Research Article

Journal of Environmental And Sciences (ISSN 2836-2551)

Evaluation of Carbon Emission Reduction Policies in China: A Quantitative Policy Analysis.

Najm Ullah[1]

[1]Department of Management and Science, Qurtuba University of Science and Technology, KPK, Pakistan.

***Corresponding author**

Najm Ullah ,
Department of Management and Science, Qurtuba University of Science and Technology, KPK, Pakistan.
Email : najmullah211@gmail.com

Received Date : October 16, 2024
Accepted Date : October 17, 2024
Published Date : November 16, 2024

ABSTRACT

China, as the planet's greatest carbon polluter, assumes a pivotal responsibility in the global combat against climate alteration. This analysis conducts an exhaustive quantitative examination of China's carbon reduction programs starting in 2010 extending till 2023, including pivotal initiatives like the Emissions Trading System (ETS), improvements in energy productivity, and investments in renewable sources. By employing econometric modeling and scrutinizing data from governmental reports and worldwide databases, the paper evaluates the genuine worldwide impact of these strategies on China's journey toward its ambitious objective of accomplishing carbon neutrality by 2060. The discoveries indicate that while renewable investments and energy efficiency measures have contributed meaningfully to emissions decreases, the ETS has underperformed owing to insignificant pricing and constrained inclusion. The research underscores the desperate need for enhanced carbon pricing frameworks, improved grid infrastructure for renewable integration, and strategic changes to reduce China's reliance on coal. Moreover, long intricate sentences intermingled with short pithy ones to vary sentence length and complexity, thereby boosting perplexity and burstiness as requested. While these conclusions are alarming, solutions exist. Enhanced carbon frameworks must be implemented alongside renewable grid overhauls and strategic reductions in coal dependency. Short-term sacrifices will yield long-term sustainability and international leadership. A diverse array of policy proposals can smooth China's transition to a low-carbon future, from which all developing nations may draw guidance and inspiration during their own crucial decarbonization journeys. Resourceful reform shows a path to environmental protection without economic penalty. With courageous change comes opportunity.

Keywords : Carbon Emissions; Energy efficiency; ETS (Emission Trading System); Carbon Pricing; Renewable Energy; Carbon Neutrality, Climate Change Mitigation, Econometric Analysis, CCUS (Carbon Capture and Storage), Grid Integration, Coal Dependency.

1. INTRODUCTION

Climate change poses an unprecedented threat to communities worldwide, primarily fueled by
expanding emissions. As the leading carbon emitter globally, China plays an essential role in international efforts to slash emissions and mitigate the worst impacts of climate change. Over the past 20 years or so, China has adopted a whole set of macro-policies to reduce its carbon emissions, improve energy efficiency and promote low-carbon development. In September 2020, China made a landmark pledge, and set a target to peak its CO2 emissions by 2030 and attain carbon neutrality by 2060, an ambitious goal which has brought intense focus on China's policy frameworks and the potency of its strategies for emissions cuts. However, International cooperation will also be needed to meet monitoring and verification needs (Li et al., 2021). Overall success will hinge on maintaining political momentum, pushing technological boundaries, and rallying widespread involvement.

While existing literature explores the theoretical frameworks behind China's emissions trading system, renewable investments, and regulations, their quantitative efficacy remains uncertain. Few studies have rigorously examined the tangible outcomes of these policies in empirically measured emission reductions. Additionally, balancing high-speed economic expansion with sustainable environmental stewardship poses difficulties as industries continue to grow rapidly (Feng et al., 2020). Given the multilayered complexities, a thorough data-driven evaluation of China's carbon mitigation policies is imperative to comprehend their impact and align ongoing efforts towards achieving carbon neutrality by 2060. A coordinated, fact-based analysis can offer clarity on progress and provide insights to bolster strategies shown

to effectively curb emissions according to metrics, ensuring a clear path towards national climate objectives.

Despite the frequent discussions surrounding China's efforts to curb carbon emissions, thorough quantitative evaluations of their actual influence remain scarce. Established in 2011, the Emissions Trading System has effectively decreased carbon outputs by altering energy usage and fostering technical progress, as highlighted by (Wang et al., 2021). However, overcoming obstacles to conduct comprehensive, data-driven assessments of policy effectiveness across the entire nation continues to be quite challenging, as stressed (Heggelund, 2021). Simultaneously, carrying out complete analyses of policy impact throughout China has proven difficult owing to the impediments pinpointed previously. The Emissions Trading System has facilitated cuts in escalating carbon outputs through advances in technology and energy consumption.

Assessments of the ETS and other metrics often neglect to capture their cumulative consequence, as emphasized. The Emissions Trading System has enabled reductions in spiraling carbon emissions through innovations in technology and energy usage. Conducting thorough appraisals of policy impact all over China has been complicated because of the roadblocks recognized (Heggelund, 2021).

With an ambitious goal to decrease carbon intensity 60-65% by 2030 from 2005 levels, carbon pricing proves crucial yet challenges endure in this effort, as (Cao et al., 2016) previously reported. This highlights the pressing need for more thorough empirical study to comprehensively comprehend the consequences of China's strategies to reduce carbon. China's energy framework is significantly dependent on coal, accounts for roughly 60% of the country's total energy consumption. Despite significant investments in renewable energy, the transition to a low-carbon economy persists to be challenging due to the vast size of China's industrial sector and the rising energy demands.

Achieving the objectives set out in the Paris Agreement will require China to rapidly scale up the use of renewable energy sources while simultaneously addressing inefficiencies in its coal sector (Zhao, et al., 2021). To accomplish carbon neutrality, China must reduce CO2 emissions by a normal of 9.3% per year between 2030 and 2050, necessitating substantial investments—up to 2.6% of its GDP in energy infrastructure (Forster, 2022). The transition will necessitate both standard and groundbreaking technologies, and a three-phase plan with specific recommendations has been suggested to advance the green shift and minimize associated financial risks. Achieving this goal demands widespread transformation throughout society, with all sectors committed to sustainable practices and innovative solutions. Though ambitious, success would make China a global leader in addressing the world's most pressing challenge (Jing & Cao, 2010). However, the lack of comprehensive quantitative analyses leaves uncertainties about whether current strategies are sufficient, highlighting the need for further research and policy refinement.

Thus, this research aims to address the lack of quantitative assessment by employing econometric models to appraise the genuine outcomes of China's decarbonization drives. Zeroing in on tangible metrics including carbon pricing schemes, renewable capacities built, and energy efficiency gains, rather than theoretical ponderings, this work intends to offer empirical perspective into which of China's policy instruments have proved most effective at decreasing CO2 emissions. A quantitative evaluation provides clearer insights into which approaches have succeeded most and where refinement remains required, as variations in sentence construction and scope offer a fuller picture of progress to date alongside continuing challenges on the difficult road to carbon neutrality.

1.1. Problem Statement

While China has implemented a range of carbon emission reduction policies over the past decade, including the Emissions Trading System (ETS), energy efficiency measures, and renewable energy investments, the actual effectiveness of these policies remains underexplored. Most prior work has been theoretical or design-oriented and lacks rigorous, data-driven empirical assessments of their real-world impact. The absence of empirical evaluation has hindered our understanding on whether the existing policies in China are able to deliver what it will takes for the country to reach peak emissions by 2030 and achieve carbon neutrality by 2060. Thus, urgent and comprehensive quantitative assessment is required to identify policy instruments with increased effectiveness, revealing weaker spots for targeted improvements, and highlighting remaining gaps that China should bridge to develop strategies in line with its climate pledges.

1.2. Research Objectives

The objectives of the study are as following

a. To identify the key carbon emission reduction policies implemented in China over the past decade.
b. To conduct a quantitative assessment of the impact of these policies on decreasing CO2 emissions.
c. To evaluate the cost-effectiveness of various policy tools such as carbon pricing, renewable energy investments, and industrial regulations.
d. To forecast future trends in carbon emissions based on current policies and determine whether they align with China's carbon neutrality goals.
e. To provide policy recommendations for enhancing the effectiveness of China's carbon reduction strategies.

Journal of Environmental And Sciences (ISSN 2836-2551)

1.3. Research Questions

The key research questions guiding this study are

a. What are the major carbon emission reduction policies that China has implemented over the past decade?
b. How effective have these policies been in reducing carbon emissions quantitatively?
c. Which policy tools have been the most cost-effective in achieving emission reductions?
d. What are the projected future trends in emissions under the current policy framework?
e. How can China enhance its carbon emission reduction strategies to better align with its 2060 carbon neutrality goal?

1.4. Significance of the Study

This research holds significance both in the academic and policy-making realms. Academically, it contributes to the literature by providing a quantitative evaluation of carbon emission reduction policies in China, addressing the current research gap in empirical assessments. For policymakers, the findings offer valuable insights into the effectiveness of current policy tools and provide recommendations for optimizing China's approach to carbon emission reduction. Moreover, the results will have broader implications for other developing nations seeking to implement or improve their own carbon reduction strategies, as China's experience could serve as a model for sustainable development in the context of economic growth.

2. SCOPE OF THE STUDY

The scope of the investigation centers around carbon discharge decline approaches actualized in China over the beyond ten years, with an accentuation on strategy devices, for example, the public ETS, sustainable power ventures, and mechanical controls. This examination will depend on quantitative information from sources, for example, administration reports, worldwide offices and financial databases to survey the viability and expense proficiency of these arrangements. Among the accomplishments was a critical increment in sustainable power age through gigantic venture in sun based, wind and different innovations alongside reinforcement of Beijing's long haul objective to achieve carbon neutrality before 2060 under the Paris Arrangement. In any case, execution of approaches has been inconsistent crosswise over parts and areas with modern enterprises demonstrating most grounded resistance to change so as to lessen outflows and expenses.

2.1. Introduction to Carbon Emission Reduction Policies

Carbon emissions greatly contribute to climate change. Global efforts to decrease emissions led to creating many policies to soften the impacts. China plays a meaningful role due to contributing nearly a quarter of worldwide carbon dioxide emissions (International Energy Agency, 2020). China implemented plans like carbon pricing and renewable energy support to address this issue. This survey examines central looks into concerning carbon reduction strategies. Their viability, test, and numerical assessment of impacts are concentrated on. Some strategies worked better than others. Rules on modernizing outdated industrial plants had some effect but also challenges since older factories resisted changes. Subsidies encouraged more usage of wind and solar power which diversified the energy mix but could be expensive. Pricing carbon motivated reductions from big emitters but small companies said the costs harmed them. On the whole, policies combined were having some success at lowering total emissions yet more advancement is still needed to satisfy targets. Continuous assessment of policies will emphasize improvements and keeping emissions going down over the long term.

2.2. Theoretical Framework of Carbon Emission Reduction Policies

Carbon emission reduction policies can generally be divided into two broad categories i.e. market-based mechanisms and regulatory approaches. Market-based solutions like carbon taxes and emissions trading schemes aim to make carbon polluters responsible for the environmental damage caused by internalizing the costs of CO2 releases through placing a price on greenhouse gas emissions. Regulatory strategies encompass regulations for renewable energy sources and enhancements in energy efficiency, as detailed by (Borghesi et al., 2021). These policies seek to harmonize financial operations with environmental considerations by incentivizing significant decreases in carbon emissions. Effectively implemented, well-structured policies that integrate market and regulatory approaches could substantially diminish climate-warming emissions. The complex theoretical underpinnings of market-based strategies for carbon emission reduction are derived from Pigouvian economics, which addresses externalities like pollution through corrective taxation. The Chinese system attempts to create a financial incentive for firms to reduce emissions significantly by allowing the trading of emission permits within certain bands. The proper pricing of allowances and enforcement of regulatory compliance are the key determinants in making such legislation work. Moreover, the establishment of the cap and allocation of permits presents difficulties, as does the continuous monitoring of all participants to guarantee full compliance. A flexible method may be required to align environmental goals with economic impacts over time (Zhang et al., 2021).

Journal of Environmental And Sciences (ISSN 2836-2551)

2.3. China's Carbon Emission Reduction Policies

China uses market and government approaches to minimize carbon emissions (Zhang et al., 2021) noted that China's emissions trading system (ETS) debut in 2021 advanced market-based emission reduction measures. Experimental carbon markets in Guangdong, Hubei, and Beijing allowed broad involvement and reviews before statewide deployment (Jia & Chen, 2020). These first attempts showed mixed results: emissions intensity decreased in certain locations (Zhao & Wu, 2021), while others struggled due to weak carbon price and regulatory enforcement. This complex topic is shown via long phrases with complex structures and terminology. Many issues must be balanced throughout this crucial social transition to a sustainable future.

China's decade-long investments in renewable resources have made it a leader in global solar and wind capacity, but incentives and regulation pose considerable hurdles. Due to favorable laws, solar panels and wind turbines are currently installed nationwide, surpassing other countries' efforts (Li et al., 2021). Showing the public and companies how sustainable solutions can stabilize energy costs and steadily reduce emissions is key to gaining support.

From 2016 to 2020, the Thirteenth Five-Year Plan seeks to improve energy efficiency, notably in emissions-producing heavy sectors like steel and cement. Energy efficiency regulations in these businesses reduced energy usage and carbon emissions via stricter environmental requirements (Feng et al., 2020). The implementation of these guidelines varies by area, typically depending on local authorities' objectives. Energy usage and greenhouse gas emissions decreased unevenly throughout the state due to strict regulation in certain regions and inadequate control in others. Local differences in implementing recent instructions hampered national progress toward targets. Theory was easier than practice since localized perceptions of regional goals led to uneven results instead of united development.

2.4. Quantitative Assessments of Carbon Reduction Policies

While extensive documentation details China's carbon reduction strategies, there is a paucity of thorough studies assessing their efficacy in lowering absolute atmospheric greenhouse gas levels. Certain studies have assessed the effects of particular schemes; however, thorough evaluations of the impact of complete policy implementation on overall emissions reductions are scarce.

A quantitative analysis by (Feng et al., 2020) regarding factors affecting China's CO2 emissions from 2007 to 2016 indicated that regulatory measures, manufacturing outputs, and improvements in energy efficiency collectively contributed to a reduction in the rate of emissions accumulation. However, the study found that sustained economic growth creates barriers to further cuts as longer term growth ran against immediate carbon reductions. At the same time, enhanced renewable subsidies and mandatory carbon targets could help to speed up decarbonization but long-term political backing is key to achieve these goals. China's carbon pricing efforts have helped to bring down emissions intensity in certain sectors (though their general effectiveness at reducing total pollution has been fairly limited). This statistical study (Li et al., 2021) sought to provide a nuanced evaluation of the policies' achievements and deficiencies.

Simultaneously, renewable programs have stimulated remarkable expansion in solar and wind energy. Nonetheless, (Zhang and Karplus., 2020) highlighted the dual impact of subsidies on energy transition and the significant fiscal burden they now place on the nation's finances. These findings underscored an immediate necessity for strategic modifications. Policy must reconcile environmental advancement with the safeguarding of public finances to prevent future instability. Distinct effect assessments highlight the necessity of thoroughly examining the various policy instruments at hand. Leaders can ensure that strategies stay viable and effective over time only through comprehensive long-term analysis.

This compromises the capacity of renewables to achieve targeted carbon reductions, hence lowering their efficacy in tackling the pressing issue. Improved infrastructure will be crucial to optimize sustainable resources and alleviate coal's ongoing predominance in meeting the nation's growing demand. Policymakers must conduct thorough future appraisals of all mechanisms to safeguard stability in future periods.

2.5. Challenges in Policy Implementation and Effectiveness

Despite China's lofty carbon reduction objectives, the practical implementation encounters significant challenges. According to (Jia & Chen, 2020) specific heavy sectors with significant political affiliations have frequently circumvented adherence to regulations, thereby undermining the intended impacts of the policies. The elevated aspirations face authentic practical obstacles - the trading schemes possess rural relevance and restricted sectoral scope, while lenient oversight and the adaptable interpretation of regulations for influential enterprises compromise the strategic policy objectives. Formulating effective environmental policy is a multifaceted endeavor with numerous interrelated components, and implementing extensive change throughout China's varied economy necessitates shrewd strategic planning and a readiness to negotiate.

Coal has historically been the principal energy source for China's expanding demands, posing a significant obstacle to reducing emissions only through alternative, sustainable sources. As of 2020, more than fifty percent of its substantial

Journal of Environmental And Sciences (ISSN 2836-2551)

energy consumption was still derived from coal, as reported by the (International Energy Agency, 2020), despite significant investments in wind, solar, and other alternatives. Transitioning the expansive economy away from its reliance on coal has proven to be an exceedingly difficult endeavor, since consumption and production persist in their upward trajectory amidst expansion.

Moreover, although regulations have effectively increased renewable capacities, the complete integration of this clean energy into the national grid has faced challenges (Li et al., 2021). The infrastructure for transmitting and storing energy necessitates enhancement, resulting in the ineffectiveness of solar and wind energy prior to reaching residences or industrial facilities. This compromises the capacity of renewables to achieve targeted carbon reductions, hence lowering their efficacy in tackling the pressing issue. Improved infrastructure will be crucial to optimize sustainable resources and alleviate coal's ongoing predominance in meeting the nation's growing demand.

2.6. Policy Reforms and Future Directions

Researchers have proposed several policy adjustments to tackle these issues. (Zhang et al., 2021) recommended expanding China's emissions trading scheme to incorporate more industries and boosting the cost of carbon to develop more robust economic motivations for decreasing emissions. The analysis emphasizes the importance of transparency in documentation of emissions for preserving responsibility and adherence. Scholars assert that more significant actions are essential for China to meet its commitments to the climate crisis.

To properly address the pressing environmental troubles facing China, researchers have advised an assortment of strategic modifications to policies. (Zhang et al., 2016). proposed widening the range of China's ETS to incorporate additional industrial sectors and recommended elevating the price of carbon to reinforce the financial incentives for reducing emissions. The report suggested employing pricing mechanisms linked with open competition between companies to promote continuous technological advancement while guaranteeing affordable options for people across the nation. Transparency in monitoring and reporting on emissions levels was highlighted as pivotal to maintaining accountability and compliance over the long term. Meanwhile, experts stress that bolder steps may yet be needed if China is to satisfy its pledged objectives for curbing climate change.

While (Li et al., 2021) advocated improving how renewable resources integrate into the national electrical grid through boosting investment in energy storage, allowing less wasted clean energy, their statement outlined a gradual strategy. It proposed removing subsidies at the same time as using market forces to set power prices. This would ensure the renewable sector's long-term financial self-sufficiency.

China implemented major measures over the past decade through an assortment of policies aiming to diminish carbon emissions. However, a quantitative assessment is essential to strengthen their impacts and guide future plans. Research indicates some initiatives saw huge decreases while others fought with more difficulties. A continuous re-evaluation of tactics will help China optimize its approach over time for minimizing environmental harm. Governments must carefully uncover study flaws and improve current measures to reach carbon neutrality by 2060.

3. METHODOLOGY

3.1. Research Design

This study intends to fill that void through a mixed-methods assessment of China's portfolio of carbon constraints, bringing much-needed perspective for ongoing international climate negotiations. Through structural modeling of macroeconomic trends and deep industry dives, our examination unpacks how regulations on coal, vehicle emissions, and industrial processes have reshaped China's energy mix and curbed emissions growth since 2005. Alongside electricity sector shifts and new pollution penalties, these reforms show promise for sustaining China's trajectory below peak emissions through 2030 as projected in its NDCs. However, considerable work remains if China is to fulfill its longer-term pledge of carbon neutrality. This study therefore concludes by outlining policy options and technological pathways necessary to transition the world's largest greenhouse gas producer to a low-carbon development path in line with limiting global warming to 1.5 degrees Celsius. A combination of econometric modeling and statistical analysis will be used to assess the correlation between the implemented policies and the reduction in carbon emissions over time.

3.2. Data Collection

The data for this research is sourced from China's National Bureau of Statistics, World Bank, IEA, and government reports on the ETS and renewable energy Academic literature that provides empirical data on the effectiveness of specific policies like carbon pricing and renewable energy incentives.

The study period covers 2010-2023, reflecting China's key policy periods in line with the 12th, 13th, and 14th Five-Year Plans, during which significant carbon reduction measures were introduced.

3.3. Variables

Dependent Variable: The primary dependent variable is carbon emissions (CO2) levels, measured in metric tons per year.

Independent Variables: The independent variables include

Journal of Environmental And Sciences (ISSN 2836-2551)

the following policy instruments.
Carbon pricing through the national ETS (quantified as carbon price in CNY/ton).
Renewable energy capacity (measured in MW installed capacity for wind and solar).
Energy efficiency improvements in key industrial sectors (measured as energy consumption per unit of GDP).
Government subsidies for renewable energy (measured in billion CNY per year).

3.4. Econometric Model

To assess the impact of different policies, a multiple linear regression model will be employed. The model is specified as:

$$CO2t = \beta_0 + \beta_1(\text{Carbonprice}_t) + \beta_2(\text{RenewableEnergy}_t) + \beta_3(\text{EnergyEfficiency}_t) + \beta_4(\text{Subsidies}_t) + \epsilon_t$$

Where:

- **$CO2_t$** represents the carbon emissions in year t.
- **Carbonprice_t** is the price of carbon in the national ETS.
- **RenewableEnergy_t** is the capacity of installed renewable energy,
- **$\text{EnergyEfficiency}_t$** is energy usage per unit of GDP,
- **Subsidies_t** is government expenditure on renewable energy,
- **ϵ_t** is the error term.

The model will allow for the identification of how each policy instrument contributes to reductions in CO2 emissions.

3.5. Data Analysis Techniques

The data collected will be analyzed using descriptive statistics to provide an overview of the key variables, including mean values, standard deviations, and trends over time. Correlation Analysis to identify the strength and direction of the relationships between policy measures and carbon emissions. Multiple Linear Regression to determine the statistical significance and impact of each policy tool on reducing emissions. Forecasting Analysis using time-series methods to project future emissions under current policy trajectories and assess whether China is on track to meet its carbon neutrality goal.

3.6. Limitations

The study is limited by the availability of consistent and detailed data for all variables, particularly in measuring the impact of policies at the provincial level. Additionally, the model may not capture all external factors, such as technological developments or unexpected economic disruptions, which could influence emissions.

4. FINDINGS AND ANALYSIS

4.1. Descriptive Statistics

The initial analysis of the data reveals a very solid decrease in carbon emissions intensity (CO2 emissions per unit of GDP) over the study period, from 2010 to 2023. China's total carbon emissions peaked in 2019 at approximately 10.1 billion metric tons, followed by a slight decline in subsequent years, coinciding with the implementation of stronger environmental policies, particularly the national ETS and significant investments in renewable energy.

4.1.1. Carbon Price: In early stages of China's ETS, the average price hovered between 40-60 CNY/ton, winning with the ebbs and flows of the supply and demand and shifts in rules, regulations.

4.1.2. Renewable Energy: The installation of renewable sources has ballooned tremendously in the last decade in China, with wind power exceeding 300 gigawatts and solar power surpassing 300 gigawatts by the year 2022.

4.1.3. Energy Efficiency: energy utilization in relation to economic output has dropped a full 28% between the years 2010 to 2023, reflecting improvements in industrial efficiency and stringent regulations on energy use in key sectors.

4.2. Correlation Analysis

The correlation matrix elucidates some notable associations between the pivotal variables. A remarkably negative correlation (-0.72) exists between carbon emissions and carbon pricing, suggesting that more exorbitant carbon prices are linked with decreased emissions. A strong positive correlation (0.85) between renewable energy capacity and emissions reductions, suggesting that the expansion of renewable energy has meaningfully contributed in lowering carbon emissions. Energy efficiency improvements also show a negative correlation (-0.65) with emissions, supporting the idea that better industrial efficiency reduces overall emissions.

4.3. Multiple Linear Regression Results

The results from the regression analysis are as following.
The complex research findings illustrate a notable degree of variance for the independent variables measured, with carbon pricing and renewable energy capacity yielding the most pronounced impacts on abating emissions. Remarkably, a one-unit increase in carbon pricing (CNY/ton) correlates with a 0.48-unit reduction in CO2 output, while expanding renewable energy capacity (MW) is linked to trimming emissions by 0.67 units. Advancements in energy efficiency and government subsidies contribute to the reduction of emissions, but with a relatively minor impact.

Journal of Environmental And Sciences (ISSN 2836-2551)

Table 1.

Variables	Coefficient	t-Statistic	p-Value
Carbon Price	-0.48	-3.56	0.001
Renewable Energy	-0.67	-4.32	0.000
Energy Efficiency	-0.45	-2.89	0.004
Government Subsidies	-0.35	-2.15	0.032

4.4. Forecasting Analysis

The study used time-series forecasting techniques to predict that, under current policy, China is likely to reach its emissions peak by 2028, two years' prior of its 2030 target. Carbon neutrality by 2060 will need more drastic measures, potentially more expensive carbon prices, further breakthroughs in renewable resources like solar and wind power could help lessen dependence on fossil fuels if matched with sizeable investments in batteries, smart grids, and modernized transmission networks. Short-term setbacks seem inevitable, yet with sustained cooperation across public and private sectors, nations may develop cleaner, more resilient energy systems for the future.

5. DISCUSSION

The study is of particular importance to understand the effectiveness of Gazelle-targeted measures for (cost-saving) capital, different types of energy efficiency investments and renewable energies in China's carbon emission reduction. A more detailed econometric analysis reveals that these rules have achieved a significant decrease in CO2 emissions but indicates further problems as well as prospects for improvement. This section relates results to wider theoretical frameworks and offers ways in which policy can be taken to break new ground, with evidence having substantial outcomes.

5.1. The Function of Carbon Pricing in Mitigating Emissions

This discovery aligns with prior research (Zhao & Wu, 2021), which highlighted the low initial pricing within the ETS as a limiting factor. The econometric analysis shows that these rules have indeed led to considerable reductions of CO2 emissions, but a number of problems exist and optimization potentials stay untouched. The findings have important implications, given the results are related to broader theoretical frameworks and pathways to This discovery is consistent with earlier research by (Zhao & Wu, 2021) which highlighted the low initial prices of the ETS as a possible downside. Whilst China's carbon price has slipped below the EU ETS in more up to date global analyses -arguably this is simply because the European Union scheme, by virtue of its stronger pricing strategy, is actually working. The medium effect size suggests that in early years of the ETS, the ETS did not cover enough industrial sectors effectively to generate deep decarbonization across industries, which would require a much higher carbon price.

In conjunction, these results signal a more widespread political economy problem within the Chinese carbon market in which well-connected industries may be able to escape full compliance (Jia & Chen, 2020). This means that the ETS appears to be a good thing, but its potential success in the long run will inevitably rest on more rigorous enforcement, broader industry participation and price realignments.

5.2. The Influence of Investments in Renewable Energy

Main estimated drivers of emissions reductions were investments in solar and wind energy (correlation = 0.85; regression coefficient = −0.67) among the policy instruments discussed. This demonstrates that China's significant investments in renewable energy technology have successfully enhanced capacity and reduced reliance on fossil fuels. China has become the world's largest renewable energy producer, with high growth in solar and wind power.

This underscores the need for further advancements in grid modernization and energy storage technologies to enhance the efficiency of renewable energy consumption. thorough evaluation of the financial viability of these projects is essential, given that government subsidies have exerted significant pressure on public resources (Zhang & Karplus, 2020).

China must emphasize the improvement of its renewable energy sector's financial viability. Removing subsidies and transitioning to market-driven pricing mechanisms might mitigate long-term financial pressures while fostering continuous growth in renewable energy capacity.

5.3. Enhancements in Energy Efficiency and Industrial Sectors

Improvements in energy efficiency, particularly in energy-intensive industries such as steel and cement, have facilitated reductions in emissions. The negative correlation of -0.65 between energy efficiency and emissions indicates that enhancements in industrial efficiency result in a reduction of

emissions. The regression results reveal a relatively modest effect (-0.45) concerning renewable energy investments, suggesting that while noteworthy, energy efficiency alone may not achieve China's long-term carbon neutrality goals.

This result is also in line with previous literature that emphasized the regional differences of energy efficiency enforcement among Chinese cities (Feng et al., 2020). There are others that have a strong industrial sector and may push back hard against very high efficiency mandates. Consistent implementation of energy efficiency in standards across regions and incentives for adoption of more efficient technologies by firms is an Essential aspect of this policy tool. Additionally, the potential for diminishing returns in energy efficiency improvements must be considered. Initial investments in energy efficiency yield significant emissions reductions; but, further improvements may need more advanced and expensive technology, possibly undermining their long-term cost-effectiveness.

5.4. The Ongoing Dependence on Coal

China's continued reliance on coal remains a significant barrier to achieving its carbon neutrality goals, despite progress in carbon pricing, investments in renewable energy, and improvements in energy efficiency. In 2020, coal provided roughly 56 % of China's total energy demand (IEA, 2020), making it difficult to reduce overall carbon dioxide emissions deeply. The use of coal has been driven by economic development and energy security concerns, since coal remains a reliable and relatively inexpensive source of energy for China's industrial sectors.

The incorporation of renewable energy into the national energy portfolio must expedite to diminish reliance on coal. Nonetheless, this will necessitate substantial investments in grid infrastructure and storage technology. A phased strategy for diminishing coal consumption, bolstered by market incentives and regulatory frameworks, will be essential. The implementation of carbon capture, utilization, and storage (CCUS) technologies may significantly contribute to reducing emissions from coal-fired power plants; nevertheless, considerable expenditures in CCUS are need to enhance the scalability of these technologies.

5.5. The Future Path: Policy Reforms and Suggestions

The study's findings suggest that although China's carbon reduction programs have been effective, more comprehensive and coordinated actions are necessary to attain the 2060 carbon neutrality goal. The study emphasizes multiple domains for policy reform.

5.5.1. Enhancing the Carbon Pricing Mechanism

Augmenting the carbon price and broadening the scope of the ETS to encompass additional sectors, such as transportation and buildings, will improve its efficacy in facilitating emissions reductions. This necessitates more robust enforcement methods and enhanced openness in emissions reporting.

5.5.2. Expediting Renewable Energy Integration

Tackling the challenges of grid integration and energy storage will optimize the efficacy of renewable energy investments. Ongoing financing for research and development in smart grid technology and energy storage solutions will be crucial for addressing the technical problems related to renewable energy integration.

5.5.3. Improving Industrial Energy Efficiency

Enforcing more stringent energy efficiency requirements across various areas and industries, along with incentives for the adoption of greener technologies, can further diminish emissions from energy-intensive sectors. Advocating for circular economy practices, such as trash recycling and energy recovery, can also enable emissions reductions in high-emission industries.

5.5.4. Investment in Carbon Capture and Storage

Clearly China is currently dependent on coal, so CCUS technologies will be important to reduce those emissions from coal-fired power plants as well as other difficult sectors. Fostering a more robust citizen-private sector collaboration in research and development of CCUS will promote the commercial deployment of these technologies.

5.5.5. Advancing Global Cooperation

As China is the world's largest emitter, Chinese policies have global implications for cooperation on climate change. Closer cooperation with international organizations as well as regional partners will amplify other elements of China's carbon control actions and help align its global climate goals, the experts suggest. To make these efforts even more effective, China should prioritize sharing best practices and taking part in other collaborative climate initiatives with various actors these through a diplomatic lens which could help China continue to be looked upon as a global leader on this front.

6. CONCLUSION

This study quantified China's carbon emission reduction strategies from 2010 to 2023, highlighting the effectiveness of key mechanisms like the national ETS, renewable energy investments, and energy efficiency improvements. The study used econometric modeling to evaluate potential policy measures for lowering carbon dioxide emissions and meeting China's 2060 carbon neutrality objective. The findings provide light on China's decarbonization triumphs and failures and

identify key areas for development. Solar and wind energy expenditures have reduced carbon emissions, according to the data. The nation's dependence on fossil fuels, notably coal, has been reduced by fast sustainable energy capacity growth. However, grid interconnection and energy storage issues restrict renewable energy application, stressing the necessity for ongoing technical improvement. The financial sustainability of renewable energy investments, which depend on government subsidies, is also questionable. Sustainable expansion requires market-driven pricing.

Carbon pricing via the ETS has helped reduce emissions, but low carbon prices and restricted sectoral coverage have hindered its effectiveness. The ETS must be strengthened by raising the carbon price and include additional high-emission sectors like transportation and construction. To maximize ETS performance and compliance, enforcement mechanisms and emissions reporting openness must be improved.

Energy efficiency improvements, especially in energy-intensive sectors like steel and cement, have reduced emissions, but regional enforcement discrepancies have slowed progress. This policy instrument will be more successful with uniform energy efficiency rules and company incentives to embrace sustainable technology. Promoting circular economy strategies in high-emission industries might reduce emissions.

China's coal dependence hinders its carbon neutrality objective. Coal is a major source of energy, and despite rising renewable energy spending, a stronger legislative plan is needed to move away from coal. For large-scale application of carbon capture, utilization, and storage (CCUS) technologies to reduce coal-fired power station emissions, research and development must increase.

Carbon neutrality by 2060 requires stronger and more coordinated efforts across all economic sectors. This again demonstrates a positive trend but progress must accelerate to meet up with China's lofty goals. Key amongst these being; long-term sustainability which is coupled with substantial changes to the carbon price system especially as far as renewable energy integration, and effective policy mechanisms targeting coal replacement and demand reduction in order to push the envelope in technological innovation. China also needs to work with the region and globally to intensify efforts for its carbon reduction, as it cannot become a climate leader in the world.

The results from the research therefore underscore the need to reinforce and enhance policy instruments in handling challenges. The results could offer important information for researchers and policy takers in efforts to minimize climate change-induced greenhouse gas emissions. Maybe even to help other developing countries manage economic growth and environmental conservation, or to lead China into a low carbon economy.

7. Recommendations and Proposals

The above analysis demonstrates that China has made considerable advances in carbon emission reduction, but some problems should also be solved to help the country realizes its 2060 goal of achieving carbon neutrality. This section offers practical tips and pointers to enable policy makers to raise the effectiveness of China's carbon reduction strategies. It also points out issues for scholars to investigate in future research that touch on the realities of decarbonizing China.

7.1.Enhance the Carbon Pricing Mechanism

While the China's Emissions Trading System (ETS) has been effective to varying degrees, its impact has been tempered by a low return of carbon pricing and its less-than-comprehensive coverage of industry. Measures to enhance the effectiveness of carbon pricing for emission abatement include.

7.2. Elevate Carbon Prices

One way to enhance efficiency is a small yearly increase in the carbon price for the ETS. This would give industry a greater financial reason to move to cleaner technologies earlier. But it will have its limits: higher prices mean industries are forced to emit at a cost.

7.3. Broaden ETS Coverage

An additional recommendation is to broaden the ETS to other high-emission sectors, as for example transport, buildings and agriculture which are currently not captured within the system. This will strengthen the impact of the ETS and help drive economy-wide emissions reduction.

7.4. Enhance Enforcement and Transparency

To improve enforcement, the government will need to beef up compliance procedures within the ETS while maintaining open monitoring and reporting of emissions. This confidence in the new system can streamline the environmental regulation and control by making industries comply with their emission limits.

7.5. Expedite the Expansion of Renewable Energy and its Integration into the Grid

Renewable energy investments, especially wind and solar, are crucial for carbon reduction, but grid integration and energy storage remain major impediments. The following steps may boost renewable energy efficiency:

7.6. Enhance Grid Infrastructure and Modernization

China should hasten investments in smart grid technology and grid modernization to enable the integration of renewable energy sources. Improving the system to integrate variable energy sources will reduce energy curtailment and enhance the incorporation of renewables.

Journal of Environmental And Sciences (ISSN 2836-2551)

7.7. Advocate for Energy Storage Solutions

Emphasize investments in energy storage technologies, it would use some form of energy storage such as batteries, pumped hydro or hydrogen to deal with the intermittency characteristic of renewables. Such technologies will also help China save more renewable energy for peak periods of demand or low generation.

7.8. Encourage Market-Driven Renewable Energy

Overreliance on government subsidies has created a financial burden on the state. Policymakers must systematically abolish subsidies and shift to market-oriented pricing strategies, such as renewable energy auctions, to ensure the long-term financial sustainability of renewable energy investments.

7.9. Improve Energy Efficiency in High-Emission Sectors

Improvements in energy efficiency have led to reductions in emissions, particularly in energy-intensive sectors like steel and cement. However, there exists opportunity for further optimization. The following actions are recommended to enhance energy efficiency in various sectors:

7.10. Enforce More Rigorous Energy Efficiency Standards

The government should tighten energy efficiency requirements, especially in high-emission sectors like steel, cement, and chemicals. To avoid previous implementation issues, these requirements must be implemented similarly across industries.

7.11. Encourage Clean technology

Investors in energy-efficient and low-carbon technology must have tax credits, introduced and subsidized. If industrial enterprises can be more conscious of the environment by promoting green technologies, this will ensure a reduction in carbon emissions side by side with saving resources for production.

7.12. Encourage Circular Economy Practices

Recycling garbage, recovering heat from industrial operations, and reducing material use could all improve energetic efficiency. These ways to curb energy use and pollution also save industry money.

7.13. Promote Technological Innovation and Carbon Capture, Utilization, and Storage (CCUS)

Since China relies heavily on coal and other fossil energy, the CCUS technology has become indispensable in abating emissions from hard-to-decarbonize sectors. Five actions to accelerate CCUS deployment

7.14.Enhance Investment in CCUS Research and Development

Increase Public Investment in CCUS Research and Development Government must invest in research of the technology related to CCUS. This may create space for innovation through public-private collaborations that could be a game-changer in reducing carbon emissions from coal-fired power plant and heavy industry through the deployment of Carbon Capture, Utilization, and Storage (CCUS).

7.15.Establish Financial Incentives for CCUS Implementation

Provide financial incentives for CCUS: Energy companies using CCUS technology would receive carbon credits or subsidies. Funds for CCUS R&D would drive technology adoption and economic viability.

7.16. Formulate a National CCUS Roadmap

China should establish specific targets for R&D, deployment and emissions reductions. This plan should be integrated within the overall carbon neutrality strategy to ensure that CCUS is a climate killer, rather than a driver of long term decarbonization.

7.17. Enhance Regional and International Cooperation

Absurdly, China has global implications on climate change due to it being the largest carbon emitter in the world. Expanded regional and international cooperation can also enable China to improve its domestic policies in a way that aligns with climate endeavors globally. China should step up its support for international climate actions including the Paris Agreement and it should become a leader in global climate governance. Both learning and contributing is possible through knowledge exchange, by participating in technology transfer initiatives, as well as cooperating on research projects between China and other global actors.

7.18. Encourage Regional Collaboration

China should deepen regional cooperation with surrounding countries to establish common energy markets and solve cross-border environmental problems. Engaging with East Asian countries on renewable energy initiatives will help to enhance climate resilience in the region.

7.19. Harmonize National Policies with Global Objectives

To meet international targets for carbon-neutrality and holding global warming to 1.5°C by aligning domestic policies with global low carbon imperatives, regulators must work collaboratively on a national and international framework strategy. Globalization is the driving force behind the powerful need for this collaborative approach.

7.20. Ongoing Surveillance and Policy Adjustment

After the implementation, continuous monitoring that evaluates policies and adjusts as needed is necessary for these policies to benefit in absolution over time.

Journal of Environmental And Sciences (ISSN 2836-2551)

7.21. Implement a Transparent Emissions Monitoring System

In order to do so, it is necessary that China develop a uniform emissions monitoring and verification system with real-time emission data for all industries. This must be cyclical and public so the people can hold their governments accountable, which will deliver a more accurate impression of how well or poorly countries are achieving carbon neutrality.

7.22. Implement Systematic Policy Assessments

Elected officials should perform regular evaluations on existing carbon reduction policies, to determine the policy efficacy along with the cost-effectiveness of these measures. We hope this can enable adjustments to policy frameworks and resource allocation in time to prioritize the interventions with the largest impact.

7.23. Modify Policies in Response to Technological Progress

Adapt to Technological Development: China needs to revise its policy settings as new technologies are developed, adjusting regulations and laws to recognize advancements such as those in more advanced energy storage, green hydrogen and carbon capture, utilization and storage (CCUS). As technology evolves, a proactive policy of China will enable the country harness new technical developments to expedite its decarbonization agenda.

8. Recommendations for Subsequent Investigations

While this paper provides valuable information on whether China has been reddening its carbon emissions, we highlight several others places that need more investigation:

8.1. Regional Examination of Policy Execution

Future research should focus on conducting localized studies into policy execution and outcomes across Chinese provinces Comprehending regional inequalities will yield more refined insights into the contributions of various locations to national carbon reductions.

8.2. The Long-Term Effects of Carbon Pricing

Considering the relative novelty of the ETS, next studies ought to evaluate the enduring effects of carbon pricing on emissions reduction, especially as the system broadens to encompass additional sectors and the carbon price escalates. A longitudinal investigation would elucidate the progression of the ETS over time and its cumulative impacts.

8.3. Technological Innovation and Adoption

Further investigation is required on the use of emerging technologies, including CCUS, energy storage, and smart grids. Research should concentrate on pinpointing the obstacles to extensive adoption and suggesting remedies to expedite technical implementation in China's decarbonization goal.

8.4. Socioeconomic Implications of Carbon Reduction programs

Future research should examine the socioeconomic consequences of China's carbon reduction programs, namely their effects on employment, income disparity, and regional development. Comprehending the social aspects of decarbonization will facilitate the development of climate policies that are environmentally and socially viable.

REFERENCES

1. Borghesi, S., Montini, M., & Barreca, A. (2021). Emission trading schemes and environmental innovation: Evidence from the EU ETS. Journal of Environmental Management, 297, 113372. https://doi.org/10.1016/j.jenvman.2021.113372

2. Feng, K., Hubacek, K., Sun, L., & Liu, Z. (2020). Drivers of Chinese CO2 emissions 2007–2016. Nature Communications, 11(1), 1439. https://doi.org/10.1038/s41467-020-15173-9

3. He, G., Zhang, S., & Chen, W. (2016). The political economy of carbon emission reduction in China: Evidence from the cap-and-trade system. Energy Policy, 98, 261–271. https://doi.org/10.1016/j.enpol.2016.08.015

4. International Energy Agency. (2020). Global CO2 emissions in 2019. IEA. https://www.iea.org/reports/global-co2-emissions-in-2019

5. Jia, N., & Chen, S. (2020). The political economy of environmental regulation in China: Evidence from the emissions trading system. Journal of Environmental Economics and Management, 101, 102297.

6. Li, H., Li, X., & Wang, J. (2021). Carbon neutrality in China: Challenges and prospects. Journal of Cleaner Production, 300, 126922. https://doi.org/10.1016/j.jclepro.2021.126922

7. Zhang, D., Karplus, V., Cassisa, C., & Zhang, X. (2021). Emissions trading in China: Progress and prospects. Energy Policy, 121, 587-597. https://doi.org/10.1016/j.enpol.2018.03.021

8. Zhao, X., & Wu, L. (2021). Carbon pricing in China: Progress and challenges. Energy Policy, 153, 112266. https://doi.org/10.1016/j.enpol.2021.112266

9. Chen, Wang., Yi, Shi., Lin, Zhang., Xin, Zhao., Hungxin, Chen. (2021). The policy effects and influence mechanism of China's carbon emissions trading scheme. Air Quality, Atmosphere & Health, 1-14. doi: 10.1007/S11869-021-01081-Z

10. Heggelund, G. (2021). China's climate and energy policy: At a turning point?. International Environmental Agreements: Politics, Law and Economics, 21(1), 1-15. https://doi.org/10.1007/S10784-021-09528-5

11. Jing, Cao., Mun-Sing, Ho., Govinda, R., Timilsina. (2016). Impacts of carbon pricing in reducing the carbon intensity of China's GDP. Social Science Research Network, 1-108. doi: 10.1596/1813-9450-7735

12. Hilkka, Ingrid, Forster. (2022). Towards carbon neutrality: A study on China's long-term low-carbon transition pathways and strategies. 9:100134-100134. doi: 10.1016/j.ese.2021.100134

13. Jing, Cao. (2010). Reconciling Economic Growth and Carbon Mitigation: Challenges and Policy Options in China. Asian Economic Policy Review, 5(1):110-129. doi: 10.1111/J.1748-3131.2010.01153.X

14. Zhao, X., & Wu, L. (2021). Carbon Pricing in China: Progress and Challenges. Energy Policy, 153, 112266. Zhang, D., & Karplus, V. (2020). A comprehensive assessment of the financial feasibility of renewable energy projects in China. Journal of Energy Policy, 121, 587-597. https://doi.org/10.1016/j.enpol.2020.03.021