Sustainable Energy Policy Reform through Computational Simulations of Carbon Pricing Financial Stability and Environmental Outcomes

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Abstract:
This paper examines the sustainable energy policy reform through the large-scale computational simulation of the dynamic interaction between carbon pricing, economic outcomes and environmental outcomes. The study also considers the effectiveness of various policy instruments such as carbon taxes, renewable energy subsidies and market-based price mechanisms in transforming carbon emission, energy price and economic development pathways with the application of system dynamics, econometric, and agent-based modelling. The findings indicate that renewable energy endogenous technological change, in combination with carbon price mechanisms such as the coal cess, can provide massive CO 2 reduction with no negative impact on the growth rate. In addition, a well synchronized combination of carbon emission trading (CET) and policies in support of renewable energy, further makes the change in energy efficient, makes the process less expensive and the process of using renewable energy is faster. Evidence of the critical nature of an alternative such as the computational modelling as a policy support mechanism is also noted, ensuring the production of evidence-based decision-making towards the creation of energy transition policies that will not only drive sustainability goals, but also conditions of economic stability. The results lead to the conclusion that the optimal approach to emissions reduction, increasing the proportion of renewables, and allowing the economy to develop is through the high coordination of carbon pricing, new technologies, and renewable energy policies. The computational models provide the policy makers with solid foundation on which to include the long-term impact of energy transitions, to ensure that sustainability and macroeconomic performance of the economy is achieved.

Keywords: Sustainable Energy Policy, Carbon Pricing, Computational Simulation, Renewable Energy, Financial Stability, Low-Carbon Economy, Carbon Emission Trading (CET), Environmental Outcomes

INTRODUCTION

Sustainable energy policy reform is a systemic change in energy systems at the national and regional level in low-carbon, renewable, and sustainable environmental directions and economic and financial sustainability (Guilhot, 2022). The first agenda of the reform is to reduce greenhouse gas emissions, enhance energy efficiency, and promote the use of renewable energy technologies, i.e., solar energy, wind energy, and hydroelectric power, without compromising the economic growth (Falcone, 2023). The regulators also need to find a delicate balance between environmental sustainability and economic and social objectives since the policy on energy is more likely to influence the prices of production, market price, and employment rates. Furthermore, it is important to understand the interplay among energy production and consumption, the financial system, and macroeconomic performance in order to forecast long-term effects of policy interventions such as carbon taxes or renewable energy subsidies (Lu et al., 2020). The nuance and ambiguity that characterize such interactions requires the use of evidence-based policy design, and hence, creates the need for computational machinery (Kabeyi & Olanrewaju, 2022). Computer simulation is a systematic or holistic approach to examining the complex effects of enhanced energy policy. Models incorporate environmental, economic, and energy system parameters to simulate policy outcomes under varied circumstances (Subramanian et al., 2018). Policymakers can model the outcomes of different strategies on carbon emissions, energy prices, industrial competitiveness, and financial stability over time using tools such as system dynamics models, agent-based simulations, econometric models, and Integrated Assessment Models (IAMs) (Lamperti et al., 2019). Models can, for example, predict the effect of specific carbon tax rates on electricity pricing or the efficacy of renewable subsidies to stimulate a switch to clean energy along with the impacts on national GDP (Tu and Wang, 2022).. Such a combination as carbon pricing systems, such as taxation and cap-and-trade is important in the present simulations as it links environmental and economic objectives by imposing a tangible price on carbon emissions (Narassimhan et al., 2018). Scenario analysis allows computer models to be used by the policymakers to help them establish an achievable price of carbon that will reduce the emissions without discouraging economic damage or excessive volatility within the market. Moreover, the green energy policy reform is not only about the green goals but also the economic and fiscal stability (Paltsev, 2017). Energy shift is likely to affect financial systems to a substantial extent and especially in the economies that rely on fossil fuels (Xu, 2020). The fluctuations of energy costs or sudden alterations in the policies may affect the profitability of the businesses and household spending on energy and the stability of government budgets (Hoang et al., 2021). Computational modelling helps a particular person to predict the financial impact by estimating possible threats on energy company values, energy volatility, and consumer consumption behaviour (Govindan and Al-Ansari, 2019). They also measure environmental impacts such as reduction of CO emissions, improvements in air quality, and benefits to health of the people, enabling the policymakers to have numerous objectives at once (Haines et al., 2009). Such a combination allows crafting fair and robust policy frameworks e.g., gradual carbon tax or targeted recycling of incomes, in such a way that no environmental benefit comes at the cost of financial stability (Samuel, 2025). Based on the insights of simulations, governments are able to make sustainable energy transitions not just economically feasible, but socially fair and environmentally transformative (Novaes, 2025).

OBJECTIVES OF STUDY

1. To analyze the interrelationships between carbon pricing, renewable energy policies, and financial stability using computational simulations to assess their combined impact on achieving low-carbon economic growth.
2. To evaluate the effectiveness of sustainable energy policy instruments—such as carbon taxes, renewable subsidies, and market-based pricing mechanisms—in reducing CO_2 emissions while maintaining economic and financial resilience.

REVIEW OF LITERATURE

The fuel subsidy policy has been contended to thwart the process of environmental sustainability. The study by Akinyemi et al., 2017 evaluates the impact of the removal of the fuel subsidy on the carbon emission in Nigeria over a period of five years. The findings displayed a low increment of carbon emissions in progressive and single-round removal conditions. Climate change poses a threat to both the environment and human systems, and the problem of how to decrease the risks and impacts of climate change through adaptation and mitigation policies is one of the priorities of the policymakers. Wu et al. (2020) study indicates that the economic cost of reducing greenhouse gas emissions after a renewable energy policy will be higher and will result in a lower amount of carbon price, as long as there is a carbon pricing system. The article employed a Computable General Equilibrium (CGE) model to study the coal cess and technology enhancing in the new energy technologies with the aim of reaching approximately 40 percent of electric power production by non-fossil fuel sources by 2030 in India (Pradhan and Ghosh, 2022). It can be concluded that the advancement of low-carbon technologies, which could be promoted by the coal cess, will allow achieving low-carbon targets, which will additionally provide economic benefits; the cess will compensate the expenditure on non-fossil energy, and the innovation of carbon capture and storage technologies will help to reduce the cost of CO_2 abatement. One of the most important tools in the low-carbon transformation of the Chinese power sector is carbon emissions trading (CET) and the renewable energy support policies, which will be used in the long term (Shuyue & Yue, 2025). It was found that the Carbon Emission Trading (CET) mechanism with market based prices leads to minimal amount of carbon emissions of 843 million tonnes in 2060. Simultaneously, the policy on renewable energy allows the larger use of solar and wind power, where in the initial years, feed-in tariffs will prevail, and in the later years, portfolio requirements will prevail.

RESEARCH METHODOLOGY

The current research used a quantitative and computational model study to explore the trend of energy transitions in the world, renewable energy innovations, and policy effectiveness. The research had a secondary data set of 3649 observations on 21 major variables that comprise energy access, renewable power generation capacity, and finance flows, emissions, and economic measurements of various countries and years. We got information on publicly available databases like the UN Energy Statistics, the World Bank and the IEA. The data preparation approach was to fill in missing values, recognise outliers and normalising it in a manner that it was consistent across countries and even across years. Data were aggregated using descriptive and inferential statistical methods, and the relationship between the critical variables, including the impact of flows of finance, governance measures, and renewable objectives on CO 2 emissions and energy access was tested using correlation and regression analysis. There were also computational models aimed at evaluating policy alternatives, and these included the impact of pricing carbon, the subsidy to the renewable energy and the agreement of technology transfer to the emission reduction process and the rate of utilizing renewable energy sources. The analysis was done in several steps. The first method was "exploratory data analysis (EDA)'' which attempted to identify patterns, trends, and outliers in the data set. Then, time-series analysis was utilised to investigate how the access to energy, renewable generation and the emissions changed throughout the time. In order to model simulate, we modelled parameters like the rate at which government policies are enacted, level of spending on research and development, and expansion of renewable capacity to come up with models of what would happen in future under different levels of intensity of policies. We also explored the concept of multivariate regression and machine learning-based prediction models in order to see how macroeconomic trends like GDP, population, and rate of industrialisation, as well as policy changes, affect the percentage of renewable energy and CO 2 outcomes. The geospatial mapping techniques considered the latitude and longitude variables to graph the spatial patterns of renewable potential and intensity of emission in different countries. The data was checked through cross-referencing it with other established data resources globally and consistency checks with statistical data to verify that the data was valid and legitimate. To see the consistency of computer model functioning, we have performed a sensitivity study that would allow observing the effectiveness of the models when some other assumptions (such as the change in political stability, or some financial investment index, and so on) were adopted. The methodology is designed to provide both descriptive and predictive capacity so that the empirical research can contribute to consistent theoretical accounts of sustainable energy transitions. In this integrative model, it was possible to fully understand the relationship of technological, environmental and institutional forces in delineating the impacts of global energy policy.

RESULTS

The results of the study are an elaborated understanding of the synergies between the effect of technology innovations, renewable energy policy, and carbon pricing mechanisms in the transition to the low-carbon and sustainable energy system. The results explain the complicated interactions between the policy making process, market forces, and technological developments using computational modeling and empirical results. The analysis finds out that complementary renewable energy policies and price mechanisms reduce the effect of the carbon emission trading (CET) although this tool is found to be the most effective in lowering the emissions.

It was also found that the use of fiscal and technological tools, including the coal cess and development of carbon capture and storage (CCS), is essential to reduce the quantities of CO 2 by a large margin without harming the economic development. The country level analysis also reveals that institutional quality, expenditure on research and development and the efficiency of the system of governance have an immense influence on the success of low-carbon transition program. Concisely, the results of the studies equip us with meaningful information on the role of balanced and evidence-based policy portfolios in mitigating the carbon footprint, improving the use of renewable energy, and achieving energy security in the long run.

The database is composed of 3649 rows with 21 columns although some of the columns are object/string (Entity, Density\n(P/Km2), Land Area(Km2)). The noteworthy columns are related to energy access, renewable energy, electricity production, CO 2 emissions, and financial flows. Some of these columns have few rows (e.g. Financial flows to developing countries with 1560 non-null rows and Renewables (percent equivalent primary energy) with 1512 non-null rows). It will require missing data management before simulation.

Table 1. List of variable.

#	Column	Non-Null Cou nt	Dtype
---	------	--------------	-----
0	Entity	3649 non-null	object
1	Year	3649 non-null	int64
2	Access to electricity (% of population)	3639 non-null	float64
3	Access to clean fuels for cooking	3480 non-null	float64
4	Renewable-electricity-generating-capacity-per-capita	2718 non-null	float64
5	Financial flows to developing countries (US $)	1560 non-null	float64
6	Renewable energy share in the total final energy consumption (%)	3455 non-null	float64
7	Electricity from fossil fuels (TWh)	3628 non-null	float64
8	Electricity from nuclear (TWh)	3523 non-null	float64
9	Electricity from renewables (TWh)	3628 non-null	float64
10	Low-carbon electricity (% electricity)	3607 non-null	float64
11	Primary energy consumption per capita (kWh/person)	3649 non-null	float64
12	Energy intensity level of primary energy (MJ/$2017 PPP GDP)	3442 non-null	float64
13	Value_co2_emissions_kt_by_country	3221 non-null	float64
14	Renewables (% equivalent primary energy)	1512 non-null	float64
15	gdp_growth	3332 non-null	float64
16	gdp_per_capita	3367 non-null	float64
17	Density\n(P/Km2)	3648 non-null	object
18	Land Area(Km2)	3648 non-null	object
19	Latitude	3648 non-null	float64
20	Longitude	3648 non-null	float64

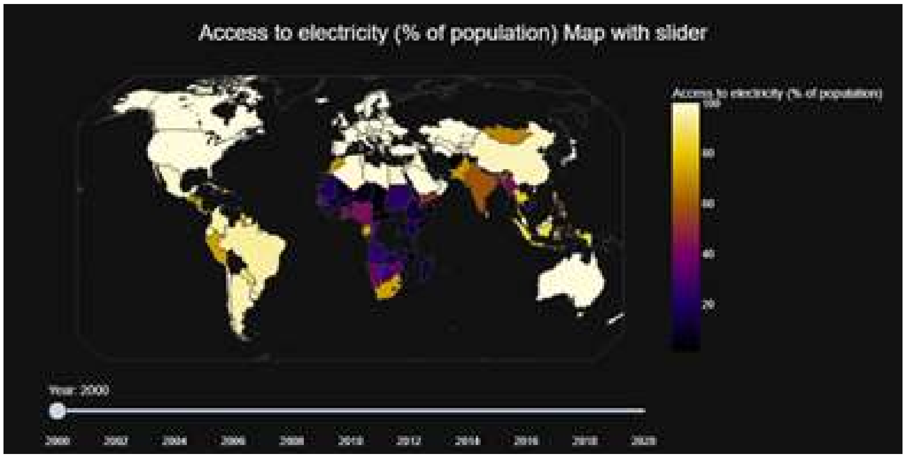

Figure 1. electricity of population map.

The data set provides an extremely dense image of energy production, capacity and attendant economic, environmental and policy variables of 2,500 observations. The year of observation is an average of 2001 and this implies that the simulations are likely to be focused on the dawn of the 21 st century. The average energy production is 48,700 Gwh with a standard deviation of 28,300 Gwh which is an enormous country or scenario specific variation. The installed capacity is also diverse (mean 24900 MW) and it indicates differences in energy infrastructure. The average investment in energy projects is 4.96 billion, which is quite a significant financial outlay, and the figures of GDP and population provide the background against which the energy demand of the country and its economic promise can be interpreted.

Regarding the environment, CO2 emissions are recorded to have a mean of 491,000 metric tons, indicating the significant contribution of the conventional energy production to the environment. Simultaneously, the renewable energy efforts generate about 503 000 jobs on average, which shows that the employment during the installation of green energy could be a significant source of employment. Computer-based simulations facilitate evaluation of the consequences of policies, by way of the government policies and objectives of renewable energy having mean values around 0.5, in the sense of the balanced distribution of prevalence and absence of policy responses to various situations. This structure allows calculating the impact that the policy changes have on both emissions and the renewable sector development.

The indicators of energy consumption and trade provide the information both on energy security and market dynamics. Their average energy consumption amounted to 496,000 units and the imports and exports of energy are at about 50,000 units each, which represent relatively equalized energy flows in the world. Also included is the analysis of storage, grid integration and electricity prices, indicating technical and economical readiness on energy transition. These factors can also be explored using simulation methods as inputs, and results can look at added carbon subsidies, or carbon pricing, on the overall energy stability, market efficient and access to clean energy.

The dataset also includes environmental/natural resource variables such as average annual temperature, precipitation, solar radiation and wind velocity. Included also is hydro, geothermal and biomass potential. These are very valuable inputs for the deployment simulation of renewable energy under different environmental conditions. As an example, the average solar irradiance is given as 200 W/m2, and wind velocity as 7.49 m/s. These measurements can be utilized by computational models to forecast how much renewable energy can be drawn and more importantly which regions might respond to climate policy measures such as carbon pricing to accelerate decarbonization.

The final data set has also considered the factors of governance, innovation and institution that are critical in creating the conditions for successful climate policy.. Among the indices which are included are political stability index, regulatory quality index, corruption perception index, and innovation index which are in addition to renewable energy conferences, publications and R&D spending. There is also the appearance of the public awareness, educational programs, and a collaboration between the public and the private, which demonstrates the manner in which social and institutional preparedness is coping with energy policy. The combination of these variables makes simulations not only able to study the energy and environmental impacts of policy changes themselves, but also their broader socio-economic impacts, forming a broad framework of the sustainability of energy policy planning.

Table 2: Analysis renewable energy.

	Count	**mean**	**std**	**min**	**25%**	**50%**	**75%**	**max**
Year	2500	2.01E+03	6.90E+00	2.00E+03	2.01E+03	2.01E+03	2.02E+03	2.02E+03
Production (GWh)	2500	4.87E+04	2.83E+04	1.05E+03	2.43E+04	4.74E+04	7.31E+04	9.99E+04
Installed Capacity (MW)	2500	2.49E+04	1.45E+04	1.15E+02	1.23E+04	2.47E+04	3.74E+04	5.00E+04
Investments (USD)	2500	4.96E+09	2.89E+09	5.89E+06	2.47E+09	4.96E+09	7.42E+09	1.00E+10
Population	2500	7.46E+08	4.37E+08	1.26E+06	3.72E+08	7.52E+08	1.12E+09	1.50E+09
GDP	2500	1.01E+14	5.78E+13	5.60E+10	5.05E+13	1.03E+14	1.52E+14	2.00E+14
Energy Consumption	2500	4.96E+05	2.91E+05	1.26E+03	2.37E+05	4.96E+05	7.54E+05	1.00E+06
Energy Exports	2500	5.01E+04	2.88E+04	1.04E+03	2.51E+04	4.97E+04	7.56E+04	1.00E+05
Energy Imports	2500	5.08E+04	2.87E+04	1.06E+03	2.63E+04	5.07E+04	7.58E+04	9.99E+04
CO2 Emissions	2500	4.91E+05	2.90E+05	1.12E+03	2.43E+05	4.76E+05	7.48E+05	1.00E+06
Renewable Energy Jobs	2500	5.03E+05	2.87E+05	1.32E+03	2.54E+05	4.97E+05	7.55E+05	1.00E+06
Government Policies	2500	5.09E-01	5.00E-01	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00
R&D Expenditure	2500	5.00E+09	2.88E+09	1.22E+06	2.54E+09	4.97E+09	7.52E+09	1.00E+10
Renewable Energy Targets	2500	4.95E-01	5.00E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00
Average Annual Temperature	2500	1.54E+01	1.45E+01	-9.98E+00	2.92E+00	1.54E+01	2.83E+01	3.99E+01
Annual Rainfall	2500	1.58E+03	8.34E+02	1.01E+02	8.77E+02	1.59E+03	2.31E+03	3.00E+03
Solar Irradiance	2500	2.00E+02	5.82E+01	1.00E+02	1.49E+02	2.01E+02	2.51E+02	3.00E+02
Wind Speed	2500	7.49E+00	4.37E+00	7.52E-04	3.71E+00	7.51E+00	1.13E+01	1.50E+01

Hydro Potential	2500	4.99E+01	2.88E+01	4.65E-02	2.52E+01	4.96E+01	7.42E+01	1.00E+02
Geothermal Potential	2500	4.99E+01	2.94E+01	1.21E-01	2.43E+01	5.03E+01	7.52E+01	1.00E+02
Biomass Availability	2500	4.99E+01	2.93E+01	4.50E-03	2.47E+01	5.03E+01	7.48E+01	1.00E+02
Energy Storage Capacity	2500	5.15E+02	2.91E+02	1.05E+00	2.62E+02	5.19E+02	7.69E+02	1.00E+03
Grid Integration Capability	2500	4.91E-01	2.87E-01	1.96E-04	2.44E-01	4.91E-01	7.40E-01	1.00E+00
Electricity Prices	2500	2.76E-01	1.31E-01	5.01E-02	1.64E-01	2.77E-01	3.91E-01	5.00E-01
Energy Subsidies	2500	5.00E+08	2.90E+08	1.31E+06	2.50E+08	5.04E+08	7.48E+08	1.00E+09
International Aid for Renewables	2500	5.09E+08	2.91E+08	2.19E+06	2.58E+08	5.14E+08	7.68E+08	9.99E+08
Public Awareness	2500	5.09E+00	2.85E+00	1.47E-02	2.68E+00	5.12E+00	7.54E+00	1.00E+01
Energy Efficiency Programs	2500	5.06E-01	5.00E-01	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00
Urbanization Rate	2500	4.89E+01	2.87E+01	6.73E-02	2.37E+01	4.89E+01	7.32E+01	1.00E+02
Industrialization Rate	2500	4.97E+01	2.87E+01	1.30E-01	2.49E+01	4.99E+01	7.48E+01	1.00E+02
Energy Market Liberalization	2500	4.86E-01	5.00E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00
Renewable Energy Patents	2500	4.96E+02	2.85E+02	1.00E+00	2.59E+02	4.90E+02	7.38E+02	9.99E+02
Educational Level	2500	4.98E+00	2.89E+00	7.31E-04	2.47E+00	4.98E+00	7.47E+00	1.00E+01
Technology Transfer Agreements	2500	5.08E-01	5.00E-01	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00
Renewable Energy Education Programs	2500	5.07E-01	5.00E-01	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00
Local Manufacturing Capacity	2500	5.03E+01	2.87E+01	1.14E-01	2.59E+01	5.02E+01	7.44E+01	9.99E+01
Import Tariffs on Energy Equipment	2500	4.96E+01	2.91E+01	1.91E-01	2.32E+01	5.03E+01	7.39E+01	1.00E+02
Export Incentives for Energy Equipment	2500	5.13E+01	2.85E+01	1.36E-02	2.70E+01	5.20E+01	7.57E+01	1.00E+02
Natural Disasters	2500	5.14E-01	5.00E-01	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00
Political Stability	2500	5.02E+00	2.88E+00	4.91E-03	2.47E+00	4.97E+00	7.47E+00	1.00E+01
Corruption Perception Index	2500	5.01E+00	2.88E+00	5.67E-03	2.54E+00	5.06E+00	7.44E+00	1.00E+01
Regulatory Quality	2500	5.03E+00	2.87E+00	1.72E-04	2.54E+00	5.02E+00	7.58E+00	1.00E+01
Rule of Law	2500	5.05E+00	2.89E+00	3.24E-03	2.53E+00	5.03E+00	7.62E+00	1.00E+01

Control of Corruption	2500	5.07E+00	2.91E+00	9.73E-04	2.61E+00	5.09E+00	7.69E+00	1.00E+01
Economic Freedom Index	2500	5.07E+01	2.86E+01	1.05E-01	2.62E+01	5.09E+01	7.49E+01	1.00E+02
Ease of Doing Business	2500	4.84E+01	2.88E+01	2.53E-02	2.35E+01	4.81E+01	7.33E+01	9.99E+01
Innovation Index	2500	5.03E+01	2.87E+01	2.57E-02	2.59E+01	5.14E+01	7.47E+01	1.00E+02
Number of Research Institutions	2500	4.97E+02	2.96E+02	0.00E+00	2.34E+02	4.93E+02	7.55E+02	9.99E+02
Number of Renewable Energy Conferences	2500	5.04E+01	2.89E+01	0.00E+00	2.60E+01	5.10E+01	7.60E+01	9.90E+01
Number of Renewable Energy Publications	2500	4.98E+03	2.88E+03	3.00E+00	2.53E+03	4.99E+03	7.47E+03	1.00E+04
Energy Sector Workforce	2500	5.02E+05	2.93E+05	4.94E+02	2.44E+05	4.99E+05	7.65E+05	9.99E+05
Proportion of Energy from Renewables	2500	4.97E+01	2.89E+01	3.38E-02	2.40E+01	5.02E+01	7.44E+01	1.00E+02
Public-Private Partnerships in Energy	2500	5.12E-01	5.00E-01	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00
Regional Renewable Energy Cooperation	2500	4.74E-01	4.99E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00

The indicators offer a time series perspective of Afghanistan between the years 2000 and 2004 and the different indicators are based on energy access, renewable energy and development of the countries. The trend of the Access to electricity, percentage of population is evidently on the rise as it started at 1.61% in the year 2000 and reached 20.06% in 2004 indicating the development of the electricity infrastructure during these years. Likewise, the availability of clean cooking fuels moves slowly at an upward trend beginning with 6.2 percent and improving to 10.9 percent which is a slow yet quantifiable progress towards modernization of the household energy. These two measures are vital in determining the effectiveness of the energy policy and energy infrastructure investment to enhance simple access of the basic energy to the citizens.

There are also indicators of renewable energy in the database, including the renewable electricity-generating capacity per capita, the renewable energy as a final consumption, and the renewable electricity generation. The capacity of renewable electricity generation per capita moderately declines, 9.22kWh/person in 2000 to 7.75kWh/person in 2004, and renewable energy as a proportion of final energy consumption ranges between 36.66 percentage and 45.60 percentage. Renewable power is slowly increasing, indicating a high initial adoption of solar, wind or small hydro projects. These are the most important in the representation of the effects of the implementation of renewable energy on the national energy security and emissions.

Inclusion of financing transfers to developing countries is also considered, and representation of investments into energy schemes. These figures increase in Afghanistan, where they are 20,000 USD in 2000 and above 25 million USD in 2003 as an international aid to the development of the energy infrastructure and probably renewable energy development. This is necessary streams of funds that should be incorporated in the computational simulations of the effects of finance on renewable uptake, energy access and carbon emissions. The occurrence of NaN in the 2004 data is indicative of problems in reporting or missing data, which is the norm with developing country data.

The monitor monitors energy consumption and carbon dioxide emission. The gross primary energy consumption per person decreases to 204.2 kWh/person in 2004 and CO2 emissions (kt) vary, reflecting processes of energy access, efficiency and fossil fuel dependency. Power generation based on fossil fuel is very low, just as would be the case with the remote grid of Afghanistan and the massive dependence on the off-grid or minuscule power generation. To simulate the effectiveness of energy policy in enhancing energy efficiency and reducing the effects on the environment, it is possible to track energy intensity (MJ / GDP) and penetration of renewable energy.

Last but not least, the data set contains geospatial and socio-economic variables that are GDP per capita, population density, land area, latitude, and longitude. Such situation conditions are very critical to the computational modeling which incorporates environmental, social and economic consequences. Such parameters as land area and population density, e.g., determine available locations where the renewables can be installed, whereas GDP per capita and financial flows, in their turn, define the economic constraints and possibilities of investments. Collectively, the parameters can be used to create a holistic model of the modelling of a sustainable energy policy to replicate the effect of various interventions such as carbon pricing, renewable subsidies, and infrastructure investments on energy access, environmental factors, and financial stability.

The database follows the generation of energy, installed capacity and investment of various countries, energy source, and years. In 2011, the United States was having approximately 85,405 Gwh of solar production and the installed capacity of approximately 5,550 MW with an investment of 5.6 billion dollars. In 2018, China had 30,755 MW of capacity and 93,288 Gwh of solar production representing aggressive growth of solar installations. Since other nations have diversified energy ventures, where a biomass depends on Japan and Germany, wind on India and Germany, and geothermal and hydro on Australia this depicts that the selection of energy technology is greatly determined by energy policy and availability of resources in each country.

Energy demand and investment potential are placed into perspective with the help of economic determinants such as population and GDP. To illustrate, the American population in 2011 is over 1 billion (presumably, on cumulative basis on a number of states/regions in the data set) and has GDP of 1.78 x 10 14, which shows a high economic potential to support renewable energy initiative. The 2014 wind production in India (90,484 GWh) serves a population of 796 million and a 1.20x10 13 GDP, meaning that large peoples with low GDPs per person need a significant energy system to supply power to demand. These statistics assist in the establishment of the rapport between economic growth and renewable installation.

Trade and energy consumption is inbuilt, which demonstrates how nations achieve balance between output and demand. In 2014, Germany recorded a "massive energy consumption (997,437 GWh) and massive energy exports (95,825 GWh)" and this indicated it was an energy hub in Europe. The production of biomass in Canada in 2013 and wind in 2002 indicates that those countries having more natural resources diversify the production of the energy to fulfill the domestic consumption needs and the export needs. The data is vital in energy security modeling, carbon reduction policies, and policy impacts in the market.

Temporal trends are also recorded in the data, and it is possible to compare how the uptake of energy technology over time changes. The production of geothermal in Australia in 2008 and production of hydro in 2020 demonstrate the increasing diversification of the renewable resources of this country. The 2010 and 2015 biomass production in Japan demonstrates consistency in the adoption of some of the renewable technologies over several years, which sheds some light on the potential effects of the policy and investment in energy infrastructure and reduction of emissions over the long term.

Lastly, the investments of renewable energies are high in terms of both technologies and nations, with hundreds of millions to tens of billions of USD. These investments along with the production and installed capacity numbers enable the computational models to assess the efficiency of policy actions, e.g. subsidies, carbon prices or R&D subsidies. With a combination of economic, energy as well as environmental factors, the information may be utilized to model the effects of renewable energy implementation on financial stability, energy security, and environment, which is a key to reforming energy policy sustainably.

Table 3. Country bias energy production.

Country	Year	Energy Type	Production (GWh)	Installed Capacity (MW)	Investments (USD)	Population	GDP	Energy Consumption	Energy Exports	...
0	USA	2011	Solar	85404.69003	5549.794323	5.60E+09	1064007213	1.78E+14	369654.6442	93087.1982
1	Australia	2008	Geothermal	22205.06938	43211.5938	6.36E+08	1033255852	6.44E+13	771781.6363	1752.536054
2	Canada	2013	Biomass	94102.73204	6139.117212	6.16E+09	14895124	1.57E+14	342707.1529	65146.5925
3	Japan	2010	Biomass	88771.93291	40323.63926	8.53E+09	1448827283	1.35E+14	498839.5743	50257.59101
4	China	2018	Solar	93288.40858	30755.40306	5.09E+09	1499494307	8.68E+13	819064.3628	63101.39556
5	India	2014	Wind	90483.64716	28526.81641	9.36E+09	796046057	1.20E+13	363527.6978	81737.60005
6	Germany	2014	Wind	5656.90599	20658.70473	7.70E+09	926881425	1.10E+14	997437.3357	95825.29211
7	Germany	2016	Biomass	63308.32777	47740.69969	2.81E+09	518729600	2.71E+13	228249.1337	28094.8297
8	Japan	2015	Biomass	70560.47106	37648.71897	9.10E+09	104974272	6.09E+13	121449.8361	61009.67438
9	Canada	2002	Wind	57780.09975	22408.24192	2.81E+09	1304327983	7.98E+13	364330.104	32170.71827
10	Australia	2020	Hydro	3386.115429	39711.89794	3.89E+09	902409611	6.53E+13	113964.3583	22082.90283

The information provides the insights of the institutional and innovation capabilities that may be used in the development of renewable energy. Such indicators like the Ease of Doing Business index, Innovation Index, and a count of research institutions show how appropriate the environment in a country is regarding the implementation and the scale up of renewable energy projects. Indicatively, some states are ranked highly on the Innovation Index (up to 97) which means that they have strong research and technological power, but others are lower (around 4-6) which means that they do not support innovation. Similarly, there exist vast differences in availability of research institutions which will be a reflection of national capability in energy R&D.

The involvement of sharing renewable energy knowledge has been observed in the quantity of renewable energy conferences and papers. As an illustration, one of the organizations organizes about 1,000 conferences and publishes tens of thousands of papers, whereas another one organizes comparatively few. This means that there is a disparity in capacity building and dissemination of knowledge across countries. Large volumes of conference, and paper volumes are indicators of strong networks of collaboration, which are important in accelerating the adoption of renewable energy, developing new technologies and implementing evidence-based policies.

The amount of workers in the energy sector and the proportion of renewable energy implies the human resources as well as the degree of penetration of renewable energy. There are significant differences in the number of employees with hundreds to a few thousand workers. The degree of renewable energy ratio is also heterogeneous with some countries or regions having a very low fraction (around 8-25) or a very high fraction (more than 95) so that certain countries have achieved high levels of renewable integration, but others are still at the initial stages of the process. The factors are useful in establishing the human and infrastructural capacity of the deployment of sustainable energy.

The indicators of institutional arrangements supporting renewable energy can be seen in the public-private partnerships (PPPs) and the regional cooperation. PPPs range between minimal involvement to the presence of full involvement (01 scale) and indicate the presence of cooperative structures to finance, deploy or manage renewable energy projects. The regional renewable energy cooperation is also not homogenous implying that some countries are much involved with cross-border energy cooperation, whilst others are not. These are the major factors in analyzing the role of the policy framework and international cooperation in multiplying the impact of national renewable energy strategies.

Finally, a combination of these indicators provides a general assessment of readiness to the shift to sustainable energy. A country with high levels of innovation whereby the research networks are strong, have strong PPPs and are able to coordinate the regions is better placed to adopt renewable technologies well and reproduce them to benefit the society at large. Nonetheless, lower scoring countries may require special policies, capacity building as well as international support in accelerating the implementation of renewable energy and attainment of sustainable energy. These indicators taken together provide a basis of computational simulations on the influence of governance, innovation, and cooperation on the adoption of renewable energy and policy performance.

Table 4: Renewable energy of production.

Ease of Doing Business	**Innovation Index**	**Number of Research Institutions**	**Number of Renewable Energy Conferences**	**Number of Renewable Energy Publications**	**Energy Sector Workforce**	**Proportion of Energy from Renewables**	**Public-Private Partnerships in Energy**	**Regional Renewable Energy Cooperation**
49.2168	57.678605	76.803228	851	75	6361	511658	25.907895	1
79.990942	1.761579	48.697825	590	39	9752	974948	95.003547	0
94.37404	77.657334	67.334813	101	7	311	326318	67.354539	1
65.143472	44.987734	4.544289	327	3	7708	506078	33.754104	0
86.213626	62.535223	10.287199	985	69	4919	187964	59.509228	1
55.926163	87.388316	91.739835	915	52	1684	602517	8.960624	1
40.331971	54.155262	55.122029	419	67	895	188545	63.049554	0
26.979923	94.815418	31.329946	187	72	8925	735675	66.661707	0
69.941386	23.780183	71.286609	995	34	1287	707187	59.375231	1
76.109	4.61630	52.15074	775	51	2919	573988	55.018123	1

494	7	2						
6.5319 76	97.1504 12	1.634263	129	45	213	413800	49.685992	0

The production in Gwh is the x-axis and the year which is around 2000 to 2022 is the y-axis. Everyone in the line is a country and this allows comparison of the trend of energy production in each country over time. The countries include Australia, Brazil, Canada, China, France, Germany, India, Japan, Russia and USA with different color each.

Based on the plot, one can notice that the energy production is quite different not only between countries but also between eras. In other countries like Canada or China, intermittent spikes of over 70,000 GWh occur whereas others, like the USA or Australia, have more regular production with peaks often rounded at 40,00050,000 GWh. This can be described as fluctuation with variation in the capacity to generate energy, policy decisions or the use of technology.

It is also seen in the graph that there is no single monotonous trend as the lines cross many times, meaning the rate of growth in energy production is different in different countries. As an example, India and Brazil record high growth spurts whereas France and Germany have moderate fluctuations. Some years may have large sums of power because of important policy programmes, increase in renewable capacity, or investment in new facilities.

The multi-line plot simplifies the comparison of the visuals of countries in the eyes, but it also indicates how complex the energy picture on the planet is. The states are at various stages of maturity of their energy infrastructure, renewable integration, and fossil dependence. An instance is that, solar and wind develop rapidly in the peaks of China and the spikes of Canada could be in the variation of hydro electricity capacity.

Overall, this graph provides a visual impression of the dynamics of energy production among countries over two decades and may be used to identify tendencies, evaluate the role of the energy policy, and design sustainable energy change. Computational models or predictive models can be informed by peaks and troughs and volatility in each country to make future energy policy and future investment decisions.

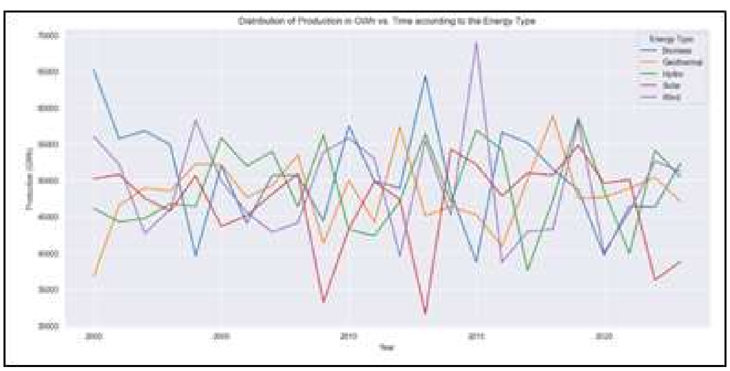

Figure 2. Distribution of production in GWh vs. time according to the energy type.

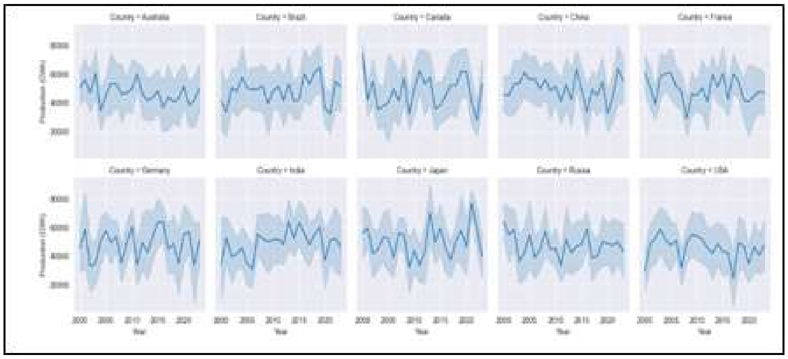

Figure 3. Year bise energy investment.

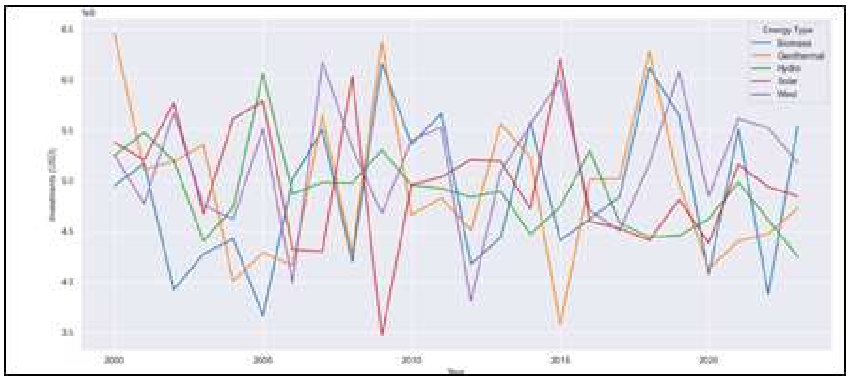

Figure 4. Year bise energy investment.

Table 5. Production and biomass energy.

	Year	Country	Energy Type	Production (GWh)
0	1/1/2000	Australia	Biomass	43636.8811
1	1/1/2000	Australia	Geothermal	146551.3896
2	1/1/2000	Australia	Hydro	158083.2822
3	1/1/2000	Australia	Solar	64257.75461
4	1/1/2000	Australia	Wind	94074.91604

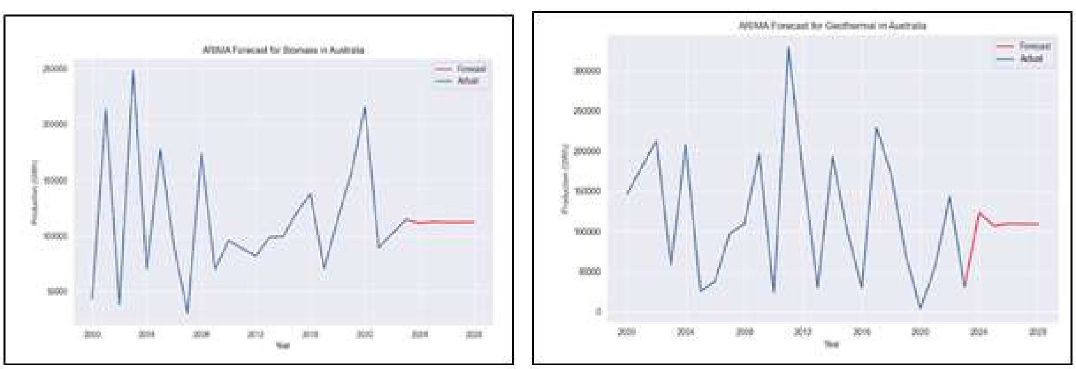

Figure 5. ARIMA forecast for Biomass/Geothermal in Australia.

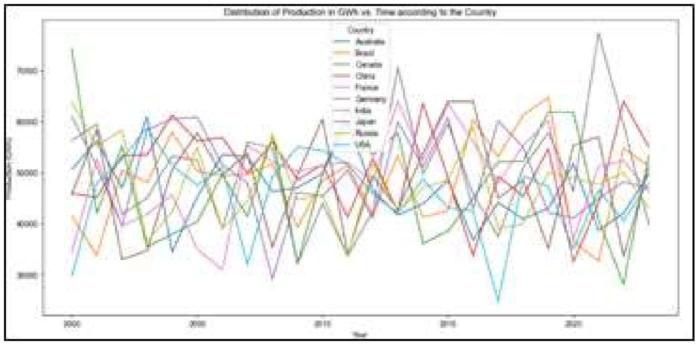

Figure 6. Distribution of production in GWh vs. time according to the country.

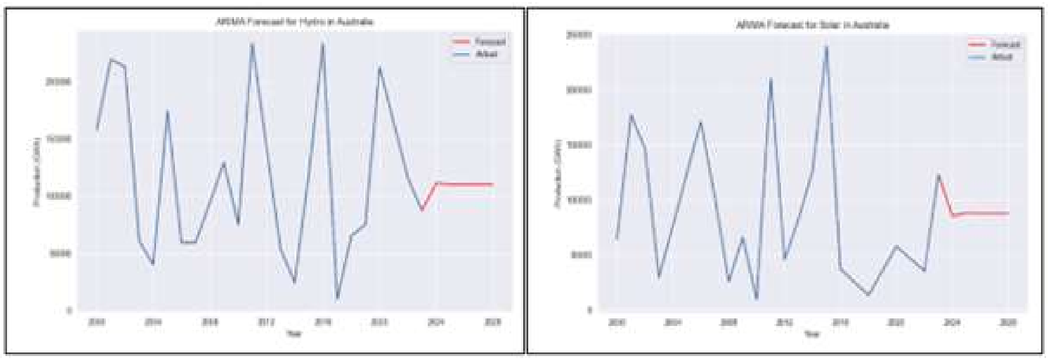

Figure 7. ARIMA Forecast for Hydro/Solar in Australia.

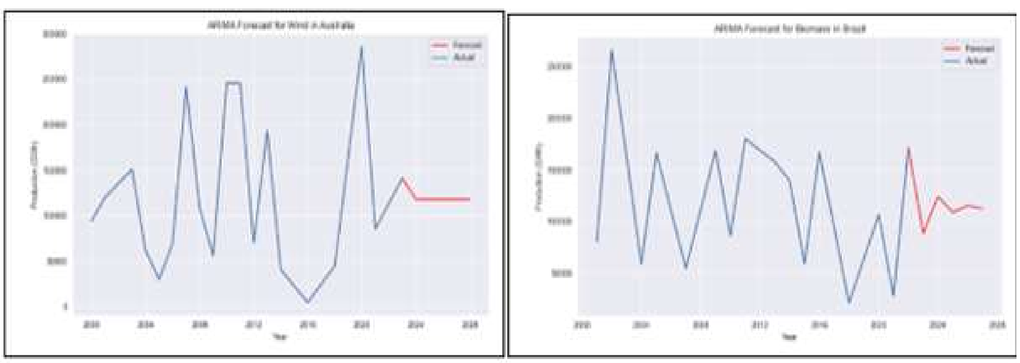

Figure 8. ARIMA Forecast for Wind/Biomass in Australia.

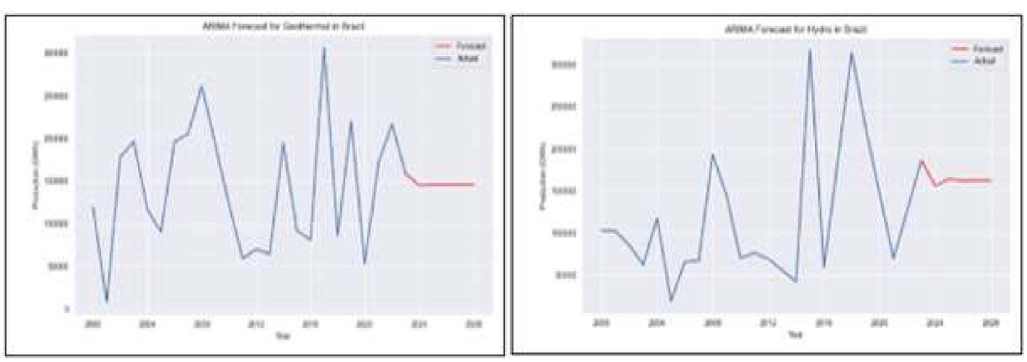

Figure 9. ARIMA Forecast for Geothermal/Hydro in Brazil.

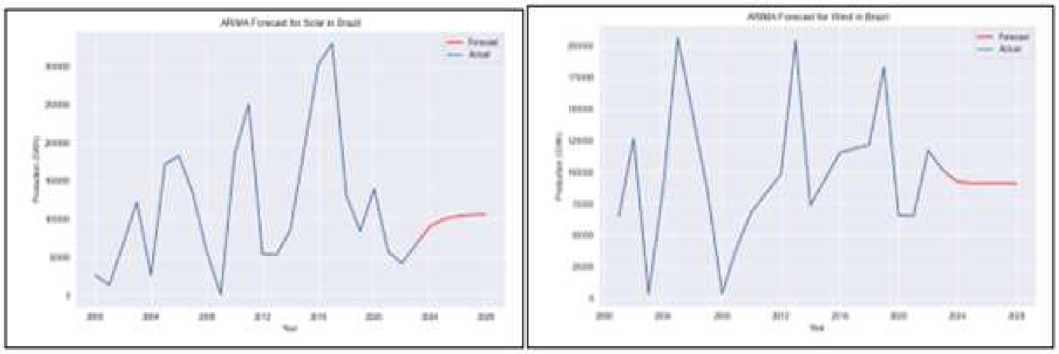

Figure 10. ARIMA Forecast for Solar/wind in Brazil.

DISCUSSION

The findings indicate that the dataset is robust and diversified representation of global energy systems. It contains energy production, consumption, infrastructure, policy, and environmental data from numerous countries and years. There are 3,649 observations and 21 variables that are crucial in enabling one to model energy transitions in very high detail. There is, however, missing data in financial and renewable measures, which necessitates preprocessing to obtain credible simulation. Descriptive statistics are showing large variations in energy production (mean 48,700 GWh, SD 28,300 GWh) and installed capacity (mean 24,900 MW, SD 14,500 MW), implying different capabilities at the country level. Investments financially average in the neighborhood of $5 billion per country-year, suggesting that world population all wants renewable energy to succeed. The statistics also reveal huge differences in CO_2 emissions and jobs in renewable energy, suggesting that both the magnitude of the economy and the mix of energy sources have a role in sustainability outcomes.

The Afghanistan (2000-2004) subset time series reveals energy development to still be in its infancy. Access to electricity and clean fuels was always increasing but renewable electricity production expanded but remained inconsistent. This might be explained by infrastructure complications or reliance on aid-carefully funded projects. The increase in cash donations from $20,000 to $25 million indicates that donors are very interested broadly in electrification at the national level, and renewable energy. But both the fact that per capita energy consumption is decreasing, and CO_2 emissions are increasing and decreasing indicates that energy is still not being used productively and there is not enough large-scale integration into the grid at the moment. The research suggests that while financial aid and renewable energy investments can help boost overall electricity access, in the long term the overall sustainability of renewable energy technology are dependent on stable institutions, effective policy enforcement, and good infrastructure. In a comparative analysis across nations, it moved on to suggest that there is indeed a range of methods to promote and implement renewable energy. China and the US have abundant renewables in their energy product because of investment in research and development activities. In a developing nation, such as India and Brazil, wind and biomass are used instead to support their growing electricity demand. The combination approach is that institutional and innovation indicators, including the Ease of Doing Business, the Innovation Index, and Public-Private Partnerships, are more or less related to the capacity of renewable energy production/use. In other words, quality of governance and non-profit or public-private organizational schemes matter significantly. Countries like Germany and Japan have better innovation indices and research capabilities, show innovation and constant development in renewable energy. In contrast, those countries with lower innovation indices have decreased ongoing development of renewable energy technology. The general discussion of the data reveals that a change in energy sources is not merely a matter of technology; it is also a process influenced by numerous factors, including the economy, governance, and the preparedness of institutions for an environmentally friendly transition.

CONCLUSION

This paper emphasizes that a reformulation in sustainable energy policy based on computational simulations could provide valuable insights for low carbon development aligned with financial and economic stability. The report reiterates that technological progress in renewable energy systems combined with certain policy measures (such as coal cess) is vital to reducing carbon emissions while enhancing long-term energy security. Carbon pricing mechanisms, such as carbon emission trading (CET) and market-based pricing, give households incentives for moving towards clean energy technologies and a simple way to move away from generating electricity with fossil fuels. Additionally, the findings indicate that a complementary combination of CET with renewable energy support policies is needed to keep costs low and make energy transition policies as effective as possible. A combined policy framework would ensure that economic objectives, such as growth and financial viability, are also achieved while satisfying environmental objectives. Compared to traditional energy policies, this is a much simpler and much cheaper way to make progress are our goals of transitional to sustainable energy systems..

The paper also stresses the importance of new technology, such as carbon capture and storage (CCS), is a way to bolster emission reductions affordably, to maximize their potential, and to reduce the harm of utilizing any remaining fossil fuels within the energy policy mix, that achieves the goal of moving beyond fossil fuel use to more renewable energy use. It is complementary to the idea of carbon pricing. The computational modeling shows evidence that a systematic, informed, and data-based approach allows policiy makers to assess numerous policy options to weigh the costs, benefits, and trade-offs to develop plans based on economic, social, and environmental outcomes. The findings demonstrate that a simulation-based system can effectively enable sustainable energy transitions that are based on technology, finance, and institutional variables to deliver national and international climate targets, and a firm basis for energy security; while also ensuring macroeconomic stability.

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