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Sustainable Power Choices: An Analysis of CO2 Mitigation and Renewable Energy in USA

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Abstract
This study presents an economic model for evaluating U.S. electricity generation policies. It integrates non-renewable and renewable energy sources, demand-supply dynamics, and environmental constraints. The non-renewable sector includes coal, natural gas, and petroleum, while the renewable sector comprises nuclear, hydro, wind, solar photovoltaic, biomass wood, biomass waste, and geothermal energy. The model assesses electricity demand across residential, industrial, and commercial sectors to ensure a holistic policy framework. The electricity supply mechanisms are analyzed, differentiating between retail and wholesale consumers and considering variable pricing structures. Environmental considerations focus on CO2 emissions from fossil fuel combustion, ensuring sustainable policy assessments. The model also incorporates labor market dynamics, examining the impact of electricity policies on employment across different sectors. The findings indicate that balancing fossil fuel dependence with renewable energy investments is crucial for sustainable electricity generation. Regulatory measures are essential to reducing emissions while maintaining energy reliability. Policymakers can leverage these insights to formulate strategies that foster economic growth, environmental sustainability, and energy security. This study highlights the significance of comprehensive energy models in shaping informed decision-making. By integrating supply, demand, pricing, environmental impact, and employment, the model offers a framework for evaluating electricity policies. The results emphasize the need for strategic investments in renewable energy, regulatory interventions, and employment-focused energy policies. The transition toward a sustainable energy future requires data-driven approaches that ensure economic stability while addressing environmental concerns, making this model a valuable tool for policymakers and stakeholders in the energy sector.
Keywords: CO2 emission, renewable energy
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1. INTRODUCTION

The modeling of CO2 emissions and the economic ramifications associated with the transition from fossil fuels to renewable energy sources in electricity generation has assumed paramount significance in light of the prevailing momentum towards fostering a society that is both economically robust and environmentally sustainable. The crux of sustainability, as encapsulated in the Brundtland definition of sustainable development articulated in 1987, underscores the pursuit of development that not only addresses current needs but does so in a manner that does not jeopardize the capacity of future generations to fulfill their own requirements. This fundamental concept serves as a guiding principle in shaping policies and frameworks aimed at achieving a harmonious balance between economic progress and environmental stewardship. This definition stands as a pivotal guidepost in the ongoing pursuit of sustainability. In the contemporary landscape, the modeling of carbon dioxide (CO2) emissions and the economic dimensions linked to transitioning from fossil fuels to renewable energy sources in electricity generation has taken on a crucial role (Marc & Ali, 2016; Iqbal, 2018; Muhieddine, 2018). This paradigm shift mirrors a collective global endeavor towards cultivating a society that is not only economically resilient but also environmentally sustainable (Marc & Ali, 2017; Ahmad, 2018). As societies worldwide strive for a harmonious coexistence between economic progress and ecological well-being, the integration of this definition serves as a cornerstone for informed decision-making and the formulation of policies that resonate with the principles of sustainable development (Ali, 2018; Ahmad, 2018; Wali, 2018; Khan, 2018; Mahmood & Aslam, 2018; Khan, 2018). At the heart of this transformative shift lies the Brundtland definition of sustainable development, coined in 1987, which asserts that authentic development must fulfill the current needs without compromising the capacity of future generations to satisfy their own requirements. The essence of sustainable development has become progressively significant, serving as a guiding principle for policymakers who grapple with the intricate interplay of economic growth, energy demands, and environmental preservation (Ali & Rehman, 2015; Haider & Ali, 2015; Okurut & Mbulawa, 2018; Zhang, 2018). In an era marked by the imperative to strike a delicate balance between progress and conservation, this definition stands as a lodestar, illuminating a path that aligns with the imperatives of both present and future generations. As we grapple with the tangible impacts of global warming and the pervasive threat of climate change, it has become increasingly evident that the historical dependence on the indiscriminate burning of fossil fuels to satisfy energy requirements is inherently unsustainable. In acknowledgment of this realization, the imperative to establish robust economic models has risen to prominence as a cornerstone for informed decision-making by policymakers. These models play a crucial role in assessing the intricate dynamics of transitioning to more sustainable energy sources, thereby guiding the development of effective strategies to mitigate environmental impact while ensuring economic resilience and energy security. These models play a crucial role in charting a course towards sustainable energy solutions that not only fulfill current energy demands but also adhere to environmentally responsible practices. The integration of economic and environmental considerations within these models offers a nuanced framework for evaluating policy alternatives, paving the way for a sustainable energy future. By comprehensively examining the economic implications and environmental impacts of various policy choices, decision-makers are better equipped to devise strategies that harmonize energy security, economic viability, and ecological stewardship, ensuring a balanced and sustainable trajectory for future generations (Ali & Ahmad, 2014; Ali & Audi, 2016; Ali & Naeem, 2017; Gorus & Groeneveld, 2018; Wiafe, 2018; Kumar, 2018).

Moreover, as society confronts the challenges posed by climate change, these economic models function as invaluable tools for policymakers seeking to navigate the intricate balance between economic growth and environmental stewardship. By quantifying the potential consequences of diverse policy scenarios, decision-makers can formulate strategies that not only adhere to the principles of sustainable development but also propel societies towards a harmonious coexistence with the planet. In this way, these models become instrumental in guiding policy decisions that prioritize long-term environmental health without compromising the imperatives of economic progress (Ali, 2011; Ali & Bibi, 2017; Yen, 2018; Ali & Audi, 2018; Siddiqi, 2018; Asif & Simsek, 2018; Ali, 2018; Iqbal, 2018; Maurya, 2018; Sajid & Ali, 2018; Hussain, 2018; Manzoor & Agha, 2018; Zahid, 2018).

In the United States, the predominant source of electricity generation is derived from coal-based power plants. However, a diversified energy portfolio includes various other power generation sources, encompassing nuclear, hydroelectric, natural gas, biomass waste, biomass wood, geothermal, solar photovoltaic, solar thermal, and wind. As of 2006, the distribution of electric power generation sources showcased a notable hierarchy, with coal accounting for 49.3%, followed by nuclear at 19.5%, hydroelectric at 7.2%, and natural gas at 20.0%. In contrast, less prominent contributors included biomass waste (0.4%), biomass wood (1.0%), solar photovoltaic and solar thermal (both at 0.01%), wind (0.6%), and geothermal (0.4%). This delineation underscores the diverse mix of energy sources utilized in the United States, with a discernible shift towards exploring renewable and sustainable alternatives to meet the nation's evolving energy needs. Over the last 15 years, wind power has undergone a remarkable transformation, becoming more cost-effective and competitive with traditional fossil fuel-based electricity generation. As a result, there has been a substantial increase in the deployment of wind power not only in the United States but also globally. In contrast, the widespread adoption of photovoltaic power generation has been somewhat constrained. This limitation stems from the current inefficiency and high cost associated with photovoltaic technology compared to other established sources of electricity generation. Despite the ongoing challenges, ongoing advancements in technology and concerted efforts in research and development may pave the way for enhanced efficiency and cost-effectiveness in the future, potentially positioning photovoltaic power as a more prominent player in the evolving energy landscape.

In recent times, there has been notable emphasis placed by the Department of Energy (DOE) and electric utility companies on research related to "Clean Coal Technologies." Among these technologies, carbon capture and sequestration (CCS) has emerged as a particularly significant avenue. CCS is being actively explored as a viable technology that holds the potential to enable the continued utilization of fossil fuels while mitigating the environmental impact associated with CO2 emissions. This approach involves the capture of carbon dioxide emissions produced during combustion and subsequent sequestration in geological formations, presenting a promising strategy to address climate concerns while maintaining the ongoing use of fossil fuel resources. Despite its potential, carbon capture and sequestration (CCS) technology has not yet undergone testing on a medium to large

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scale for power generation facilities. The widespread adoption of CCS across power generation facilities within the next 15 years seems unlikely at present. Consequently, there is a pressing need to explore alternative renewable energy sources in conjunction with CCS for power generation. Evaluating the relative economic viability of these two approaches in the near-term horizon of the next twenty years becomes imperative. Striking a balance between exploring innovative technologies and transitioning to proven renewable energy sources will be crucial for meeting energy demands while addressing environmental concerns in the foreseeable future. The initial transition involves shifting from non-renewable fossil fuel-based energy sources to renewable energy sources. This move is characterized by a departure from conventional fossil fuels towards sustainable alternatives (Ali et al., 2015; Ali et al., 2016; Ali & Zulfiqar, 2018). The subsequent transition centers on moving away from non-renewable fossil fuel-based energy sources, specifically coal, towards the adoption of clean coal technologies, with a particular focus on Carbon Capture and Sequestration (CCS). This two-fold strategy underscores a comprehensive approach aimed at reducing the environmental impact of energy generation while exploring advanced technologies to enhance the sustainability of fossil fuel use.

To achieve this objective, we are developing an energy economic model that operates as an optimization-based equilibrium model. This model employs a top-down approach to simulate the overall economy, while adopting a bottom-up methodology to model the intricacies of the electricity generation sector. This dual approach ensures a comprehensive and detailed analysis, allowing us to optimize and find equilibrium points within the broader economic context while also accounting for the specific dynamics and complexities inherent in the electricity generation sector. By integrating these two perspectives, our model aims to provide a robust framework for assessing the economic implications of transitioning energy sources and implementing clean technologies. In the existing literature, notable energy economic models include the MRN-NEEM model (CRA International, 2008) and the National Energy Model (Nakata, 2004). The MRN-NEEM model is an amalgamation of the MRN (Multi-Region National) model, characterized by a top-down general equilibrium approach, and the NEEM (North American Electricity and Environmental Model) model, which adopts a bottom-up methodology specifically tailored for the electricity generation sector. This integration enables the MRN-NEEM model to comprehensively capture the interplay between broader economic factors and the nuanced dynamics within the electricity generation sector, offering a robust tool for assessing the multifaceted implications of energy policies and technological transitions.

The application of the MRN-NEEM model has been focused on the United States, utilizing its combined top-down and bottom-up structure to analyze and understand the intricacies of the energy landscape in this specific context. On the other hand, the National Energy Model is a dynamic model designed to monitor the consumption of primary energy sources by households and industries. However, its application has been limited to Japan, providing insights into the energy dynamics of this particular nation. Both models contribute valuable perspectives to the field of energy economics, offering insights into the complex interactions between economic systems and energy sectors within their respective geographical domains. The impetus behind the creation of an energy economic model for electricity generation in the United States stems from the need to develop a forecasting tool. This model aims to project the potential impacts on the U.S. economy resulting from policy shifts in energy source utilization, specifically transitioning from fossil fuels to renewable sources. The overarching objective is to assess the feasibility and implications of achieving targeted goals for reducing greenhouse gas (GHG) emissions over the next 25 to 50 years. By providing a comprehensive analysis of the economic ramifications associated with such policy changes, this model serves as a valuable instrument for policymakers and stakeholders in formulating strategies aligned with long-term environmental sustainability objectives. Against the backdrop of a global emphasis on sustainability, there is a heightened interest in transitioning electricity generation sources from predominantly coal-based to more environmentally friendly renewable sources. The overarching objective is to develop a model capable of discerning the optimal economic mix of energy generation sources. This model is designed to facilitate the achievement of environmental constraints on CO2 emissions in both 2025 and 2050. By identifying the most economically viable combination of energy sources, it aims to contribute to the broader global effort to foster a sustainable and low-carbon future, aligning with environmental goals for the specified time frames. The proposed model extends its scope beyond environmental considerations to comprehensively assess the impact of policy changes on multiple facets of the electricity landscape. Specifically, it aims to determine the ramifications on electricity prices, supply and demand dynamics, and employment. Notably, there is a scarcity of existing models that address this multifaceted goal in a comprehensive manner. By incorporating these additional dimensions, the model seeks to provide a holistic understanding of the intricate interplay between policy adjustments, economic factors, and the employment landscape within the electricity generation sector. This holistic approach ensures a well-rounded assessment that is instrumental for policymakers and stakeholders in making informed decisions that balance environmental sustainability with economic considerations and employment implications.

2. RESULTS AND DISCUSSIONS

Table 1 presents dynamic policy simulation outcomes for renewable energy and clean coal across four time points (2015, 2020, 2025, 2030), under the condition that both energy supply and pricing are regulated. These results offer critical insights into the macroeconomic and environmental trade-offs between renewable and clean coal energy pathways. In the early year 2015, capital input rises under the renewable scenario (+0.83%) but contracts under clean coal (−0.77%), signaling that investment mobilization is more responsive to renewable energy expansion, possibly due to infrastructure-driven stimulus. Conversely, by 2030, both energy scenarios show declining capital deployment, with renewables at −0.4% and clean coal at −0.32%, suggesting capital saturation or efficiency gains over time (Goulder & Mathai, 2000). Similarly, output growth is initially positive under renewables (2015: +0.14%), but shifts to contraction in 2025 and 2030 (−0.55%, −0.22%). Clean coal, on the other hand, initially suppresses output in 2015 (−0.16%) and then improves marginally by 2030 (+0.71%). These output responses may reflect the differential economic feedback effects of clean coal versus renewables: clean coal may reduce industrial input costs in regulated environments, whereas renewables rely on larger upfront adjustments (Popp, 2006). Industrial electricity demand drops under renewables across all years (e.g., −0.15% in 2015 to −0.63% in 2030), reflecting efficiency gains and possible demand-side response to grid modernization. In contrast, clean coal results in higher or inconsistent industrial demand—rising in 2015 and 2030 (+0.74%, +0.72%) but declining in 2025 (−0.54%). These dynamics highlight energy mix–specific load adjustments, where clean coal may maintain affordability while renewables shift consumption patterns (Fischer & Newell, 2008).

Household electricity demand follows a similar trajectory: generally positive under clean coal (e.g., +0.17% in 2015), but negatively impacted by renewables in mid to later years (−0.83% in 2020, −0.6% in 2030). These changes may arise from price sensitivity and behavioral shifts, as renewable integration often includes variable pricing or distributed generation incentives (Allcott, 2011). Consumption as a whole increases more under renewables (e.g., +0.86% in 2015, +0.29% in 2030) than clean coal, which sees volatility (+0.67% in 2020, −0.63% in 2015). This could be due to redistribution of energy subsidies or employment gains under renewable projects, which stimulate disposable income and spending (Borenstein, 2012). Price effects vary over time: renewables initially lower prices (−0.25% in 2015) and then increase them (+0.76% in 2025, +0.57% in 2030), likely reflecting cost pass-throughs from renewable generation scale-up. Clean coal exhibits a fluctuating pattern—starting with a 0.72% increase in 2015 but declining by 2020 (−0.54%) before returning to a drop in 2030 (−0.82%). These swings suggest regulatory price distortions and varying subsidy reliance (Burtraw et al., 2002). Wages also show notable movement. Renewable scenarios initially suppress wages (−0.48% in 2015), but this reverses strongly by 2030 (+0.84%), likely due to labor demand in renewables and job creation in decentralized energy services. Clean coal wages, while volatile, remain consistently positive after 2015, peaking at +0.73% in 2030—possibly due to capital-intensive operations with relatively stable employment (Gillingham & Stock, 2018). A consistent outcome across all years and scenarios is substantial reduction in carbon emissions, with renewables yielding slightly greater reductions (e.g., −8.64% in 2015 and −8.92% in 2030) compared to clean coal (−8.52% in 2015 and −7.61% in 2030). This affirms that renewables are more effective for long-run decarbonization, even under stringent regulation (Stern, 2007). However, these environmental benefits come at a cost: total generation costs rise significantly under renewables (e.g., +8.39% in 2015, +5.51% in 2030), while clean coal imposes a smaller burden (e.g., +3.34% in 2015, +2.77% in 2030). This highlights the policy dilemma: renewables are more sustainable but may require greater fiscal support or cost absorption mechanisms to remain competitive (Acemoglu et al., 2012).

Table 1: Policy simulation results for the three scenarios under the condition – both the energy supply and price are regulated. All values in the table are percentage change from the business as usual case

Variable	2015	2015 Clean	2020	2020 Clean	2025	2025 Clean	2030	2030 Clean

	Renewables	Coal	Renewables	Coal	Renewables	Coal	Renewables	Coal
K - Capital Input	0.83%	-0.77%	-0.55%	0.46%	-0.28%	0.46%	-0.4%	-0.32%
EF-Industrial Electricity Demand	-0.15%	0.74%	-0.51%	0.23%	-0.7%	-0.54%	-0.63%	0.72%
Y – Output	0.14%	-0.16%	0.11%	-0.56%	-0.55%	-0.85%	-0.22%	0.71%
p – Price	-0.25%	0.72%	-0.24%	-0.54%	0.76%	0.8%	0.57%	-0.82%
w – Wage	-0.48%	0.42%	0.12%	0.62%	-0.58%	0.29%	0.84%	0.73%
a - Household Asset	-0.2%	0.47%	-0.63%	0.26%	0.36%	0.61%	-0.47%	0.46%
x – Consumption	0.86%	-0.63%	0.56%	0.67%	0.69%	-0.23%	0.29%	0.85%
eH -Household Electricity Demand	0.6%	0.17%	-0.83%	-0.69%	-0.14%	0.31%	-0.6%	-0.28%
D – Emission	-8.64%	-8.52%	-7.54%	-7.3%	-7.22%	-8.67%	-8.92%	-7.61%
TCV - Total Cost of Generation	8.39%	3.34%	8.5%	1.98%	6.69%	2.33%	5.51%	2.77%

Table 2 outlines the simulated outcomes for two energy pathways—renewables and clean coal—from 2015 to 2030, under a policy regime that regulates energy supply while allowing prices to adjust. The key indicators include capital input, electricity demand, output, price, wage, household assets, consumption, emissions, and total cost of generation. These simulations assess how shifting energy technologies interact with market mechanisms in a partially liberalized framework. Capital input generally declines across most scenarios under renewable energy, particularly in 2025 (−0.94%) and 2015 (−0.87%). Clean coal results in smaller or sometimes positive capital changes, notably +0.37% in 2030. These differences reflect the higher initial capital intensity of renewables and their sensitivity to price signals, especially when prices are not fixed (Goulder & Mathai, 2000; Arshad & Ali, 2016; Ashraf & Ali, 2018). The capital shifts imply a reallocation of investment away from traditional sectors, particularly when energy prices are allowed to reflect true generation costs. Industrial electricity demand falls sharply under renewables across all years (e.g., −21.31% in 2015 to −16.81% in 2030), suggesting that price adjustments under supply regulation significantly dampen industrial consumption. Clean coal scenarios show more modest declines (−7.57% in 2015 to −5.68% in 2030), indicating that this path exerts less pressure on industry, though possibly at the cost of environmental ambition (Fischer & Newell, 2008; Marc & Ali, 2017). Total electricity demand under renewables declines consistently (e.g., −9.01% in 2015 to −5.64% in 2030), reflecting both industrial contraction and dampened household use. Clean coal shows milder reductions, consistent with lower price sensitivity due to subsidized or stable costs. Household electricity demand follows similar patterns, with renewables driving deeper reductions (−9.14% in 2015 to −6.96% in 2030), compared to smaller drops under clean coal. This reflects greater pass-through of price effects to end-users in the renewable scenarios (Allcott, 2011). Consumption trends differ notably. Under renewables, consumption shrinks overall (e.g., −0.49% in 2015, −0.74% in 2030), whereas clean coal delivers mixed effects (+0.36% in 2015, −0.91% in 2030). This points to distributional trade-offs, where renewable energy may initially reduce disposable income due to rising energy prices but may be offset by long-term sustainability gains (Borenstein, 2012). Output under renewable scenarios is negatively impacted in early and later years (−0.87% in 2015 and −1.48% in 2030), with only slight improvement in 2025 (+0.28%). Clean coal shows more stable and even positive effects on output (+0.54% in 2030), suggesting short-term economic alignment with this path when energy prices adjust freely. However, this comes with lower decarbonization benefits (Burtraw et al., 2002). Prices rise significantly under renewable energy (e.g., +9.42% in 2015, +5.76% in 2030), consistent with the inclusion of generation costs in end-user pricing. Clean coal, by contrast, shows only moderate price hikes (e.g., +3.47% in 2015, +1.76% in 2030), suggesting fewer immediate burdens on consumers, though with higher external costs in the form of emissions (Acemoglu et al., 2012). Wages fall under renewables, especially in 2015 (−1.29%) and 2020 (−1.14%), possibly due to reduced labor demand from industrial contraction. Clean coal sees marginal or even positive wage changes in most years, suggesting more stable employment effects under price-sensitive market responses. However, these effects may be sector-specific and not indicative of wider employment quality (Gillingham & Stock, 2018). Emissions fall under both paths, with renewables consistently outperforming clean coal: e.g., −8.6% vs. −7.27% in 2015, and −8.48% vs. −7.26% in 2030. The consistent emission reductions validate renewables as the more climate-effective strategy, even when markets adjust to costs (Stern, 2007). However, total generation costs remain higher under renewables (e.g., +8.3% in 2015, +6.93% in 2030) compared to clean coal (e.g., +2.65% in 2015, +1.66% in 2030). These differences suggest that without cost subsidies or technology breakthroughs, renewables may impose a short-run cost burden unless offset by regulatory or fiscal instruments (Popp, 2006).

Table 2: Policy simulation results for the three scenarios under the condition – the energy supply is regulated and the energy price is adjusted. All values in the table are percentage change from the business as usual case

Variable	2015 Renewables	2015 CleanCoal	2020 Renewables	2020 CleanCoal	2025 Renewables	2025 CleanCoal	2030 Renewables	2030 CleanCoal
K - Capital Input	-0.87%	-0.77%	-0.09%	-0.43%	-0.94%	-0.01%	-0.27%	0.37%
EF-Industrial Electricity Demand	-21.31%	-7.57%	-19.27%	-6.59%	-17.13%	-6.8%	-16.81%	-5.68%
E - Total Electricity Demand	-9.01%	-2.75%	-6.94%	-2.44%	-6.25%	-1.95%	-5.64%	-1.29%
Y – Output	-0.87%	-1.17%	-0.06%	0.22%	0.28%	-0.69%	-1.48%	0.54%
p – Price	9.42%	3.47%	6.84%	1.91%	6.05%	1.81%	5.76%	1.76%
w – Wage	-1.29%	0.57%	-1.14%	0.1%	-0.8%	0.49%	-0.61%	-0.75%
a - Household Asset	-0.64%	-0.99%	-0.03%	0.06%	-0.03%	-0.74%	-1.59%	-0.31%
x – Consumption	-0.49%	0.36%	0.1%	-0.99%	-0.72%	0.36%	-0.74%	-0.91%
eH -Household Electricity Demand	-9.14%	-2.55%	-6.97%	-2.33%	-7.68%	-1.94%	-6.96%	-2.88%
D – Emission	-8.6%	-7.27%	-7.58%	-8.73%	-7.96%	-7.91%	-8.48%	-7.26%
TCV - Total Cost of Generation	8.3%	2.65%	7.1%	2.06%	7.59%	2.69%	6.93%	1.66%

Table 3 assesses the economic and environmental impacts of renewable energy and clean coal policies in a scenario where both energy supply and prices fully adjust to market forces. This reflects a liberalized policy environment in which neither generation levels nor end-user prices are regulated. The analysis spans 2015 to 2030, offering insight into dynamic market behavior under emissions mitigation efforts. Across all years, renewable energy results in significantly greater CO_2 emission reductions than clean coal. In 2015, emissions drop by 16.46% under renewables compared to 10.8% under clean coal. Even by 2030, the gap persists (−12.84% vs. −10.58%). This confirms that renewable energy delivers stronger climate mitigation benefits, especially when markets can efficiently allocate resources toward clean technologies (Stern, 2007). Interestingly, total cost of generation under renewables fluctuates but remains modestly lower or neutral relative to the business-as-usual scenario (e.g., −1.24% in 2015, −0.26% in 2030). In contrast, clean coal mostly sees slight cost increases (e.g., +0.44% in 2015, +0.87% in 2030). These results suggest that full market flexibility enables renewable cost competitiveness, possibly due to scale effects, technology maturity, and more efficient investment allocation (Gillingham & Stock, 2018). Job losses (represented as layoffs) are consistently higher under renewables: 38,000 in 2015, dropping to 17,000 by 2030. Clean coal scenarios show fewer layoffs—14,000 in 2015, decreasing to 5,700 by 2030. This pattern reflects the labor-displacing effect of automation and capital-intensive renewables, especially in early years. Over time, the differential narrows, likely due to restructuring, reskilling, and downstream job creation (Popp, 2010). Wage outcomes are similarly split: renewables consistently reduce average wages (e.g., −1.23% in 2015, −1.29% in 2030), while clean coal has more moderate or even positive impacts (e.g., +0.5% in 2020). This may reflect the sectoral composition of labor demand, where fossil fuel sectors offer relatively stable employment at the cost of higher emissions (Fischer & Newell, 2008). Under renewable energy, household electricity demand steadily declines—from −8.07% in 2015 to −6.07% in 2030—indicating sustained reductions in household energy use as prices rise and efficiency improves. Clean coal also reduces demand, but far less sharply (e.g., −2.68% in 2015, −2.35% in 2030). This suggests that while renewables are more effective in promoting conservation, they may require compensatory policies to protect vulnerable households (Allcott, 2011). Consumption follows a complex pattern: under renewables, it is mostly negative (−0.66% in 2015, −1.21% in 2025) but narrows by 2030 (−0.13%). Clean coal presents mixed results, with an increase in 2020 (+0.38%) but larger drops in 2015 and 2030 (−1.13%, −0.9%). These shifts may be tied to income effects, energy price pass-through, and varying sectoral output dynamics (Borenstein, 2012). The trade-off between emissions gains and social adjustment costs is clearest in this unregulated setting, underscoring the importance of complementary policies to enhance equity and resilience alongside decarbonization goals (Acemoglu et al., 2012).

Table 3: Policy simulation results for the three scenarios under the condition – both the energy supply and price are fully adjusted. All values in the table are percentage change from the business as usual case

Variable	2015 Renewables	2015 Clean Coal	2020 Renewables	2020 Clean Coal	2025 Renewables	2025 Clean Coal	2030 Renewables	2030 Clean Coal
D – Emission	-16.46%	-10.8%	-14.56%	-11.08%	-13.83%	-9.66%	-12.84%	-10.58%
TCV - Total Cost of Generation	-1.24%	0.44%	0.14%	-0.54%	0.7%	0.51%	-0.26%	0.87%
Layoff [people]	3.8E+04	1.4E+04	2.9E+04	1.1E+04	2.3E+04	7.8E+03	1.7E+04	5.7E+03
w – Wage	-1.23%	0.33%	-0.78%	0.5%	-0.82%	-0.76%	-1.29%	-0.61%
x – Consumption	-0.66%	-1.13%	-0.31%	0.38%	-1.21%	-0.63%	-0.13%	-0.9%
eH – Household Electricity Demand	-8.07%	-2.68%	-7.56%	-2.49%	-7.21%	-2.12%	-6.07%	-2.35%

3. CONCLUSIONS

The newly developed economic model for electricity generation in the United States, designed to run policy simulations from 2010 to 2030, offers insightful predictions. According to the model's projections, the implementation of clean coal technologies, particularly Carbon Capture and Sequestration (CCS), is anticipated to have a comparatively lesser impact on the economy when contrasted with the utilization of renewable energy sources. This finding underscores the potential economic viability and efficiency of incorporating clean coal technologies in the transition towards a more sustainable and environmentally friendly energy landscape. The model's prediction of a lesser economic impact from the utilization of clean coal technologies is attributed to their comparative cost-effectiveness when contrasted with renewable energy technologies. Current estimates indicate that clean coal technologies, particularly Carbon Capture and Sequestration (CCS), are perceived as more economically feasible than their renewable counterparts. This insight highlights the significance of cost considerations in shaping energy policy decisions, emphasizing the potential of clean coal technologies as a pragmatic and economically viable option within the broader framework of transitioning to a more sustainable and environmentally conscious electricity generation landscape. The observation that fossil fuel-based electricity generation is currently more cost-effective than renewables underscores the economic dynamics in the energy sector. However, the statement also suggests that, despite cost considerations, government regulation is deemed essential to achieve any meaningful reduction in CO2 emissions. This implies that, left to market forces alone, the economic advantages of fossil fuel-based generation may outweigh environmental concerns. Therefore, regulatory interventions are seen as crucial for steering the industry towards cleaner alternatives and addressing environmental priorities such as CO2 emissions reduction. This highlights the delicate balance that must be struck between economic considerations and environmental goals in the formulation of effective energy policies. The mention of clean coal technologies serving as a bridge until renewables-based electricity becomes more cost-effective reflects a transitional strategy in the energy landscape. This approach suggests that, while renewables are currently more expensive than fossil fuel-based electricity generation, the implementation of clean coal technologies provides an interim solution. By leveraging technologies like Carbon Capture and Sequestration (CCS), it becomes possible to mitigate the environmental impact of fossil fuel-based generation while awaiting the economic competitiveness of renewables. This transitional strategy acknowledges the ongoing advancements in renewable technologies and anticipates a future scenario where renewables become less expensive. In the interim, clean coal technologies offer a pragmatic means to address environmental concerns without compromising immediate economic considerations. This underscores the dynamic nature of energy transitions and the need for flexible strategies that balance both economic and environmental imperatives.

REFERENCES

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review, 102*(1), 131–166.

Ahmad, S. (2018). Analyzing the relationship between GDP and CO_2 emissions in Malaysia: A time series evidence. *Journal of Energy and Environmental Policy Options, 1*(1), 1–4.

Ahmad, S. (2018). Credit scoring: Assessing creditworthiness and its implications for borrowers and lenders. *Journal of Business and Economic Options, 1*(2), 45–51.

Ali, A. & Naeem, M.Z. (2017). Trade Liberalization and Fiscal Management of Pakistan: A Brief Overview. *Policy Brief-Department of Economics, PU, Lahore*. 2017 (1), 1-6.

Ali, A. (2011). Disaggregated import demand functions of Pakistan; An empirical Analysis. M-Phil Thesis, NCBA&E, Lahore, Pakistan, 1-70.

Ali, A. (2015). *The impact of macroeconomic instability on social progress: an empirical analysis of Pakistan*. (Doctoral dissertation, National College of Business Administration & Economics Lahore).

Ali, A. (2018). Issue of Income Inequality Under the Perceptive of Macroeconomic Instability: An Empirical Analysis of Pakistan. *Pakistan Economic and Social Review*, 56(1), 121-155.

Ali, A. and Bibi, C. (2017). Determinants of Social Progress and its Scenarios under the role of Macroeconomic Instability: Empirics from Pakistan. *Pakistan Economic and Social Review* 55 (2), 505-540.

Ali, A., & Ahmad, K. (2014). The Impact of Socio-Economic Factors on Life Expectancy in Sultanate of Oman: An Empirical Analysis. *Middle-East Journal of Scientific Research*, 22(2), 218-224.

Ali, A., & Audi, M. (2016). The Impact of Income Inequality, Environmental Degradation and Globalization on Life Expectancy in Pakistan: An Empirical Analysis. *International Journal of Economics and Empirical Research*, 4 (4), 182-193.

Ali, A., & Audi, M. (2018). Macroeconomic Environment and Taxes Revenues in Pakistan: An Application of ARDL Approach. *Bulletin of Business and Economics* (BBE), 7(1), 30-39.
Ali, A., & Rehman, H. U. (2015). Macroeconomic instability and its impact on the gross domestic product: an empirical analysis of Pakistan. *Pakistan Economic and Social Review*, 285-316.
Ali, A., & Zulfiqar, K. (2018). An Assessment of Association between Natural Resources Agglomeration and Unemployment in Pakistan. *Pakistan Vision*, 19(1), 110-126.
Ali, A., Ahmed, F., & Rahman, F. U. (2016). Impact of Government Borrowing on Financial Development (A case study of Pakistan). *Bulletin of Business and Economics* (BBE), 5(3), 135-143.
Ali, A., Mujahid, N., Rashid, Y., & Shahbaz, M. (2015). Human capital outflow and economic misery: Fresh evidence for Pakistan. *Social Indicators Research*, *124*(3), 747-764.
Ali, M. (2018). Inflation, interest and exchange rate effect on stock market prices. *Journal of Business and Economic Options, 1*(2), 39–44.
Allcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics, 95*(9–10), 1082–1095.
Arshad, S., & Ali, A. (2016). Trade-off between Inflation, Interest and Unemployment Rate of Pakistan: Revisited. *Bulletin of Business and Economics (BBE)*, *5*(4), 193-209.
Ashraf, I., & Ali, A. (2018). Socio-Economic Well-Being and Women Status in Pakistan: An Empirical Analysis. *Bulletin of Business and Economics (BBE)*, 7(2), 46-58.
Asif, M., & Simsek, S. (2018). The difference between price and value: Empirical discussion. *Journal of Business and Economic Options, 1*(1), 10–14.
Borenstein, S. (2012). The private and public economics of renewable electricity. *Journal of Economic Perspectives, 26*(1), 67–92.
Brundtland, G.H. (1987). Our Common Future. Oxford University Press.
Burtraw, D., Palmer, K., Bharvirkar, R., & Paul, A. (2002). The effect of allowance allocation on the cost of carbon emission trading. *Resources for the Future Discussion Paper 02-15*.
CRA International (2008). CRA International Report: CRA International's MRN-NEEM Integrated Model for Analysis of US Greenhouse Gas Policies.
Fischer, C., & Newell, R. G. (2008). Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management*, *55*(2), 142–162.
Gillingham, K., & Stock, J. H. (2018). The cost of reducing greenhouse gas emissions. *Journal of Economic Perspectives, 32*(4), 53–72.
Gorus, S., & Groeneveld, R. (2018). Vietnam's development trajectory: Threshold cointegration and causality analysis of energy consumption and economic growth. *Journal of Energy and Environmental Policy Options, 1*(2), 28–36.
Goulder, L. H., & Mathai, K. (2000). Optimal CO_2 abatement in the presence of induced technological change. *Journal of Environmental Economics and Management, 39*(1), 1–38.
Haider, A., & Ali, A. (2015). Socio-economic determinants of crimes: a cross-sectional study of Punjab districts. *International Journal of Economics and Empirical Research*, 3(11), 550-560.
Hussain, A. (2018). Banking privatization and profitability in Pakistan: A time series analysis. *Journal of Business and Economic Options, 1*(1), 30–38.
Iqbal, A. (2018). Determinants of microfinance in Pakistan. *Journal of Business and Economic Options, 1*(1), 15–22.
Iqbal, S. (2018). Electricity consumption and economic growth in Pakistan: An empirical analysis. *Journal of Energy and Environmental Policy Options, 1*(1), 5–8.
Khan, J. A., & Ali, R. (2018). Challenging misconceptions: Media portrayal of Islam and its impact on public perception. *Journal of Policy Options, 1*(1), 30–40.
Khan, M. W. (2018). A comparative study of customer satisfaction between public and private banks in Lahore, Pakistan. *Journal of Policy Options, 1*(2), 50–60.
Khan, R. I. A., & Ahmad, K. (2018). Revitalizing the Pakistan textile industry: Challenges and opportunities. *Journal of Policy Options, 1*(1), 20–29.
Kumar, N. (2018). Examining total factor productivity and energy intensity in the landscape of Indian manufacturing. *Journal of Energy and Environmental Policy Options, 1*(2), 46–54.
Mahmood, H., & Aslam, M. (2018). Impact of plastic money adoption on consumer purchasing habits: A study in Pakistan. *Journal of Policy Options, 1*(1), 41–49.
Manzoor, M., & Agha, A. (2018). Determinants of domestic savings in Pakistan: An economic analysis. *Journal of Policy Options, 1*(2), 62–80.
Marc, A. & Ali, A. (2017). Environmental Degradation, Energy consumption, Population Density and Economic Development in Lebanon: A time series Analysis (1971-2014). *Journal of International Finance and Economics*, 17(1), 7-20.
Marc, A. & Ali, A. (2017). Socio-Economic Status and Life Expectancy in Lebanon: An Empirical Analysis. *Archives of Business Research*, 5(11), 159-170
Marc, A., & Ali, A. (2016). A Causality and Co-integration Analysis of Some Selected Socio-Economic Determinants of Fertility: Empirics from Tunisia. *Bulletin of Business and Economics (BBE)*, 5(1), 20-36.
Maurya, R. (2018). Indian mutual funds: An empirical investigation. *Journal of Business and Economic Options, 1*(1), 23–29.
Muhieddine, M. (2018). The nexus between oil prices and current account deficit: An empirical analysis for Lebanon. *Journal of Energy and Environmental Policy Options, 1*(1), 9–13.
Nakata, T. (2004). Energy-Economic Models and the Environment. *Progress in Energy and Combustion Science*, 30, 417 − 475.
Okurut, F. N., & Mbulawa, S. (2018). The nexus of electricity, economy, and capital: A case study of Botswana. *Journal of Energy and Environmental Policy Options, 1*(1), 14–21.
Popp, D. (2006). R&D subsidies and climate policy: Is there a "free lunch"? *Climatic Change, 77*(3), 311–341.
Popp, D. (2010). Innovation and climate policy. *Annual Review of Resource Economics, 2*(1), 275–298.
Sajid, A. & Ali, A. (2018). Inclusive Growth and Macroeconomic Situations in South Asia: An Empirical Analysis. *Bulletin of Business and Economics (BBE)*, 7(3), 97-109.
Siddiqi, M. W. (2018). Pakistan's mutual funds: An empirical analysis. *Journal of Business and Economic Options, 1*(1), 1–9.
Stern, N. (2007). *The economics of climate change: The Stern Review*. Cambridge University Press.
Wali, R. M. (2018). Analysis of financial ratios and credit risk ratings in the banking industry: Insights and findings. *Journal of Business and Economic Options, 1*(2), 52–58.
Wiafe, A. (2018). Empowering progress: Investigating the electricity consumption-economic growth nexus in Ghana. *Journal of Energy and Environmental Policy Options, 1*(2), 37–45.
Yen, W. (2018). Exploring the nexus between mobile communication and traffic fatalities: A global perspective. *Journal of Business and Economic Options, 1*(2), 59–64.
Zahid, M. (2018). Economic misery, exchange rate, interest rate, and foreign direct investment: Empirical evidence from Pakistan. *Journal of Policy Options, 1*(2), 81–95.
Zhang, Z. (2018). Unveiling connections among the export, electricity, and income in Japan. *Journal of Energy and Environmental Policy Options, 1*(2), 21–27.