreasing ceiling on emissions from the covered sectors and targets a 62% reduction in emissions from the covered sectors by 2030 compared to 2005. In the meantime, China's national carbon market has entered a new phase, expanding from the power sector to steel, cement, and aluminum, significantly scaling up and diversifying sectoral governance of carbon trading [6]. The developments confirm that carbon markets are more relevant than ever for emissions reduction, as well as for industry competitiveness, the energy transition, and environmental resource allocation.

But whether emissions go down or not is not the only way to measure the effectiveness of carbon trading. Carbon trading markets are set up so that the firms that have lower marginal abatement costs can sell allowances, and the firms that have higher marginal abatement costs can buy them, thereby reducing emissions at a lower economic cost. Hence, the effectiveness of carbon trading systems should be judged on both economic and environmental grounds. On the economic side, there are compliance costs, costs of purchasing allowances, monitoring, reporting and verification costs, transaction costs and investment costs associated with using low carbon technologies [7]. Meanwhile, carbon trading can yield benefits like abatement-cost savings, auction revenues, energy efficiency, green innovation, and improved allocation of production factors. With respect to environmental resource management, carbon trading can help to strengthen carbon productivity, resource-use efficiency, pollution-control ability and environmental governance capacity [8]. A main analytical challenge is that these costs, benefits and environmental outcomes are closely connected and are often assessed separately.

Existing studies have yielded valuable evidence on the economic and environmental impacts of carbon trading. One strand of research has focused on the abatement cost savings and economic benefits of carbon-emission trading, particularly the efficiency gains that could be achieved under a market-based allocation [8]. Other studies have investigated the effectiveness of emissions trading schemes (ETS) in cutting emissions, stimulating green innovation, enhancing total factor productivity (TFP), or influencing enterprise behavior, using econometric models and quasi-natural experiments based on difference-in-differences [9]. In more recent studies, the integrated energy, environmental, and economic impacts of carbon market policies have also been assessed, indicating a shift toward integrated assessment. However, the literature is still scattered. Cost-benefit analysis of the economy is often analyzed from the angle of the compliance burden, macro-economic impacts, or marginal abatement costs, while environmental performance analysis is often analyzed in separate indicators, such as carbon intensity, green innovation efficiency, or resource productivity. This separation constrains the capacity to account for how economic incentives in carbon trading are translated into measurable improvements in environmental resource management.

This review article fills this gap by providing an integrated analytical point of view on the economic cost-benefit analysis and environmental resource management performance evaluation under the carbon trading market. Its novelty is, first, the change in evaluation logic from emission reduction alone to a dual-objective economic-environmental evaluation framework. This review understands carbon trading not only as a way to control emissions but also as a governance instrument that affects enterprise costs, market incentives, resource allocation, technological upgrading, and ecological performance [10]. This is significant because carbon markets can yield different outcomes across sectors, regions, and firm types. A high carbon price can spur innovation in one industry while imposing a heavy compliance burden on another. Likewise, if not well designed, free allocation of allowances can lower the risk of carbon leakage and diminish incentives for deep decarbonization. Thus, the scope of a comprehensive review should include efficiency and effectiveness; it should include market performance and environmental results.

Second, this article contributes by systematically comparing and linking cost-benefit analysis and environmental performance evaluation methods. Net present value analysis, marginal abatement cost curves, social cost of carbon estimation, computable general equilibrium models and input-output analysis are all widely used tools for cost-benefit analysis [11]. On the other hand, environmental performance evaluation frequently relies on data envelopment analysis, stochastic frontier analysis, entropy-weight methods, multi-criteria decision-making models, and causal inference [12]. These methodological traditions have grown side by side, and there is still a lack of integration. This article aims to present a line of reasoning that, through an examination of the complementarities of these different methods, can help the evaluation of the net economic benefits of carbon trading and its impact on the performance of environmental resource management. Through such integration, one-sided conclusions could be avoided, e.g., regarding a carbon market as successful if emissions are reduced, as well as the costs of the carbon market, while not taking into account the potential long-term innovation and resource-efficiency benefits.

Third, this review highlights the importance of carbon-market design in shaping economic and environmental outcomes. The effective implementation of institutional designs, such as the stringency of the cap, the allocation of allowances, auctioning rules, offset eligibility, price-stabilization mechanisms, the quality of monitoring and verification, and the coverage of sectors, is crucial for market performance [13]. The EU ETS also shows how reducing the emissions cap and making it applicable to more sectors can amplify the mitigation incentives in the ETS, and in this case, ETS2 will expand carbon pricing to buildings, road transport, and more sectors from 2027. The sectoral growth also illustrates the process of carbon markets moving from the power sector to wider industrial governance in China. These institutional variations affect the cost of compliance, liquidity, the price of allowances, investment prospects, and the credibility of the emission reduction signal [14]. So, the performance of environmental resource management cannot be divorced from the rules and constraints of the carbon market.

Fourth, this article focuses on heterogeneity and dynamic feedback. The impact on enterprises and industries, and the regions, varies according to energy structure, technological capability, maturity of the market, compliance rate of the regulations, and resource endowment [15]. Carbon trading could act as an incentive for faster energy substitution and process innovation in resource-intensive sectors, but it could also increase production costs and raise competitiveness concerns. The market may pass carbon prices on more effectively to green investment decisions in areas where financial markets and environmental regulations are more advanced. The effectiveness of policy can be diminished by a low capacity to monitor, or by a lack of access to low-carbon finance in less developed regions [16]. A review that accounts for heterogeneity can help explain variation in cost-benefit ratios and environmental performance outcomes across different contexts with the same carbon-market policy.

With these considerations in mind, this article attempts to review, both theoretically and economically, the cost-benefit mechanisms, environmental performance evaluation approaches, and integrated assessment frameworks related to carbon trading markets [17]. The paper is a review and makes the following contributions to the literature: first, carbon trading establishes economic incentives for reducing emissions; second, these incentives impact environmental resource management; and third, future research can be oriented toward building more robust evaluation systems. It also has practical implications for policymakers seeking to better design carbon markets, for companies seeking to optimize their compliance and investment strategies, and for researchers seeking to build multidimensional evaluation models. The overall research logic and integrated analytical pathway of this review are summarized in **Figure 1**. By integrating economic cost-benefit analysis with environmental resource management performance evaluation, this article provides a more complete understanding of how carbon trading markets can support the coordinated achievement of economic efficiency, environmental effectiveness, and sustainable resource governance [8].

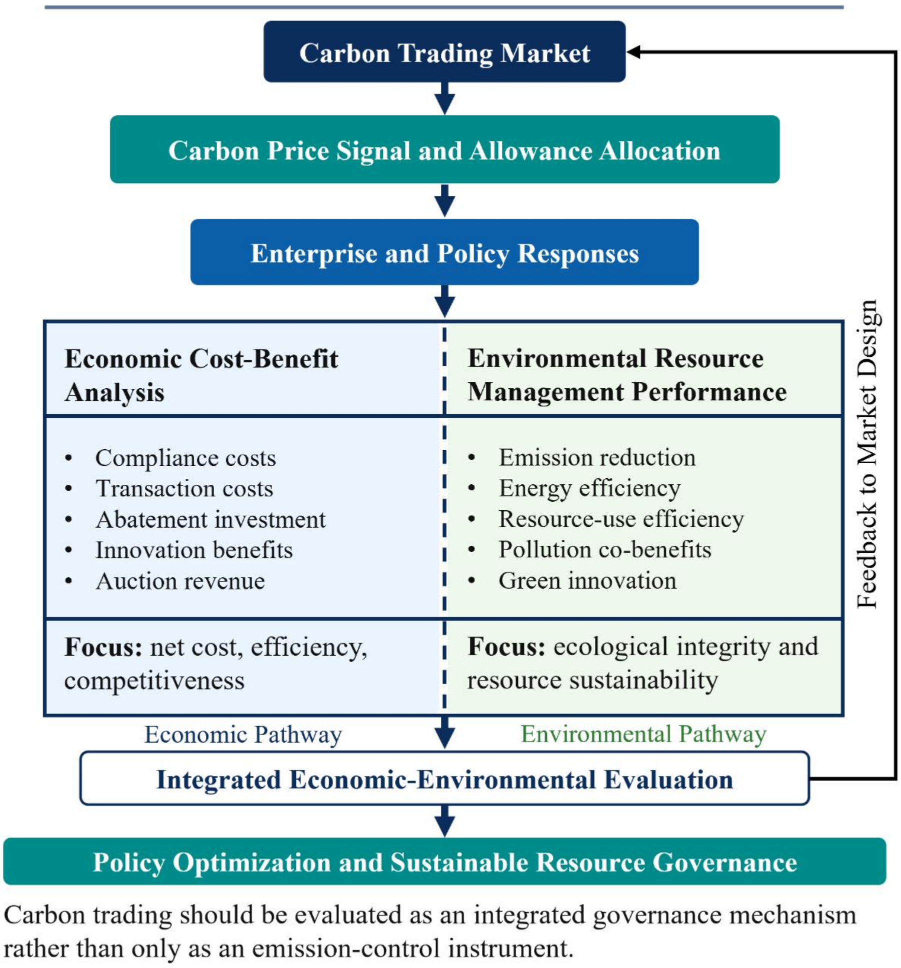

Figure 1. Conceptual framework.

Note: The framework links carbon trading markets, economic cost-benefit analysis, environmental resource management performance, and policy optimization.

2. Theoretical Foundations of Carbon Trading Markets

2.1. Conceptual Logic of Carbon Trading

Carbon trading is a market-based environmental regulation mechanism that aims to make greenhouse gas emissions an economic resource by treating them as a scarce commodity, removing them from the status of an unpriced externality [1]. Its basic reasoning is that the atmosphere has a limited absorptive capacity that needs to be allocated, priced, and traded within the rules of a set of institutions. Carbon trading is a flexible mechanism because regulated entities can either reduce emissions on-site or trade emission allowances with others who can reduce emissions more cheaply. The flexibility is expected to lead to a lower overall cost of achieving a specific environmental target, since firms with lower MAC can reduce emissions more and sell excess allowances to firms with higher MAC, which in turn can buy them.

Carbon markets have been expanding fast and exerting a greater influence on climate governance. Currently, approximately 28% of global emissions are subject to carbon pricing, and in 2024, these measures raised over USD 100 billion in public revenues worldwide, according to the World Bank. Environmental economists see this as a sign that emission rights are increasingly being considered not only as environmental constraints but also as financialized regulatory assets. But carbon trading is not just about "putting a price on carbon." Whether the market price truly signals scarcity, how strict the caps are, and whether the carbon price is perceived as a reliable signal for long-term technological investment are all crucial in determining its effectiveness [18].

2.2. Externality Theory and Property-Rights Allocation

The basic theory of carbon trading comes from the theory of externalities. Social costs of greenhouse gases (GHGs) are not fully internalized in their prices, leading to over-emissions that unregulated markets generate. Carbon trading is an effort to internalize this externality through a price on pollution. In this way, the carbon allowance serves as an institutional link between private production decisions and social and environmental costs [10].

The theory of property rights also helps explain why tradable emission allowances can have an allocation-enhancing effect. If emissions rights are well specified, measured, and controlled, firms can trade them to optimally distribute the burden of abatement. This concept is similar to the Coasian tradition, but in practice, carbon markets face problems with transaction costs, information asymmetries, market power, and regulatory uncertainty. Thus, the establishment of carbon property rights is not just a legal process; it is a governance process involving a series of allowance allocations, compliance enforcement, registry management, and market supervision [19].

The important point is that the effectiveness of carbon trading would depend not only on property rights but also on their initial distribution [20]. While free allocation can minimize political opposition and ensure emission-intensive industries are not hurt during the transition, it can also dilute the carbon-cost signal and generate windfall profits. Auctioning has the effect of improving price discovery and can give public revenues for low-carbon investment; however, it can drive up the short-term compliance costs for companies. This makes the allocation of allowances a distributional justice problem as well as an economic design problem.

2.3. Cap-and-Trade Mechanism and Market Architecture

The standard carbon trading model is the cap-and-trade system [21]. Regulators set an overall emissions cap, distribute or auction allowances, and require covered entities to surrender allowances equal to their verified emissions. The cap determines environmental ambition, while trading determines cost-effective allocation. If the cap is loose, carbon prices remain low, and abatement incentives weaken. If the cap is too stringent and lacks supporting transition mechanisms, firms may face excessive cost pressures and competitive risks.

The majority of emissions trading systems today are becoming more complicated. They involve banking and borrowing regulations, offset mechanisms, auction platforms, price containment, stability reserves, and monitoring, reporting, and verification systems [22]. These are not "secondary" factors; rather, they spell the difference in the market's ability to generate credible and stable incentives. For instance, offsets can lower compliance costs by enabling emission reductions outside covered sectors; however, excessive reliance on low-quality offsets can undermine environmental integrity. In the same way, allowances granted in one compliance period that carry over to the next will benefit intertemporal flexibility, while excessive allowance surpluses will reduce carbon prices and motivate delays in investing in clean technologies.

According to the International Carbon Action Partnership, in 2025, 38 emissions trading systems (ETS) were in place worldwide, and 20 others were either being developed or considered. These systems contributed approximately 23% of GHG emissions. This diversity indicates that carbon trading has evolved from an institution to a policy family. Jurisdictions develop their market structures according to their economic structure, administrative capacity, energy mix, and political constraints [23].

2.4. Carbon Price Formation and Investment Incentives

Carbon price formation is central to the functioning of carbon trading markets. In theory, the allowance price should reflect the marginal cost of abatement required to meet the emissions cap. In practice, prices are influenced by energy demand, fuel prices, industrial output, weather, technology costs, financial speculation, policy expectations, and macroeconomic conditions. Therefore, carbon prices are both environmental signals and macroeconomic indicators [24].

A well-functioning carbon price should guide firms toward least-cost abatement and encourage long-term investment in energy efficiency, renewable energy, process optimization, and low-carbon innovation [23]. However, price volatility can reduce investment certainty. When carbon prices are too low, firms may treat allowances as routine compliance expenses rather than strategic incentives for transformation. When prices fluctuate sharply, firms may delay investment because future returns become uncertain. This creates a policy dilemma: carbon markets need price flexibility to reflect scarcity, but they also need sufficient stability to support long-term decarbonization.

The EU ETS illustrates the importance of cap stringency in price formation. The European Commission states that the revised EU ETS cap is designed to reduce covered-sector emissions by 62% by 2030 compared with 2005 levels, with the annual reduction factor increasing to 4.3% for 2024–2027 and 4.4% from 2028. This tightening strengthens scarcity expectations and improves the credibility of carbon pricing. Nevertheless, even mature systems must balance environmental ambition with industrial competitiveness, social acceptability, and energy-security concerns [25].

2.5. Carbon Trading and Environmental Resource Allocation

Carbon trading affects environmental resource management by reshaping how firms allocate energy, capital, technology, and production capacity [8]. When carbon emissions carry a market price, high-carbon production processes become more expensive, while low-carbon technologies become more attractive. As a result, carbon trading can promote resource reallocation from carbon-intensive activities to cleaner, more efficient ones. This mechanism links carbon markets with broader environmental resource management performance, including energy efficiency, pollution reduction, industrial upgrading, and ecological governance.

However, the relationship between carbon trading and resource management is not automatic. Firms may respond to carbon prices through genuine emission reductions, allowance purchases, output adjustments, cost pass-through, or relocation [26]. Only the first two responses are directly embedded in the intended market logic, while relocation and cost pass-through may weaken domestic environmental gains or create social distributional concerns. Therefore, evaluating carbon trading requires attention to behavioral responses rather than merely observing aggregate emissions.

Another critical issue is the interaction between carbon trading and other environmental policies. Carbon markets often coexist with renewable-energy subsidies, energy-efficiency standards, pollution-control regulations, green finance policies, and industrial restructuring programs [14]. These overlapping policies may reinforce each other, but they may also reduce carbon-market efficiency if they create redundant incentives or distort allowance demand. A theoretically sound evaluation of carbon trading must therefore consider policy interaction effects rather than isolating the carbon market from the wider environmental governance system.

2.6. Comparative Insights from Major Carbon Trading Systems

The EU ETS and China's ETS are two powerful models that differ structurally. The EU ETS is an absolute cap, with successive phases of operation that increase and decrease the cap over time. It now addresses large-emitting sectors and has increasingly focused on auctioning, reducing the cap, and integration with the EU's overall climate targets. The European Commission also says that the 2023 revision toughened up the cap and updated free allocation rules, including those tied to decarbonization measures [5]. This is a mature-market logic in which carbon trading is expected to drive greater structural transformation.

The national carbon market in China is different. Its origins were in the power industry, and now it's spreading to the cement, steel, and aluminum industries. International Carbon Action Partnership (ICAP) said the growth would bring approximately 1,500 new businesses and a rise in covered emissions of approximately 3 Gt CO_2e. China's system has focused more on intensity-based allocation and has included a few sectors gradually as compared to the EU ETS [6]. This design addresses the issue of balancing emissions and economic development, industrial stability, and energy security. The contrast reveals that the extent of national development stages and institutional capacity, rather than theoretical efficiency criteria, drives carbon trading systems.

2.7. Critical Synthesis

The theoretical basis for carbon trading is a strong but contingent argument that market instruments can deliver environmental outcomes at lower economic cost when emission rights are limited, tradable, credible, and enforceable [27]. **Table 1** provides an overview of the key theory behind carbon trading markets and their implications for economic efficiency, environmental regulation, and institutional governance. This proposition can serve as a basis for integrating economic cost-benefit analysis and environmental resource management performance evaluation. However, the effectiveness of carbon markets in the real world depends on market liquidity, the credibility of the regulations, the availability and quality of data, and firms' ability to adapt.

Therefore, carbon trading should be viewed not as a self-sufficient solution but as an adaptive governance mechanism. Its success depends on continuous adjustment of caps, allocation rules, price-stabilization mechanisms, sectoral coverage, and monitoring systems [14]. The central challenge is to ensure that carbon prices are strong enough to change behavior, stable enough to guide investment, and fair enough to maintain political legitimacy. This theoretical understanding provides the foundation for evaluating the economic costs, benefits, and environmental management outcomes discussed in the following sections.

Table 1. Theoretical foundations of carbon trading markets and their implications for economic efficiency and environmental governance.

Theoretical Foundation	Core Assumption	Application in Carbon Trading	Critical Insight
Externality theory	Greenhouse-gas emissions impose social costs not reflected in market prices	Carbon trading internalizes emission externalities by assigning a price to carbon emissions	Effectiveness depends on whether the carbon price is high and credible enough to change behavior
Property-rights theory	Clearly defined and enforceable rights improve resource allocation	Emission allowances define the right to emit a limited quantity of carbon	Poor allowance allocation may create windfall profits or weaken emission-reduction incentives
Coase theorem	Trading can improve efficiency when rights are defined and transaction costs are low	Firms trade allowances according to their marginal abatement costs	Real-world transaction costs, information asymmetry, and regulatory uncertainty limit ideal efficiency
Marginal abatement cost theory	Firms have different costs for reducing emissions	Low-cost firms reduce more emissions and sell allowances; high-cost firms buy allowances	Market efficiency depends on liquidity, transparent prices, and accurate emissions data
Market equilibrium theory	Prices balance allowance supply and demand	Carbon prices emerge through trading under a fixed or gradually tightening cap	Price volatility may weaken long-term low-carbon investment incentives
Environmental governance theory	Market mechanisms require institutional support	Monitoring, reporting, verification, enforcement, and registry systems sustain market credibility	Carbon trading is not self-executing; it requires strong governance capacity

3. Economic Cost-Benefit Analysis under the Carbon Trading Market

3.1. Analytical Logic of Cost-Benefit Evaluation

The purpose of economic cost-benefit analysis for a carbon trading market is to establish whether the economic benefits of market-based emission reduction are greater than the economic burden placed on enterprises, industries, governments and society. Carbon trading is not just about compliance with a set technical standard, as in traditional environmental regulation. Instead, it sets a price signal on carbon emissions and enables firms to make a price comparison between abating carbon emissions within their own business and buying allowances. Therefore, the question of cost-benefit analysis is at the heart of the debate on whether carbon markets can deliver emission reductions at the lowest social costs [28].

The economic principle is that those firms that have a lower marginal abatement cost should abate more emissions, and those who have a higher marginal abatement cost can buy allowances [29]. Theoretically, this allocation reduces the overall abatement costs in the system being regulated. Yet in reality, it requires some conditions: the cap needs to be stringent enough, the allocation of the allowance needs to be carefully managed to not allow too many to be issued, transaction costs need to be kept manageable, and the carbon price needs to be high enough to affect corporate decisions. In the absence of these conditions, carbon trading could shift to being a compliance tool without having transformative consequences.

One of the biggest problems with cost benefit analysis is determining what constitutes a benefit. Focusing on narrow evaluations can mean that costs and benefits are assessed in narrow terms, e.g., as allowance trading revenue or reduced compliance expenditure. The other advantages of carbon trading, however, are energy efficiency, technological innovation, lower air pollution, health co-benefits, higher environmental quality, and long-term competitiveness of industries. So, a strict cost-benefit analysis framework must also include market measurable benefits as well as broader social-environmental benefits [17]. In the absence of that, the value of carbon trading could be under-estimated.

3.2. Compliance Costs and Direct Economic Burdens

The economic cost incurred by the regulated entity, which is the first to come to mind, is called compliance cost. This covers the expenses associated with the acquisition of allowances, the installation of emission monitoring equipment, the production of reports, the verification of emission data, and the modification of production and/or energy-use structures [30]. These costs can have a substantial impact on short-term profitability for companies with high emissions in carbon-intensive industries, particularly during periods of high and rapid carbon prices or when the number of carbon allowances is reduced.

Maybe the most obvious item of compliance cost is the cost of purchasing allowances. If a firm's emissions go over the targets it has to purchase ETS permits from the market. This has a direct financial cost, and serves as the intended incentive for emissions reduction. The real issue is whether this pressure can be used as a positive force for upgrading the technologies or it can serve only as an extra operating expense. The reduction effect of carbon emissions may be limited if firms can pass on the carbon costs to consumers without altering production processes. In a competitive market, firms that cannot shift energy costs may have to become more efficient in their use of energy and/or lower their emissions [31].

The monitoring, reporting, and verifying costs are also relevant but not always given due attention. The key to carbon trading is accurate emissions data. Allowance distribution, compliance evaluation and market credibility are undermined if there is no reliable data [32]. But providing high quality monitoring systems does need an investment in measurement equipment, digital reporting platforms, third-party verification, and internal capacity to manage the monitoring system. While these costs might be reasonable for enterprises of large size, they may be too pricey for smaller businesses. Hence, there is a possibility of unintentional pressure to comply with the trading system between different sized companies.

3.3. Abatement Investment and Technological Transition Costs

In addition to direct compliance costs, carbon trading might also encourage companies to invest in emission reduction technology. Investments can cover energy-saving equipment, transition to renewable energy, process optimization, carbon capture methods, waste heat recovery, digital energy management and cleaner production systems [33]. These investments are necessary for long-term decarbonization, but they can be costly and uncertain.

The economic challenge is that carbon trading alters the investment landscape but doesn't ensure technological change. Companies will invest in low carbon technologies if and only if the expected benefits are greater than the costs. The benefits are subject to the level of carbon pricing, the emergence of carbon scarcity, technology readiness, financing criteria and policy stability. With low or volatile carbon prices, companies can postpone investment and keep buying carbon allowances. This results in a "low-price trap," that is, the market exists in form but it does not induce deep emission reductions incentives [34].

Technological lock-in is another important issue. Companies with significant capital invested in high carbon equipment could be on the verge of significant transition expenses[35]. Production assets can have long lives in certain industries, such as steel, cement, chemicals and power generation. Timing replacement of these assets could lead to stranded costs, and late replacement could reduce the strength of emission reductions. Therefore, cost-benefit calculation should not only consider immediate compliance costs, but should also consider the time path and trajectory of the capital stock change.

3.4. Transaction, Administrative, and Market-Operation Costs

Transaction and administrative costs are also factored into carbon trading markets. Transaction costs consist of expenses associated with obtaining market information, using off- and online trading platforms, contracting, hedging price risk, and professional advice. Administrative costs refer to government expenditures on the registry system, allowance allocation, market supervision, emissions verification, legal enforcement, and policy adjustment[36].

A theoretical advantage of a carbon market is that it decentralizes carbon trading. In practice, transaction costs can compromise this efficiency. Firms with limited market knowledge may be unable to play an effective role and could be highly reliant on intermediaries. The intricacies of the market can also encourage speculative trading, particularly if financial institutions and trading agencies are involved. Financial involvement can improve liquidity, but can also lead to price volatility if trade is separated from actual abatement requirements.

Capacity building is particularly important in the context of a new carbon market. Poor regulation can result in inadequate emissions reporting, poor quality verification, an excess of allowances, or poor enforcement of compliance. These vulnerabilities put the market's credibility and the success of carbon pricing at risk. Administrative costs shouldn't be viewed as "burdens". Administrative investment is essential for market integrity if carefully designed. A well-designed, non-interventionist carbon market can lead to poor environmental and economic outcomes if it is low-cost yet poorly governed[37,38].

3.5. Economic Benefits: Cost Savings and Efficiency Gains

The primary economic benefit of carbon trading is cost savings relative to uniform regulation. By allowing firms to choose the most cost-effective abatement strategy, carbon trading can reduce total compliance costs at the system level[14]. This is particularly important when firms differ significantly in marginal abatement costs. In such cases, a uniform emission-reduction requirement may force high-cost firms to reduce emissions inefficiently, while low-cost reduction opportunities remain underused. Carbon trading corrects this inefficiency through market exchange.

Carbon trading can also improve resource allocation efficiency. Once carbon emissions are priced, firms have an incentive to use energy, raw materials, and production capacity more efficiently[26]. This can reduce waste, improve productivity, and encourage the shift from high-carbon to low-carbon activities. In this sense, the benefit of carbon trading is not limited to emission reduction; it may also support broader environmental resource management by improving the efficiency of resource use.

However, efficiency gains are not guaranteed. If allowance allocation is too generous, firms may have little incentive to reduce emissions. If markets are illiquid, prices may not reflect true scarcity. If firms receive free allowances based on historical emissions, high emitters may be rewarded rather than penalized. These problems show that the economic benefits of carbon trading depend heavily on institutional design[39]. A poorly designed market may produce low compliance costs, but such "low costs" may simply reflect weak environmental ambition rather than genuine efficiency.

3.6. Innovation Benefits and Green Transformation

One of the most significant long-term effects of carbon trading is that it can drive green innovation. A credible carbon price yields higher returns on low-carbon technologies, incentivizing companies to invest in research and development (R&D), implement cleaner processes, and enhance energy management systems. Carbon trading can offer greater opportunities for ongoing, flexible innovation incentives than command-and-control regulation by allowing companies to benefit from emissions reductions below their caps[40].

However, the innovation effect of the carbon trading is contingent. A lack of strong carbon prices could not compensate for the uncertainty surrounding technology and financing barriers [41]. Firms can opt for an inexpensive solution that is low in investment with a short repayment period instead of developing a complex technology. In some instances, carbon trading can even propel companies to buy and sell carbon permits rather than structurally transform their operations. This is especially true if the allowance price is less than the cost of significant technology improvements.

The link between carbon trading and innovation also varies from company to company [41]. Larger companies typically have greater financial strength, more technical resources available and have more experience in regulatory compliance. They might be more likely to take advantage of carbon trading and gain a competitive edge based on carbon constraints. Smaller companies may incur greater relative costs and have less innovation potential. Thus, without green finance, technology diffusing mechanisms and policy support, the performance gap could be expected to expand between enterprises under the carbon trading system.

3.7. Public Revenue and Social Benefits

Carbon trading can be a source of significant public revenues when allowances are traded on an auction [42]. This revenue can be directed to support renewable energy, low carbon infrastructure, industrial transition, household compensation, adaptation, or other distortionary taxes. The utilization of auction revenues is important from a social cost-benefit point of view. When revenue is used for low-carbon development and/or for social inequality reduction, the total benefit of carbon trading is enhanced.

Additionally, indirect social benefits from carbon trading could include lower air pollution levels, lower public health costs, and improved ecological quality [43]. Plus, many carbon reduction measures also reduce SO_2, NO_x, PM and other pollutants, such as improving energy efficiency and reducing coal use. These co-benefits might be very significant, particularly in areas where pollution is an issue. These benefits are not evident in corporate financial statements, however, so they are often overlooked or underestimated as part of the firm level cost/benefit analysis.

One of the major drawbacks of traditional cost-benefit analysis (CBA) is its tendency to undervalue environmental and health impacts more significantly than economic [44]. This can lead to an undue distortion of the evaluation of climate policies, as many benefits of carbon trading are only realized over the long term. So, the discount rate, time horizon and social valuation technique will have a significant effect on the overall evaluation outcome. The key economic cost and benefit elements outlined above are grouped in **Table 2**, which also specifies indicative elements and issues for evaluation.

Table 2. Economic cost-benefit components, measurement indicators, and evaluation challenges under carbon trading markets.

Category	Main Components	Typical Measurement Indicators	Evaluation Challenges
Compliance costs	Allowance purchase, surrender obligations, internal compliance management	Allowance expenditure, compliance cost per unit of output, cost-to-revenue ratio	Difficult to separate carbon-market costs from general production-cost changes
Monitoring and verification costs	Emission accounting, data collection, third-party verification, reporting systems	MRV expenditure, verification frequency, reporting accuracy	Costs vary significantly across firm size, sector, and technical capacity
Transaction costs	Market participation, brokerage fees, information search, risk management	Trading fees, bid-ask spread, trading frequency, liquidity indicators	Low liquidity may increase costs and weaken price discovery
Abatement investment costs	Energy-saving equipment, cleaner production, renewable-energy substitution, process upgrading	Capital expenditure, marginal abatement cost, payback period	Long-term benefits are uncertain and depend on future carbon prices
Administrative costs	Registry systems, regulatory enforcement, market supervision, policy adjustment	Government expenditure, regulatory staff cost, enforcement cost	Often excluded from firm-level analysis but important for social cost-benefit evaluation
Direct economic benefits	Allowance sales, reduced energy costs, avoided penalties, auction revenue	Trading revenue, energy savings, net present value, public revenue	Benefits may be unevenly distributed across firms and regions
Indirect economic benefits	Innovation, productivity improvement, green competitiveness, industrial upgrading	Green patents, total factor productivity, carbon productivity	Difficult to quantify and often appears only in the long term

Table 2. *Cont.*

Category	Main Components	Typical Measurement Indicators	Evaluation Challenges
Social co-benefits	Pollution reduction, health improvement, ecological benefits, climate-risk reduction	Reduced pollutant emissions, avoided health costs, social cost of carbon	Frequently underestimated because they are not directly reflected in corporate accounts

3.8. Methodological Approaches to Cost-Benefit Analysis

There are a number of approaches to estimating the economic impacts of carbon trading. Net present value analysis can help determine whether low-carbon investments can be expected to yield a positive return in the long term [45]. Marginal abatement cost analysis is a tool that can be used to help determine the cost of abating the next unit of emissions and to compare the costs of various abatement options [46]. To assess economy-wide impacts, such as output, consumption, trade, employment, and welfare impacts, computable general equilibrium models are used. Input-output analysis can identify indirect effects in a supply chain. Econometric approaches have become more popular to estimate the causal effects of carbon trading policies, particularly quasi-natural experiments.

There are pros and cons to both of them. Net present value (NPV) analysis is useful at the project/firm level but requires a lot of assumptions regarding future carbon prices and discount rates [45]. Comparisons using marginal abatement cost curves are intuitive, but can be misleading with respect to behavioral responses and technological learning [46]. Macroeconomic interactions are captured in computable general equilibrium models, which are based on theoretical assumptions that could be different from the actual conditions in firms. High-quality data and careful identification strategies are necessary, but the econometric methods are able to offer more convincing evidence of causality.

One of the key methodological issues is how to combine private cost-benefit analysis with social cost-benefit analysis. While direct financial costs and returns are the primary consideration for firms, social welfare, environmental externalities, distributional effects and long-term climate benefits are issues that must be taken into account by policymakers [47]. From a company's viewpoint, a carbon trading policy might cost an individual company money, but benefit society as a whole. On the other hand, a policy can seem to be successful for companies if they are given free allowances, but have little environmental value. Hence, it is necessary to establish the perspective for the evaluation.

3.9. Sectoral and Regional Heterogeneity

The impacts of carbon trading on costs and benefits are very unevenly distributed by sector and region. A range of abatement technologies, cost structures, market competition and capacities to pass-through carbon costs exist for power generation, steel, cement, chemicals, aviation and other energy intensive industries [48]. For instance, the power sector might have fairly well-defined options for substitution of renewables, and/or for efficiency improvements, whereas the cement sector has process emissions which are more challenging to abate. Consequently, the economic effects and environmental results can vary significantly between different economic sectors depending on the same carbon price.

Heterogeneity is also the key element of the region. Carbon trading could be more beneficial to regions with more developed financial markets, more robust regulatory capacity, and cleaner energy structures [49]. Transitions can be more expensive for regions that rely on coal or heavy industry or resource extraction. There are questions regarding fairness and policy coordination. Increased carbon trading could result in uneven development effects and political resistance in less-developed, resource-dependent areas if these areas are not given support for transition.

Heterogeneity at the firm level is also important. Some enterprises which have advanced technology and good management systems can have lower emission costs and obtain trading benefits at relatively lower cost [41]. Older companies or those that have poor financial resources may experience high compliance costs. This can stimulate the upgrading of industry through carbon trading but can also undermine the more fragile firms' competitiveness and market viability. Distributional impacts should thus be included in a cost-benefit analysis, not just efficiency impacts.

3.10. Potential Negative Mechanisms of Carbon Trading

While the preceding sections highlight synergistic benefits, three negative mechanisms warrant scrutiny. First, greenwashing may occur as firms overreport emission reductions from low-cost, non-additional actions while deferring genuine abatement. Second, carbon leakage risks intensify when regulated industries relocate production to jurisdictions with weaker carbon constraints, potentially increasing net global emissions. Third, distributional injustice can arise if carbon costs are passed to households via higher energy prices, disproportionately affecting lower-income groups that spend larger shares of income on energy. These mechanisms do not necessarily negate synergies but suggest that policy design—including border adjustments, revenue recycling, and robust monitoring, is critical to mitigating adverse outcomes[50].

3.11. Critical Synthesis

Economic cost-benefit analysis reveals that carbon trading is neither automatically efficient nor inherently burdensome. Its economic performance depends on the interaction between carbon price signals, allowance allocation, firm behavior, technological capacity, and regulatory credibility[10]. A well-designed carbon market can reduce total abatement costs, stimulate innovation, improve resource efficiency, and generate public revenue. A poorly designed market may create compliance burdens without meaningful environmental improvement, or allow firms to profit from free allowances while delaying real transformation. The key insight is that the costs and benefits of carbon trading are dynamic. Early market implementation costs are potentially substantial, especially if monitoring systems need to be established and production processes changed, in the short run. In the longer term, however, benefits could be enhanced as firms innovate, energy efficiency grows and low carbon technologies become more competitive. Evaluation must thus go beyond a static approach to accounting and incorporate a dynamic approach that reflects technological learning, market maturation, policy adjustment, and environmental co-benefits[51].

For this reason, economic cost-benefit analysis should be closely linked with environmental resource management performance evaluation[52]. The benefits of carbon trading must be demonstrated by cost saving, but not if the reductions in emissions and improvements in resource efficiency are not significant. Likewise, emission reductions that cost too much have a negative impact on the sustainability of the policy. The key challenge is to determine if carbon trading can yield coordinated economic and environmental benefits. The above integrated perspective forms the foundation for the next section on environmental resource management performance evaluation.

4. Environmental Resource Management Performance Evaluation

4.1. Conceptual Scope of Environmental Resource Management Performance

Environmental resource management performance under a carbon trading market indicates how well the carbon pricing mechanism increases resource allocation efficiency, quality, and sustainability, and decreases GHG emissions and environmental pressures. It's wider than just emission reductions. In addition to carbon emissions reduction, the environmental resource management effect of a carbon market can also be evaluated from the perspectives of energy efficiency, material utilization, cleaner production, green innovation and ecological governance capacity improvement[23].

This wider knowledge is required since carbon emissions are closely related to the consumption of energy, land, water, minerals and industrial raw materials. The production is resource intensive and pollution intensive too, and it is carbon intensive. Thus, carbon trading can alter production cost structures and hence impact broader resource consumption behaviour[41]. A firm that is implementing a firm response to carbon prices could make investments in equipment, lower fossil fuel use, re-optimize production processes, switch to renewable energy, recycle waste heat, or restructure supply chains. These changes can have a positive impact on the management of resources other than the reduction in carbon.

However, the relationship is not automatic. A carbon trading market can improve environmental resource management only when the carbon price is transmitted into real behavioral and technological change[41]. If firms respond mainly by purchasing allowances rather than reducing emissions, environmental performance may remain weak. If allowances are overallocated, the carbon constraint may be too soft to change resource-use behavior. Thus, environmental resource management performance evaluation must move beyond observing whether a market exists and instead examine whether market incentives actually generate resource-efficiency improvements.

4.2. Carbon Emission Reduction as the Core Performance Dimension

The key performance measure remains carbon emission reduction as the ultimate goal of carbon trading is to reduce carbon emissions [43]. Typically, the evaluation is based on the total emissions, the emission intensity, the carbon productivity and the rates of reduction of emissions within a firm, industry or region. Absolute reduction in emissions is considered a reduction in total emissions, and relative reduction in carbon intensity is considered an improvement in the efficiency of emissions. Carbon productivity is a measure of the productivity of carbon emissions, which is usually defined as economic output per unit of carbon emissions.

One of the problems to be solved is the fact that there are various indicators and interpretations. As an example, an increase in economic activity can lead to a decrease in carbon intensity while total emissions also increase. This can be a sign of relative decoupling, but not absolute decarbonisation. On the other hand, emissions can fall even in the face of an economic recession and no technological change. So, it is not appropriate to assess the emission performance by a single indicator. A sound evaluation would separate out absolute reduction from the relative efficiency improvement and temporary cutbacks due to external economic conditions [53].

Causal attribution is another challenge. Reduction in emissions post carbon trading could be due to the introduction of carbon pricing or due to the factors of energy prices, industrial restructuring, economic cycles, administrative regulation or renewable energy policies [14]. If not properly identified, the evaluators can go over or under estimate the role of carbon trading. This is especially important in jurisdictions with multiple environmental and industrial policies in place, where carbon trading is used in parallel.

4.3. Energy Efficiency and Resource-Use Efficiency

Energy efficiency is an important part of the measurement of the performance of environmental resource management, as energy consumption is a primary source of carbon emissions in most industrial systems [54]. By increasing the cost of using fossil fuels, carbon trading can help to increase energy efficiency as it makes businesses more likely to reduce their energy waste. Companies can use more effective boilers, motors, production equipment, heat-recovery systems and digital energy-management systems. Carbon trading at the regional level could help move away from energy mixes dominated by coal to cleaner energy sources and renewables.

Resource-use efficiency broadens these arguments to include the use of other resources. It incorporates the efficient utilization of water, raw materials, land and industrial by-products. A carbon market can have an indirect impact on material efficiency if companies restructure their manufacturing processes to lower their emissions and resource use. For instance, circular-economy principles like material recycling, waste reuse and industrial symbiosis offer the potential of reduction in carbon emissions and increase in material productivity [55].

However, carbon trading is not always an effective way of improving overall resource-use efficiency [8]. If the carbon price is seen as just the carbon price, companies can adopt carbon reduction strategies and ignore other environmental pressures. Certain low-carbon technologies could demand significant quantities of minerals, water, or land, hence different resource management challenges. So, there is a need to take into account any trade-offs between carbon reduction and other resource uses in performance evaluation. The narrow carbon efficiency improvement is not equivalent to the overall environmental sustainability.

4.4. Pollution Control and Ecological Co-Benefits

Pollution-control co-benefits can be important with carbon trading, as many carbon-reduction measures have conventional pollutant reductions. New technologies and production practices that reduce the amount of coal burned, increase combustion efficiency, and reduce pollution sources will all help to reduce SO_2, NO_x, PMs and other pollutants[56]. These co-benefits are particularly relevant in fossil-fuel-burning areas, where they help to reduce air pollution and associated public health effects.

But the size of these co-benefits will vary with the type of abatement response. Pollution-control benefits from energy efficiency and fuel switching may be significant[43]. Local pollution could not be reduced if the firms are based primarily on using allowances or offsets. This is important as it is a characteristic of carbon markets that compliance is flexible. Flexibility increases economic efficiency, but can result in non-uniform spatial environmental impacts. A company can meet the requirement by purchasing allowances but not actually reduce emissions in the region, so the region may not see immediate benefits.

Assessment of ecological benefits is even more challenging. If the proceeds of the auctions are allocated to forest sinks, wetland protection, or land rehabilitation, carbon trading can help ecological restoration[57]. However, the environmental integrity of such projects relies on the additionality, permanence, leakage prevention and monitoring quality. Ecological offsets if poorly verified could have a negative effect on the carbon market and overestimate the environmental performance. Thus, the quality of carbon credits, in terms of the ecological legitimacy of the projects they are based on, must be taken into account in the evaluation of performance.

4.5. Green Innovation and Low-Carbon Transformation Performance

Green innovation is one of the most significant indicators of the performance of the management of environmental resources in the long term[58]. One potential way of promoting innovation through carbon trading is to increase the cost of carbon-intensive production and boost the profit to be harvested from low-carbon technologies. There are a number of solutions that firms can take, such as implementing new production processes, using clean energy, enhancing carbon management systems, or investing in carbon capture, utilisation and storage. This can help lower the abatement costs and make deeper reductions more feasible over time.

The innovation effect of carbon trading is however very conditional. If carbon prices are weak, it might just compel marginal adjustments in operations, not real innovation. Early stage efficiency measures could be implemented at a low cost, while structural changes are avoided. Furthermore, when the policy is uncertain, companies could have an incentive to delay innovative investments due to the uncertainty over carbon prices and rules[18]. So, carbon markets need to offer a price signal as well as a clear long-term policy expectation.

Then the indicators of the innovation performance of the Green Innovation should be assessed using both input and output indicators[11]. Examples of input indicators can involve the use of green finance, investment in low carbon equipment, R&D spending, etc. Green patents, energy-saving technology, reduction in emissions and increased productivity are examples of output indicators. However, the number of patents does not necessarily translate to actual environmental value as some patents are more practical than others. A critical evaluation should address whether actual resource efficiencies and emissions reductions are achieved as a result of innovation outcomes.

4.6. Evaluation Indicator Systems

To assess environmental resource management performance in the context of carbon trading, an extensive indicator system is required. This system should comprise carbon-emission indicators, energy-efficiency indicators, resource-productivity indicators, pollution-control indicators, green-innovation indicators and governance-capacity indicators. It should also embody short-term compliance results and long-term transformation potential[59].

There are a number of methodological decisions in the design of indicators. First, the evaluators have to determine whether they want to use absolute indicators, relative indicators, or composite indices[60]. Absolute indicators are those that show direct environmental pressure but may be economically scaled, e.g., total emissions or total energy use. Relative indicators, like emissions per unit of output, can be used to compare emissions between companies or between regions, but they can fail to show that the total environmental burden is increasing. Multidimensional performance can be measured using a composite index, which requires weightings and indicators.

Second, indicators need to be correlated with the level of analysis. Within the firm, performance assessment can include energy efficiency, compliance activity, technology uptake and carbon asset management [10]. Evaluation at the industry level can focus on structural upgrading, the average abatement cost and the emission intensity of the sector. Resource carrying capacity, industrial structure, environmental quality and policy implementation capacity are all evaluated at the regional level. Inappropriate matching of indicators and evaluation scales can lead to inaccurate results.

Thirdly, indicators should be dynamic rather than static [61]. The purpose of carbon trading is to plan for a long-term transformation and appraisal should analyse trends over time. A firm may be poor at the beginning because of the technology transition costs, but improve at the end of the period due to technology improvements. On the other hand, if strict short-term emission cuts are achieved through temporary shut-downs of production, they may not be viable in the longer term. It is therefore crucial to perform a dynamic assessment to differentiate structural improvement from transitory fluctuations. The operational indicator framework for environmental resource management performance for carbon reduction, energy efficiency, resource efficiency, pollution control, innovation, governance and dynamic environmental resource transformation is provided in **Table 3**.

Table 3. Indicator framework for environmental resource management performance evaluation under carbon trading markets.

Evaluation Dimension	Representative Indicators	Evaluation Focus	Critical Considerations
Carbon emission reduction	Total CO_2 emissions, emission intensity, emission reduction rate	Measures direct mitigation performance	Total emissions and emission intensity should be assessed together to avoid misleading conclusions
Carbon productivity	GDP or output per unit of carbon emission	Evaluates economic value generated per unit of emission	High carbon productivity may coexist with rising total emissions
Energy efficiency	Energy consumption per unit of output, fossil-energy share, renewable-energy share	Assesses energy-use optimization	Energy-market distortions may weaken the transmission of carbon-price signals
Resource-use efficiency	Material productivity, water-use efficiency, waste recycling rate	Evaluates broader resource management performance	Low-carbon technologies may create new material or water pressures
Pollution-control co-benefits	SO_2, NO_X, PM, and wastewater reduction	Captures environmental benefits beyond carbon reduction	Co-benefits depend on whether firms reduce emissions internally or simply buy allowances
Green innovation	Green patents, R&D investment, low-carbon technology adoption	Measures technological transformation capacity	Patent quantity may not reflect actual environmental effectiveness
Governance performance	MRV accuracy, compliance rate, enforcement strength, data transparency	Assesses institutional capacity of the carbon market	Weak governance can create formal compliance without real emission reduction
Dynamic transformation	Long-term emission trend, technology upgrading path, structural adjustment	Evaluates sustainability of performance improvement	Short-term reductions caused by output decline should not be mistaken for structural progress

Note: GDP: Gross domestic product.

4.7. Quantitative Evaluation Methods

There are a number of quantitative approaches to assessing performance in environmental resource management. When there are many inputs and outputs, there is a wide spread use of data envelopment analysis to measure relative efficiency [62]. It can take both desirable and undesirable outputs, like carbon emissions or pollutants, or economic value. This makes it appropriate to test the effectiveness of firms or regions in reducing environmental impacts and increasing outputs. Data envelopment analysis (DEA) results are, however, subject to input-output selection and sample composition. It is only a relative measure of efficiency and is not an absolute measure of sustainability, so a more efficient unit could push environmental pressures up to very high levels.

Another way to measure efficiency, accounting for statistical noise, is through stochastic frontier analysis. It can identify random disturbances and inefficiency, which is helpful in complex systems such as economics and the environment. However, it is a model that assumes a functional form and an error distribution. Results may be biased if these assumptions are not applicable [63].

Various methods for building composite performance indices are discussed, including entropy-weight methods and multi-criteria decision making approaches [64]. The good thing about them is that they can incorporate various aspects of environmental management. Sometimes, however, important trade-offs can be hidden in the composite indices. For instance, if energy efficiency performance is high, its low mathematical score on pollution control does not offset its high score on energy performance, although both types of performance are important to the environment. Thus, the evaluation of individual indicators should be used in conjunction with index-based evaluation.

A growing number of causal inference methods, particularly difference-in-differences models, have been applied to estimate the effects of carbon trading policies [65]. These techniques can be used to determine whether performance changes are due to carbon trading or other factors. These, however, are based on assumptions such as parallel trends and stable treatment effects. Such assumptions can be challenging in carbon-market studies if there are systematic differences between the pilot regions, regulated sectors or covered companies and other companies.

4.8. Governance Capacity and Institutional Performance

The capacity of governance is also crucial for environmental resource management performance. Key elements of carbon trading are an accurate accounting of emissions, transparent registries of the allowances, credible verification, effective enforcement and robust market supervision [66]. If they are absent, the performance of the environment can be exaggerated or even fabricated. Governance indicators, therefore, should be part of the performance assessment.

Monitoring, reporting and verification systems are especially crucial [32]. If emissions data are false, the whole market is undermined in terms of credibility. Firms may be able to underreport emissions under weak verification, and different standards in the different areas or sectors may decrease comparability. Enforcement also matters. Low penalties for non-compliance can make it easier for firms to consider compliance violations as a cost of doing business rather than a serious risk to compliance.

The transparency and public accountability of the institutions should also be taken into account when assessing their performance [67]. There are valuable emission assets in carbon markets and distributional conflicts can arise in the allocation of emission allowances. Transparent Rules Less Rent-seeking and More Trust. Opaque allocation, on the other hand, can undermine legitimacy and alter market dynamics. So, environmental performance is not only a technical result; it is also an institutional one.

4.9. Critical Synthesis

A simple accounting of emissions is not enough to assess environmental resource management under carbon trading. The measurement of carbon trading's impacts should include a mature evaluation framework for assessing impacts on carbon productivity, energy efficiency, resource-use efficiency, pollution control, green innovation, and governance capacity [9]. It should also be able to distinguish between compliance performance and transformation performance. Compliance requires the surrender of allowances to comply with the rules, transformation requires a change of production systems and resource-use patterns.

The main lesson is that carbon trading offers potential for improved environmental resource management; opportunities are contingent [8]. A tight cap, credible carbon prices, reliable data, and effective enforcement, including supportive innovation policies, are necessary to ensure strong performance. Without these conditions, carbon trading can result in a formal compliance framework without some actual environmental benefit. However, under certain market conditions, with robust governance and technological capabilities, carbon trading can act as a strong tool to coordinate emission reduction, resource efficiency and green industrial transformation.

Hence, the environmental resource management process should be assessed as a multi-dimensional and dynamic process [67]. It should not only quantify the reduction, but also how it has been reduced, at what cost, with what resource implications, and whether the improvement is sustainable. This view is essential in developing the concept of combining environmental performance evaluation and economic cost benefit analysis in the next step.

5. Integrated Framework Linking Economic Benefits and Environmental Performance

5.1. Need for an Integrated Evaluation Perspective

A comprehensive analysis of carbon trading markets is needed because the economic cost benefit and environmental management of resource use results are not separable in the analysis. The purpose of carbon trading is to cut emissions by financial instruments; therefore, environmental impacts are created via cost changes, investment choices, reallocation of resources and technological adaptation [3]. Evaluating economic and environmental impacts separately could result in a partial or even false picture. Economically efficient may seem like a carbon market, but it might be a sign of weak carbon prices and a lack of pressure to reduce emissions. On the other hand, a carbon market can be perceived as a good environmental result since emissions are reduced, but the reduction could be due to high costs and economic burden, contraction of production or the displacement of production.

An integrated perspective thus poses a broader question: is the carbon trading market able to achieve environmental improvement at a reasonable economic price while promoting long-term resource efficiency and a low-carbon transition? This question goes beyond simple compliance evaluation. It demands both attention to the amount of emission reductions and attention to the quality of the economic process that is used to achieve the reduction. The goal is not just emissions reduction, but a combined enhancement of carbon productivity, technological innovation, resource-use efficiency and economic resilience [8].

5.2. Coupling Mechanism between Economic Incentives and Environmental Outcomes

The underlying mechanism of the carbon trading is, of course, the carbon price. When emissions are costly, enterprises have incentives to consider three alternatives: internally reducing emissions; buying emission allowances; or altering production scale and structure. Environmental benefits may be achieved through internal abatement, through a reduction in fossil energy use, an improvement in process efficiency and the use of clean technologies. While purchasing allowances can help to guarantee compliance, it does not necessarily enhance the buyer's environmental performance. Production adjustment can result in a reduction in emissions but can also have economic and social costs associated with a decrease in output, loss of employment or industrial restructuring [10].

This mechanism demonstrates that the environmental impacts of the same carbon price can vary according to firm actions. Technological upgrading will lead to a reduction in economic costs over time, and to improvements in environmental performance, if the carbon price encourages technological upgrading. If the carbon price is viewed as a compliance cost, companies can reduce immediate expenses without reducing their resource utilization [31]. Thus, the relationship between economic outcomes and environmental outcomes is influenced by corporate strategy, technological capability, market expectations and regulatory credibility.

The coupling mechanism is also dynamic. In a short-term time frame, companies could face higher compliance costs, as the allowances need to be purchased, monitoring systems installed, and energy-saving technologies must be developed [14]. Over the long term, these costs can turn into a competitive advantage, as the efficiency gains, reduction in energy use, enhancement in carbon asset management and green innovation can reduce these costs. Therefore, there is a need to differentiate between transitional costs and structural benefits when evaluating integrated evaluations.

5.3. Trade-Offs between Economic Efficiency and Environmental Effectiveness

In theory, carbon trading is attractive because it will allow emissions to be reduced at lower cost [41]. But, economic efficiency and environmental effectiveness are often in conflict. A flexible emission cap can lower compliance costs and improve the political acceptability, but it can be less stringent on the environmental side. A strict cap will lead to better performance on the side of emission reduction, but will have a higher cost for enterprises and consumers, particularly those with intensive use of carbon. The design of carbon trading is, therefore, constantly between reach and stretch.

This compromise is particularly evident in the distribution of allowances. Free allocation can help manage compliance pressure and avoid 'carbon leakage' but it can also limit 'deep emission reduction' incentives if allowances are given too much. Auctioning can enhance carbon-cost internalisation and raise public revenue, but can also raise short-term costs. The question is not whether free allocation or auctioning is universally better; it is whether the allocation mechanism is consistent with market maturity, industrial competition and environmental goals [8].

The other trade-off relates to market flexibility. Market stability and lower compliance costs can be achieved through mechanisms like offsets, allowance banking and price-containment reserves [68]. But the over-flexibility of emission reductions can be postponed until later or decrease the scarcity signal. For instance, if companies are more dependent on low-cost offsets, their performance in the compliance area can be better, but actual change in the sectors subject to coverage can be minimal. Any such flexible scheme must therefore consider the possible negative effects of flexibility measures on costs or on the ambition to environmental objectives.

5.4. Synergies between Economic Benefits and Environmental Performance

While there are trade-offs, there can also be important synergies in carbon trading [69]. Carbon prices can simultaneously cut down on emissions and cut operating costs if they incentivize the improvement of energy efficiency in companies. Investments in energy efficiency can also bring multiple benefits, as they can decrease carbon emissions and fuel costs. Likewise, optimizing processes can enhance material productivity and reduce wastee and emissions. In this scenario, economic and environmental performance go hand in hand.

Another great source of synergy is green innovation. A credible carbon market can incentivize companies to either invest in low carbon technologies or implement them, thereby lowering abatement costs and environmental impacts in the future. Technological learning can reduce the costs of emission reduction, leading to more economically feasible targets over time. Such a dynamic relationship is at the heart of the long-term value of carbon trading. The market is not only distributing the current volume of abatement opportunities, it's also fostering innovation in order to generate new opportunities [58].

If strategically used, public revenue from allowance auctions can enhance synergy as well. There are many different ways to use revenues to benefit renewable energy, industrial decarbonization, worker transition, low income household compensation or research and development. These costs can be lowered and environmental improvements can be made sooner through recycling of carbon-market revenues. Thus, the economic-environmental efficiency of carbon trading is not only determined by market transactions, but also by the use of the income and incentives resulting from the market [70].

5.5. Integrated Evaluation Model

The integrated evaluation model should integrate economic cost-benefit indicators with environmental resource management indicators. On the economic side, the model should consider compliance costs, costs of compliance by purchasing allowances, transaction costs, administrative costs, abatement investment, energy-cost savings, benefits of innovation, auction revenue and competitiveness effects [7]. In terms of the environment, it should contain total emissions, emission intensity, carbon productivity, energy efficiency, resource-use efficiency, pollutant reduction, green innovation output, and governance quality [8].

The model should not just incorporate these indicators without interpretation in a composite score. A mechanical index may mask significant paradoxes. A region, for instance, might have high economic output with low compliance cost, and yet this region has no reduction in absolute emissions. In another area, emissions may be lowered greatly, but by cutting back on industry, not efficiency. So the outcomes of the evaluation should be divided into various performances [71].

They could be grouped as co-ordinated improvement, economic-dominant performance, environmental-dominant performance, and low quality performance. Coordinated improvement occurs when carbon trading brings both economic gains and good environmental results. Economic-dominant performance is when costs are low or economic efficiency is enhanced, but environmental benefits are less. Environmental-dominant performance is one in which emissions are reduced while the economic costs are too great or are not sustainable. Low quality performance is when the carbon markets impose costs without any environmental benefit. This classification is helpful in applying the definition without making all the emission savings or cost savings look equally good[10]. **Figure 2** visualizes the integrated economic-environmental performance matrix, distinguishing coordinated improvement from economic-dominant, environmental-dominant, and low-quality performance outcomes.

Table 4 further explains the characteristics, interpretations, and policy implications of each integrated performance type.

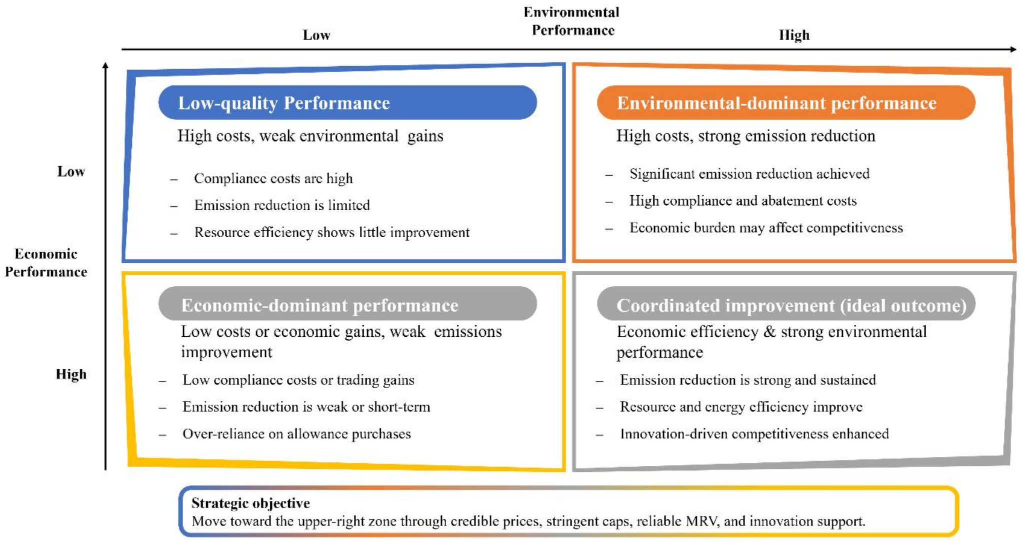

Figure 2. Integrated economic-environmental performance matrix for classifying carbon-market outcomes.

Table 4. Integrated economic-environmental performance types, interpretations, and policy implications under carbon trading markets.

Performance Type	Economic Outcome	Environmental Outcome	Interpretation	Policy Implication
Coordinated improvement	Compliance costs are manageable and efficiency gains increase	Emissions decline, resource efficiency improves, and innovation strengthens	Ideal outcome showing that carbon trading supports both economic and environmental goals	Maintain cap tightening, improve market liquidity, and support green innovation
Economic-dominant performance	Firms face low costs or obtain trading benefits	Environmental improvement is weak or temporary	May indicate excessive allowance allocation, low carbon prices, or weak enforcement	Strengthen cap stringency, reduce allowance surplus, and improve MRV systems
Environmental-dominant performance	Emission reduction is achieved with a high economic burden	Emissions decline but firms face significant cost pressure	May reduce policy acceptability and industrial competitiveness	Use revenue recycling, transition finance, and targeted support for vulnerable sectors
Low-quality performance	Compliance costs rise without clear economic gains	Environmental improvement is limited	Indicates poor market design, weak governance, or ineffective price signals	Reform allocation rules, enhance supervision, and coordinate with energy and finance policies
Innovation-led transformation	Initial investment costs are high but long-term productivity improves	Green technology adoption reduces emissions and resource intensity	Shows dynamic benefits beyond short-term cost accounting	Provide stable price expectations and expand green finance support
Compliance-only performance	Firms meet surrender obligations mainly through allowance purchases	Internal resource-use patterns remain largely unchanged	Formal market compliance does not necessarily mean real transformation	Encourage internal abatement through stricter caps, benchmarking, and technology incentives

5.6. Causal Pathways and Feedback Relationships

Economic benefits and environmental performance should be linked by means of causal pathways and not just correlation. Carbon trading first impacts on enterprise expectations and its cost structure[10]. These changes have an effect on compliance strategies such as allowance trading, internal abatement, technological investment and production adjustment. These strategies then impact emissions, energy consumption, resource efficiency, innovation and competitiveness. Last but not least, the policies shape the market outcome through changes in the supply of allowances, cap adjustment, sectoral expansion and policy reform.

The feedback relationship is significant since carbon markets change over time [10]. Early-stage markets may focus on establishing the system, collecting data, and implementing discipline. In mature markets, the focus is more likely to be on cap tightening, auctions, financial regulation and deep decarbonization. Hence, it is important to have integrated evaluation as it should be stage sensitive. A new carbon market should not be measured by the same yardstick as a mature market, but it should be measured to see whether it is establishing the institutional mechanisms for the market to be effective in the future.

Feedback also takes place at the firm level. Reducing emissions successfully can allow firms to build up technical knowledge, build up carbon management capacity and benefit in the markets. More investment in low carbon transformation could be driven by these benefits. Those companies that don't adapt could end up with increasing costs and decreasing competitiveness. Carbon trading can ultimately, then, influence industrial structure by encouraging low-carbon efficiency and discouraging the continued high-carbon production [72]. But such a change needs to be handled very carefully to not cause too much social and regional disruption.

5.7. Heterogeneity across Sectors, Regions, and Enterprises

Heterogeneity needs to be addressed in an integrated framework. The impacts of carbon trading vary by industry, since the source of emissions, abatement technologies, costs, and product-market conditions are different for each [73]. In the power sector, emission reduction can be achieved through fuel switching, integration of renewable energy and efficiency improvement. Process emissions and capital-intensive technologies are more challenging and expensive to decarbonize in cement and steel. As a result, a given carbon price could have a significant impact on one sector, but a modest impact on another.

Regional heterogeneity also has to be taken into account. The potential impacts of carbon-market pressure on innovation and efficiency enhancement are more likely to play out in regions with more advanced industrial structures, cleaner energy systems, and better financial capacity [74]. The costs of transition for regions that rely heavily on coal, heavy industry, or resource extraction could be more significant, as well as the threats to job opportunities. If these differences are not taken into account, carbon trading can exacerbate regional inequality. Therefore, integrated evaluation should take into consideration whether the economic costs and environmental benefits are distributed fairly between regions.

Climate heterogeneity also matters when it comes to outcomes [75]. Big companies are typically more likely to have resources to upgrade technology, access to financing, and greater compliance capacity. Small and medium-sized enterprises (SMEs) might have a higher relative cost and lower market participation capacity. In expanding carbon markets, policymakers must not allow for non-uniform compliance costs to lead to a situation where the market is not legitimate. This can necessitate the provision of differentiated support mechanisms, access to technical assistance, access to green finance and access to transparent information services.

5.8. Policy Interaction and System Coordination

Carbon trading works alongside other things. It has interconnections with renewable-energy policy, energy-efficiency standards, industrial policy, pollution-control regulation, green finance and fiscal policy. These interactions may be positive or negative to the integrated performance. For instance, renewable-energy subsidies can decrease emissions and demand for allowances, leading to a decline in carbon prices if the cap does not move. Energy-efficiency standards can be used to overcome information barriers and behavioural inertia to complement carbon trading. Green finance can help companies address the initial investment hurdles and catalyze the transition to new technology as a result of the price of carbon [14].

Policy coordination is the main issue. When multiple policies aim at similar objectives without coordination, they can result in a loss of efficiency of the carbon market and/or conflicting incentives [76]. As an illustration, if administrative emission-control levels are cut, the demand for allowances declines and market liquidity is diminished. Too many subsidies can lead to misinvestment. Yet, solely using carbon prices can be insufficient if firms are under financial constraints, cannot be certain about the technology, or are restricted on infrastructure. Thus, a holistic approach should take into account the carbon market and the policies that surround it.

As well as policy coordination efforts, there should be social and distributional measures. Carbon trading may increase energy and product prices and impact households and downstream industries. Without careful management, these effects could undermine the longevity of carbon-market reforms in the face of public opposition. The economic acceptability and environmental effectiveness can be improved through revenue recycling, targeted compensation and just-transition policies. This demonstrates that social equity cannot be divorced from market performance, but is a prerequisite for long term policy stability [10].

5.9. Critical Synthesis

An integrated model linking economic and environmental outcomes shows that carbon trading is better understood as a dynamic governance system rather than a limited trading mechanism. It is contingent upon whether a combination of a carbon price, allocation of allowances, market regulations, firm behavior, technological change and policy coordination can lead to a sustainable low-carbon transformation. Economic efficiency and weak environmental effectiveness show that environmental regulation is not effective. Policies with low economic sustainability may have low environmental effectiveness and therefore short life cycles. Coordinated improvement is the best possible scenario, carbon trading helps lower emissions, enhances resource efficiency, fuels innovation, and keeps transition costs manageable [39].

The key idea is that carbon trading provides a conditional link between economic incentives and environmental performance. However, the pathway only functions if prices are credible, caps are strong, data is reliable, markets are liquid and firms have access to technologies and finance. Mechanisms should therefore be the focus of integrated evaluation, as well as outcomes. It should question whether the emission reductions observed are due to genuine efficiency improvements, whether there are any transitional or permanent economic costs, whether the innovation is incremental or transformative, and whether benefits and costs are equitably distributed [77].

The integrated framework allows cost benefit analysis to be linked to environmental resource management performance assessment, and thus gives a more realistic context to the assessment of carbon trading markets. It is aware of the promise as well as the limits of market-based climate governance. Carbon trading can be an effective policy tool to incentivise economic activities to be environmentally friendly if it is underpinned by a credible, adaptive and coordinated governance framework [47].

6. Current Challenges and Future Research Directions

6.1. Carbon Price Volatility and Weak Long-Term Expectations

Carbon price volatility is one of the most crucial issues in the carbon trading markets. The carbon price should, in principle, be the cost of reducing emissions by a marginal amount, with a cap on emissions. In reality, macro-economic cycles, energy prices, industrial production, fuel switching, policy surprises, the availability of spare allowances, speculation in the market and geopolitical risks influence the price of carbon [14]. When prices change significantly, enterprises might struggle to calculate the payback period for low-carbon investments. This undermines carbon trading's steering role in long-term technological change.

Low and volatile carbon prices could lead companies to view allowances as a "normal" compliance cost rather than an innovation signal. This can make it more advantageous for the companies to opt for short term allowance buying rather than long-term investment in clean production. On the other hand, if the carbon price is set too high, it could make production more expensive, less competitive and could face social opposition if producers shift costs to consumers. The challenge is not just higher carbon prices, however, but a socially acceptable, stringent and predictable price corridor [41].

The relationship between price stability and investment behavior should receive more attention in future research. Many of the past studies consider whether carbon trading reduces emissions or makes efficiency improve, whereas fewer studies report on how firms interpret the carbon price signals under conditions of uncertainty. Further analysis is required regarding expectations about the carbon price, the timing of investments, the real options effect, and the price at which low-carbon technologies will be stimulated. This would illuminate when carbon trading is more than a quick fix compliance program and is a real structural change[34].

6.2. Allowance Allocation, Market Liquidity, and Distributional Fairness

One of the core design issues is the allocation of allowances. While free allocation could lessen opposition from regulated firms and shield trade-exposed sectors, overabundant free allocation could reduce incentives for emission reductions and lead to windfall profits. Auctioning has the effect of better internalizing the carbon cost and generating public revenue, but it can also lead to an immediate increase in compliance costs, particularly for energy-intensive industries. Thus, the allocation mechanism has an impact on both economic efficiency and environmental effectiveness and political legitimacy[29].

Another important issue is the liquidity of the market. For a functioning carbon market, it's essential that there be an open and clear price for trading allowances. Low liquidity can result in price distortion, high transaction costs, and poor price discovery. This is particularly the case in early-stage carbon markets where few firms participate, few trades occur and firms are still learning about carbon asset management. The theoretical benefits of carbon trading, namely the cost-effective allocation of carbon through exchange, cannot be fully achieved in a situation of insufficient liquidity[78].

Distributional fairness is closely related to allocation and to liquidity. Carbon trading results in winners and losers. Firms with positive allowances or a good abatement capacity may be better off, but firms with less adequate technologies may see their costs increase. There could be more benefits for regions with clean energy structures and more costs for coal dependent and heavy-industrial regions. Future research should thus go beyond aggregate-level efficiency and investigate who gains, who loses, and who covers the costs of transition between firms, sectors, regions and social groups. Distributional analysis is crucial, as unequal burden-sharing can undermine public acceptance and fuel a long-term lack of stability for carbon markets[79].

6.3. Carbon Leakage and Competitiveness Risks

Carbon leakage is the term used when emission reductions in one regulated area result in emission increases in one or more areas that are either by themselves regulated or not regulated[80]. It can occur when companies shift their production because of carbon pricing, or when domestic goods are substituted with imports from areas where the climate policy is less stringent. Carbon leakage undermines the environmental integrity of carbon trading and raises concerns about competitiveness in industries.

The risk of carbon leakage is sectoral, which means it does not apply to all sectors. Those that are more vulnerable are industries that are affected by international trade and are energy intensive (steel, cement, aluminum, chemicals and refining)[81]. In these industries, a company may be unable to shift the carbon costs to consumers since they are in global competition. Firms might decrease domestic production or relocate investments to other regions if the carbon trading raises production costs but does not have equivalent climate policies in other regions.

Free allocation, output-based allocation, border carbon adjustment and financial compensation are policy options that could be used to lower the risk of leakage[82]. But all the answers are flawed. Free allocation shields firms, and can reduce the incentive to abate. Border adjustment can be helpful to enhance fairness, but it can also cause trade tensions and administrative complexity. Output-based allocation may decrease relocation incentives and incentivize the production of carbon-intensive goods to continue. These mechanisms should be critically assessed, both from the perspective of leakage avoidance and with regard to environmental ambition, trade compatibility and innovation incentives in the future.

6.4. Monitoring, Reporting, Verification, and Data Quality

Carbon trading is based on the premise of reliable monitoring, reporting and verification systems[32]. If emissions are not properly measured, allowances can not be distributed fairly, compliance can not be properly monitored and market prices can not reflect the true lack of supply. Issues with data quality can jeopardize trust in the entire system. When companies report lower than actual emissions, or when verification requirements are not uniform, carbon trading can result in compliance in form only, with no actual environmental benefits.

The challenge is particularly relevant in complex industrial sectors with emissions generated from a number of processes, fuels and production phases. Process emissions in cement, steel, chemicals and other heavy industries are more challenging to measure than just direct emissions from fuel combustion. Monitoring systems need to be increasingly sophisticated, uniform, and technologically sophisticated as carbon markets reach more industries [81].

Third-party verification also gives rise to issues of governance. Verifiers should be independent, technically capable and answerable [83]. Verifications can become a regular administrative service without proper quality control and this can lead to conflicts of interest. Further studies are required on the potential of digital monitoring, blockchain-based registries, remote sensing, artificial intelligence, and automatic reporting systems to enhance the reliability of the data. But at the same time technological solutions should not be considered a replacement for institutional integrity. Digital tools have the potential to enhance transparency, but they still need standards, regulation and enforcement capacity.

6.5. Integration with Energy Markets and Green Finance

Carbon trading is closely intertwined with energy markets. Carbon prices and the demand for allowances are affected by changes in coal, oil, natural gas and electricity prices [24]. Meanwhile, carbon prices influence energy decisions by altering the relative price of fossil fuels and low carbon options. Where there is distortion in energy markets due to subsidies, regulated electricity prices or a lack of competition in energy markets, the carbon price signals may not be fully passed on to producers and consumers.

This interaction will be especially relevant to decarbonizing the power sector. Carbon trading in electricity systems with generators not facing market-based prices for carbon may have a weak impact on dispatch and investment incentives. On the other hand, if electricity markets are competitive and carbon costs are incorporated into electricity prices, carbon trading can speed up the switchover to low carbon fuels and the deployment of renewable energy. Hence, reform of the carbon market should go hand in hand with energy market reform [84].

Another complementary mechanism that is vital is green finance. Many low-carbon technologies have high upfront costs and benefits emerge over time in the form of lower energy costs and lower carbon liabilities. Carbon prices may make it difficult for firms with little access to finance to adjust. To address this investment barrier, green credit, green bonds, transition finance, carbon funds and sustainability-linked loans play a role. Future research is needed to study the impacts of carbon prices on financial risk assessment, the application of carbon assets in corporate finance, and the impact of green finance on the cost-benefit performance of carbon trading [14].

6.6. Policy Interaction and Regulatory Coordination

Traditional carbon trading typically takes place as part of a wider policy framework, such as renewable-energy supports, energy-efficiency requirements, industrial policies, pollution-control standards, fiscal measures and climate targets [59]. While these policies can enhance carbon trading, they can also lead to overlaps and distortions. For instance, the subsidies on renewable energy can decrease the demand for the allowances and carbon price, if not changed accordingly. Market transactions can be dampened by administrative emission-reduction goals, which can lower the need for transactions and decrease liquidity. Energy price controls may prevent carbon costs from being transmitted through the economy.

The challenge lies in creating a policy mix that is coordinated. Carbon trading shouldn't be seen as the magic bullet to overcome all the challenges of decarbonisation. Additional policies might be necessary to tackle the barriers, including technological uncertainty, infrastructure, behavioural inertia and financing gaps. But complementary policies must be designed in such a way that they don't weaken the carbon market but enhance it. This will involve adaptive regulation, frequent adjustment of caps, clear communication of policy, and coordination between environmental, energy, financial and industrial authorities [85].

Policy interaction effects should be studied more systematically in the future [2]. A number of studies have assessed carbon trading as a stand-alone policy, but in practice the effects of a carbon price are influenced by other policies that interact with it. Research needs to be done to determine which policy mixes are synergistic, which are redundant, and which have unintended consequences. This is particularly relevant for countries that are aiming for carbon neutrality and energy security, as well as industrial upgrading and economic growth.

6.7. Methodological Limitations in Current Research

There has been significant research progress on carbon trading recently, although a number of methodological flaws still exist. Studies, in particular in emerging markets, are based on short observation periods, primarily [86]. Short-term studies can underestimate the long-term impacts of carbon trading on innovation, industrial restructuring and resource efficiency, or overestimate the initial costs of compliance, as the effects of carbon trading can take years to show up.

Secondly, causal identification is still challenging. Carbon trading policies are not typically adopted haphazardly. Pilot regions or covered firms or regulated sectors can also have different economic development, industrial structure, environmental regulation and technological capacity than the control groups. While difference-in-differences and other quasi-experimental techniques can enhance causal inferences, they require assumptions that are unlikely to be satisfied. Future studies will benefit from robustness checks, heterogeneous treatment analysis, mechanism testing and other identification strategies to enhance credibility [87].

Thirdly, numerous studies focus on aspects of environmental performance such as carbon intensity or total emissions [88]. These indicators are helpful but not comprehensive of environmental resource management performance. Energy efficiency, material productivity, pollution co-benefits, green innovation, governance capacity, and social distributional effects should be part of more comprehensive studies. Fourth, indirect benefits like health improvements, ecological restoration, lower climate risk and technological spillovers are rarely included in the cost benefit analysis [89]. This can lead to a negative conclusion on carbon trading as the “easy” or apparent short-term costs are emphasized.

6.8. Future Research Direction: Dynamic and Multidimensional Evaluation

New evaluation frameworks are needed; dynamic ones that follow the evolution of carbon trading over time [66]. Carbon markets are not immutable entities. These impacts vary with increases in the level of caps, the methods used to allocate allowances, the experience of firms, the development of technologies, and policy credibility. The dynamic approach should consider technological learning, investment reallocation, industrial upgrading and long-term resilience along with immediate emission reduction and compliance costs.

A multi-dimensional evaluation is also required. The social, institutional, technological, environmental and economic dimensions should be included in future studies [90]. An integrated framework can help to assess whether carbon trading brings about coordinated improvement or simply redistributes costs between sectors and regions. Research of this type should integrate microdata on firms with production data on the sector, data on the environment in the region and data on transactions in the market. It should also follow a mixed methods approach, that is, a combination of econometric analysis, case studies, interviews, lifecycle assessment and scenario modelling.

One of the areas that has been suggested as a possible avenue of research is research on firm behavior. Companies can’t simply receive carbon pricing; they create their own strategies to comply with it. Some companies may invent, some companies may engage in strategic trading of allowances, some companies may shift the costs to consumers, and some companies may lobby for a favorable allocation. It is important to understand these behavioural reactions in order to assess the true impact of real policies. Therefore, future research needs to focus on the capability of carbon management, managerial expectations, risk perception and strategic decision-making in the context of carbon-market regulation [78].

6.9. Future Research Direction: Digital Governance and Intelligent Carbon Management

New governance and environmental performance assessment opportunities with digital technologies. Emissions monitoring, data verification, market transparency, and risk management can be enhanced with the use of big data, artificial intelligence, internet-of-things sensors, satellite monitoring, and blockchain-based registries [91]. These technologies can help to decrease information asymmetry and increase the credibility of carbon trading.

But there are risks that are equally new in digital governance. The data systems may be expensive, segmented or tamperable. Incomplete or biased training data can result in inaccuracies in artificial intelligence models. While blockchain systems can enhance the traceability aspect, they do not guarantee the accuracy of the original emissions data. So digital tools should be judiciously used. Their worth rests on their ability to be integrated with good accounting principles, regulatory supervision, and institutional responsibility [91].

Further work is needed to examine the potential of intelligent carbon management systems for aiding the firm-level decision-making process. Companies require tools for predicting carbon prices, performing abatement calculations, optimizing carbon portfolios, and incorporating carbon costs into investment processes. This type of system could change the nature of carbon trading from compliance to a strategic management tool. This is especially relevant in the context of the growing integration of carbon markets in different sectors and with green finance and supply-chain management [92].

6.10. Critical Synthesis

Whether existing problems can be leveraged to foster institutional development for carbon trading markets will ultimately determine future market development. Carbon trading systems have a number of limitations, such as carbon price volatility, allocation disputes, leakage concerns, poor data systems, liquidity issues and policy coordination challenges. However, this does not mean that carbon trading is not working. Instead, they demonstrate that carbon trading is a governance tool that is complex and needs to be continually tweaked, built on institutions and can be complemented by other policy tools [85].

Future research should go beyond the question of 'does carbon trading work?' and shift to the question of 'how, when, for whom, and at what cost does it work?' This change will help to develop a more mature understanding of carbon markets. More attention needs to be given to institutional design and firm behaviour, and research should combine economic cost-benefit analysis and environmental resource management performance evaluation, introduce some heterogeneity and dynamic feedback [52,54].

So, the four aforementioned priorities are worthy of a critical research agenda: enhancing causal evidence, creating multidimensional evaluation systems, examining behavioral and distributional mechanisms, and examining the role of digital and financial innovation. Future research can be more robust on the theoretical and practical basis of carbon trading as a tool for economic development, environmental protection and sustainable use of resources upon fulfilling these priorities.

7. Conclusions

Carbon trading markets are now a key tool for combating climate change without sacrificing economic flexibility. Carbon trading is a market-based system where emission rights are priced, allocated and traded, as opposed to the traditional command-and-control regulation. The aim of this mechanism is to lower the social cost of reducing greenhouse-gas emissions while giving the regulated entities the option to either self-abate or trade in the allowances. But the impact of carbon trading can only be judged based on emission reductions and compliance costs. A more holistic assessment should include economic measurements of cost-benefit analysis in addition to environmental resource management performance.

This review demonstrates that there are direct and indirect economic effects of carbon trading. Direct costs consist of allowance purchase costs, monitoring and verification expenses, transaction costs, administrative costs and investment in low-carbon technologies. Meanwhile, carbon trading can generate carbon abatement-cost savings, energy efficiency benefits, green innovation, auction revenue, and reallocated resource benefits. Those benefits are not guaranteed; they rely on the credibility of the carbon price, market liquidity, how the carbon allowances are distributed, how they are enforced, and the technological abilities of companies. A low-cost carbon price or a large allowance surplus might not encourage real transformation in the short term, but may also decrease the cost of compliance.

Carbon trading also has a multidimensional dimension in environmental resource management. It involves, apart from carbon emission reduction, carbon productivity, energy efficiency, resource-use efficiency, pollution-control co-benefits, green innovation, and governance capacity. Carbon markets can stimulate companies to shift to cleaner power technologies, reduce energy usage, and increase production efficiency. However, if companies opt for the purchase of allowances primarily to comply with the regulations, or if monitoring is lax or carbon prices are not having an impact on investment decisions, environmental improvements may still be modest. Thus, there is a need to distinguish between formal and substantive low-carbon transformation in the context of performance evaluation.

One of the major features of this article is the creation of an integrated approach that connects economic and environmental aspects. Carbon trading is not just a trading tool, but a governance mechanism. It is dependent on the transformation of economic incentives into actual achievement of enhanced environmental resource management. Ideally, the outcome of carbon trading is coordinated improvement that lowers emissions, reduces long-term abatement costs, encourages innovation, enhances resource efficiency, and preserves economic resilience. Low cost, no environmental progress, however, or excessive economic cost for emission reduction should not be considered high quality performance.

There are also some challenges highlighted in the review. A variety of factors can decrease the impact of carbon trading, such as carbon price volatility, allocation disputes, carbon leakage risks, weak monitoring and verification systems, weak liquidity of carbon markets and the lack of adequate coordination with energy and financial policies. These problems suggest that there will be a need for ongoing institutional modification in carbon markets. The design of future carbon trading systems should consider reinforcing cap-setting mechanisms, optimizing allocation mechanisms, boosting data transparency, increasing high-quality monitoring and verification, and linking with green finance, energy-market reform, and industrial transition policies.

Future studies should shift the debate on the effectiveness of carbon trading from questions of "yes" versus "no" to the question of "how, when, for whom, and at what cost". Greater emphasis is needed on the behavioral responses of firms, regional and sectoral variation, dynamic cost-benefit impacts, co-benefits for the environment, and distributional justice. From a methodological perspective, future studies should combine causal inference, efficiency evaluation, life-cycle assessment, scenario simulation, and qualitative institutional analysis. This multi-dimensional research can give a more solid basis for improving the design of the carbon market.

In summary, the potential for carbon trading to contribute to a coordinated and sustainable economic development and environmental governance is conditional. A carbon market is an effective instrument to sustainably manage resources only when it delivers credible price signals, is environmentally sound, fosters technological innovation, and is equitably designed for the cost of transition. Combining economic cost-benefit analysis and environmental resource management performance assessment is a more comprehensive way to analyze and optimize the carbon trading markets in the context of low-carbon development.

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