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Research article

The role of techno-economic factors for net zero carbon emissions in Pakistan

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Abstract: The Government of Pakistan has established clean energy transition goals in the national Alternative and Renewable Energy (ARE) Policy. The goal of this policy is to increase the 30% capacity of green energy in total energy mix by 2030. In this regard, the aim of this study is to develop a de-carbonization plan for achieving net zero emissions through the deployment of a green energy system for the period 2021 to 2040 by incorporating the ARE policy targets. The Low Emissions Analysis Platform (LEAP®) software is used for finding the unidirectional causality among gross domestic product, population within the country, energy demand, renewable energy production and CO_2 emissions for Pakistan. The results revealed that energy production of 564.16 TWh is enough to meet the energy demand of 480.10 TWh with CO_2 emissions of 22.19 million metric tons, having a population of 242.1 million people and GDP growth rate of 5.8%, in the year 2040 in

Pakistan. The share of green energy production is 535.07 TWh, which can be utilized fully for meeting energy demand in the country, and almost zero emissions will produce till 2040. CO_2 emissions produced by burning natural gas were 20.64 million metric tons in 2020, which then reduced to 3.25 million metric tons in 2040. CO_2 emissions produced by burning furnace oil are also reduced from 4.19 million metric tons in 2020 to 2.06 million metric tons in 2040. CO_2 emissions produced by burning coal were 24.85 million metric tons in 2020, which then reduced to 16.88 million metric tons in 2040. Energy demand is directly related to the population and GDP of the country, while renewable utilization is inversely proportional to carbon emissions. The declining trend of carbon emissions in Pakistan would help to achieve net zero emissions targets by mid-century. This technique would bring prosperity in the development of a clean, green and sustainable environment.

Keywords: environmental monitoring; CO_2 emissions; climate change; green economy; Pakistan

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Abbreviations: LEAP®: Low Emissions Analysis Platform; SDG: Sustainable Development Goals; SDG12: Sustainable Climate Change; SDG7: Making Electricity Affordable and Accessible; UNESCAP: United Nations Economic and Social Commission for Asia; ADB: Asian Development Bank; MTOE: Million Tons of Oil Equivalent; GDP: Gross Domestic Product; PP: Population within the Country; ED: Energy Demand; REP: Renewable Energy Production; CE: CO_2 emissions; EKC: Environmental Kuznets Curve; ARDL: An Autoregressive Distributed Lag; GMM: Gaussian Mixture Model; OECD: Organization for Economic Co-operation and Development; IEA: International Energy Agency; WASP: Wien Automatic System Planning package; ENPEP: Energy and Power Evaluation Program; MAED: Model for Analysis of Energy Demand; SIMPACTS: Simplified Approach for Estimating Impacts of Electricity Generation; MESSAGE: Model for Energy Supply Systems and General Environmental Impacts; ACP: Alternative Compliance Payment

1. Introduction

Governments of developing nations are not doing enough to address the issue of growing emissions [1]. According to the most recent Sustainable Development Goals (SDG) development report, Pacific countries and the Asia region must address the growing emissions issues [2]. While advanced countries are making enormous gains toward a future powered by clean energy and a cleaner environment, they are simultaneously seeing a rise in emissions and dealing with issues related to bad climate change. The effective fossil fuel-based economic boom patterns in several countries have been identified as one of the main sources of climate problems [3]. Many countries are being pressured to achieve SDG 13's targets for climate action and reduce their ongoing reliance on fossil resources. By evaluating the financial boom patterns of bad environmental nations, the SDG development document 2019 found that the countries bordering Southwest and South Asia are the stragglers in fulfilling the goals of SDG 13 [4]. These states have made some improvement toward achieving SDG 7's objectives (affordable and easy access to green supply) but are also lacking in arranging financial investments [5]. This issue has been highlighted in the most recent United Nations report on the achievement of the SDG, which also discusses how these nations choose to invest in renewable systems rather than fossil fuel related activities [6]. Developing countries are mostly running on fossil fuels, given their greater willingness to pursue economic growth at the expense of environmental protection. These countries continue to lose their natural resources, so this enables harnessing the maximum production of renewables [7]. The continual depletion of natural resources could have a detrimental impact on the economic growth of the country. Reaching the goals of SDG 13, or accountable consumption and production, might become problematic due to the depletion of natural resources and typical green policy myopia in these nations [8]. These challenges are mentioned in the most current energy security assessment report for Asian countries by the Asian Development Bank (ADB), which considers the important role that natural resources play in guaranteeing power security and also discusses that alternative energy sources have been explored as a possible option for fossil fuel alternatives, leading these nations toward a future with sustainable energy [9]. As a result, domestic energy assets are considered as a policy tool for ensuring sustainable climate change (SDG12) and making electricity affordable and accessible (SDG7). In order to properly state this, the policy framework must be created in a way that allows SDG 12 and SDG 7 to be addressed [10]. This study's emphasis is to combine SDG7 and SDG12 under a unified regulatory framework.

The United Nations Economic and Social Commission for Asia (UNESCAP) and Asian Development Bank (ADB) have clearly written in their report that Pakistan will overcome difficulties in achieving sustainable development goals through the implementation of successful financial and technical policies [11]. On the other hand, Pakistan is a growing country that always seeks to supply through conventional forms of energy that are needed to power the entire country [12]. In Pakistan, the price of gasoline fluctuated from 97.63 rupees per liter in December 2018 to 113.90 rupees per liter in December 2019 to 102.04 rupees per liter in December 2020 [13]. Since 1991, the total imports of oil into the nation have increased at a rate of 3.8% annually. In 2016, the total amount of fossil fuels consumed was 74 million tons of oil equivalent (MTOE), up from 28.6 million tons of oil equivalent (MTOE) in 1990 [14]. Around 61% of Pakistan's power is generated thermally, which is essential for baseload production and grid dependability [15]. Furnace oil still plays a significant role in the energy mix, accounting for 5,958 MW of all connected capacity in the power industry, followed by coal at 5,332 MW and natural gas at 3,536 MW [16]. The percentage of energy produced by coal is even higher since it has consistently provided over 30% of the electricity sent to the national grid since 2019 [17]. This could be a costly bet for Pakistan in the energy transition mechanism and coal retirement facility. Around 6.5 GW of thermal generation is projected to retire by the end of 2022 [18]. So, the Government of Pakistan must take serious action on the precise measurement of the energy transition mechanism [19]. Also, care must be taken for ensuring the lower production of carbon emissions (SDG12) for the affordable and accessible supply of green electricity (SDG7) and also for sustainable implementation of an energy transition mechanism. In this regard, the Government of Pakistan has set the target for achieving 20% green energy capacity addition by 2025 and 30% green energy capacity addition by 2030 through the ARE policy of 2019 [16]. So, this study develops an integrated energy policy for clean energy transition in Pakistan for deploying the ARE policy targets and checked the renewable energy generation pattern from 2021 to 2040. This study also investigates the dynamic impacts of techno-economic factors on the net zero carbon emissions in relation to the use of fossil assets and clean energy sources (renewables).

This study is structured into five sections. Section 2 presents literature on unidirectional causality among gross domestic product (GDP), population within the country (PP), energy demand (ED), renewable energy production (REP) and CO_2 emissions (CE) at a global level. Section 3 presents the empirical method of investigating the unidirectional causality of techno-economic factors and net zero emissions in Pakistan. Finally, results, discussion and conclusion are given in section 4, section 5 and section 6.

2. Literature review

It may be difficult to review all relevant work on the Environmental Kuznets Curve (EKC), but a substantial summary of the important studies is provided below. Pao H-T, et al. [20] checked EKC using yearly GDP and CO_2 emission information for Brazil. An autoregressive distributed lag (ARDL) technique demonstrated that GDP had a fantastic coefficient, whereas GDP square had a bad coefficient. Saboori B, et al. [21] investigated the reliability of EKC for Malaysia using economic growth, CO_2 emissions and energy use. They did not check the accuracy of EKC when overall power consumption reaches a higher level. However, they did establish the EKC proof at the disaggregated strength. Furthermore, they failed to use novel methodologies to find any immediate evidence of EKC, classifying it as a longer-term phenomenon. However, a causal relationship of a bi-directional nature between CO_2 emissions and economy was identified. Pao H-T et al. [22] examined the connection between CO_2 emissions, the financial boom and power consumption for Russia from 1990 to 2007. They stopped finding EKC evidence and recommended energy conservation as a way to fight environmental contaminants for Russia. Nasir M, et al. [23] examined the connection among power, economic growth, foreign alternatives and CO_2 emissions with the help of Johansen cointegration for Pakistan, and they eventually verified the EKC technique.

Wang SS, et al. [24] looked at the U-shaped relationship for 28 Chinese provinces among energy consumption, CO_2 emissions and economic growth which supported the conclusion that EKC is invalid in China. Another recent observation was made with the help of [25], who looked at the presence of an EKC for China's consumption of coal. Twenty-nine provincial facts were utilized between 1995 and 2012, and they obtained the cubic shape among economic factors and confirmed the validity of EKC. Saboori B, et al. [26] discovered the causality of a unidirectional nature between CO_2 emissions and economic growth, and a U-shape curve was obtained using the ARDL method for long and short terms. Granger causality was absent in short term and present in long term between CO_2 emissions and economic growth for Malaysia. Ozturk I, et al. [27,28] examined the relationship among CO_2 emissions, employment, financial growth and energy consumption with the ARDL method. In that study, CO_2 emissions became disastrous because of greater energy consumption, and they summarized that conservation of electricity and CO_2 reduction coverage will not have a damaging impact on Turkey's economic growth. Apergis N, et al. [29] observed the relationship among CO_2 emissions, economic growth and energy consumption for eleven commonwealths nations, and they found that EKC was genuine. They came to their conclusion by stating that environmental issues can be addressed through economic growth. Jaunky VC [30] used panel co-integration and Gaussian mixture model (GMM) to evaluate the EKC in the thirty-six high-income international localities. He determined the validity of EKC for some nations, but the author was unable to identify the validity of EKC during panel analyses. Additionally, Acaravci A, et al. [31] inspected the connection among energy consumption, CO_2 emissions and economic development for nineteen countries of Europe and identified that EKC had ceased to be valid in the majority of nations. The relationship among economic growth, energy consumption and CO_2 emissions was uncovered by Saboori B, et al. [32] for five Association of Southeast Asian Nations (ASEAN) countries. They discovered using the ARDL technique that the EKC is valid for Thailand and Singapore and is not valid (insignificant) for Malaysia.

For the years 2005 to 2013, Zaman K, et al. [33] looked at EKC for varied regions, including Organization for Economic Co-operation and Development (OECD) and non-OECD nations, East Asia, the Pacific and the European Union. The study examined the connection among electricity trade, economic growth and CO_2 emissions for fifteen transitioning countries.

According to Shahbaz M, et al. [34], there is a dynamic connection found using ARDL in Romania's carbon emissions, economic growth and energy consumption. The correlation between India's coal consumption, GDP growth, CO_2 emissions and trade openness was examined by Tiwari AK, et al. [35]. They confirmed the effectiveness of EKC using the ARDL technique. Yavuz NÇ [36] used information on CO_2 emissions, economic development and energy usage from 1960 to 2007 to investigate the reliability of the EKC for Turkey. The study reiterated the durability of EKC. The authors of [37] discovered a significant monotonic association between Turkey's CO_2 emissions and economic growth and came to the conclusion that economic expansion is not always sufficient to reduce environmental degradation. The under-consideration study leads to a variety of findings based on different variables like time, the examination procedure and the financial state.

All the above stated studies suggest a link between economic factors and CO_2 emissions, but none of the studies incorporated all the techno-economic factors. In contrast, this study focused on the unidirectional causality among all techno-economic factors including gross domestic product, population within the country, energy demand, renewable energy production and CO_2 emissions at the national level.

3. Material and methods

This study used the LEAP® model for finding the relationships among the key variables GDP, PP, ED, REP and CE for Pakistan. This study took as input data from the year 2000 to 2020 and made future estimations for the year 2021 to 2040. The research flow diagram for this study is given in Figure 1 for economic and environmental planning using the LEAP® software. The International Energy Agency (IEA) suggested energy models for developing energy policies. Initially, the Wien Automatic System Planning package (WASP) was the first model recommended by IEA. The WASP model can be utilized for predicting power generation potential based on the technical parameters, but this software has some limitations. For example, it cannot handle the complete spectrum of variables and is unable to predict the CO_2 emissions. Some other models also suggested by IEA include the Energy and Power Evaluation Program (ENPEP), LEAP®, Model for Analysis of Energy Demand (MAED), Simplified Approach for Estimating Impacts of Electricity Generation (SIMPACTS) and Model for Energy Supply Systems and General Environmental Impacts (MESSAGE). This study was conducted on the LEAP® model. LEAP® can be used to track energy consumption based on the techno-economic parameters, and it also estimates future energy production based on the domestic energy resource extraction and assesses the climate change externalities for sustainable development. LEAP® software has the capability to do planning of regional, national and provincial energy systems, and it is available free of cost for the non-developing and developing countries around the globe. It is a vital and genuine fact that efficient energy policy requires some high level of consideration in relation to the economic facts. The empirical model representing the key relationship is defined in Eq (1) as follows:

$$REPct = \beta_0 t + \beta_1 CO_2 ct + \beta_2 GDPct + \beta_3 PCct + Rct \quad (1)$$

here, REPct is production of green energy for a country "c" at time "t"; CO_2ct was the carbon dioxide emissions in million metric tons for a country "c" at time "t"; GDPct is the real GDP per capita for a country "c" at time "t"; PPct is the population for a country "c" at time "t"; Rct is the residual for a country "c" at time "t". Beta coefficients for long term planning of economic growth and CO_2 emissions are β_0, β_1, β_2 and β_2.

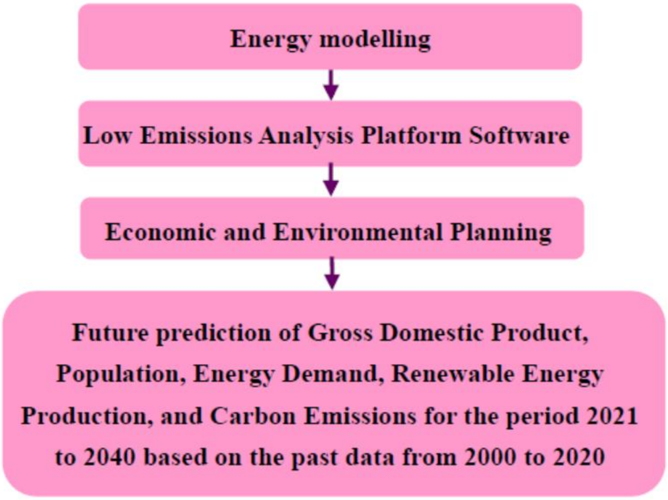

Figure 1. Research flow diagram of economic and environmental planning.

4. Empirical results

Results were calculated using the LEAP® software for finding the relationship among GDP, PP, ED, REP and CE. We got input data from the available literature and also from the research publications. Data was collected for the year 2000 to 2020, and we used this data as input for the LEAP® model for future prediction of GDP, PP, ED, REP and CE for the year 2021 to 2040.

GDP of the country identifies the economy size and also suggests how the economy is performing. Sectorial GDP of the country is depicted in Figure 2 from the year 2000 to 2040. Growth of industrial GDP is recorded as higher (1.5% in 2000, 1.4% in 2010, 10% in 2020, 9% in 2030 and also 9% in 2040) as compared with the others, followed by growth rates of residential sector (4.8% in 2000, 3.2% in 2010, 5.5% in 2020, 4.2% in 2030 and also 4.2% in 2040) and agriculture sector (6.1% in 2000, 0.2% in 2010, 4% in 2020, 3% in 2030 and also 3% in 2040). The overall growth rate of GDP in the country increases from 2.6% in 2010 to 5.8% in 2040. PP refers to the number of people in the specific country, region and area. PP of Pakistan is depicted in Figure 3. PP of the country increases from 150.9 million in 2000 to 210.1 million in 2020 and then increased to 242.1 million in 2040.

ED is also forecasted for the study period 2021 to 2040 on the basis of the past consumption data from 2000 to 2020. ED of the country is depicted in Figure 4. The residential sector consumes greater power as compared with the other sectors. The residential sector is highly dependent upon the PP or urbanization of the country. Demand of the residential sector is greater (23.20 TWh in 2000 to 55.13 TWh in 2020 and further increased to 257.72 TWh), followed by the industrial sector (15.10 TWh in 2000, 25.64 TWh in 2020 and 140.04 TWh in 2040), another sector for public services (3.94 TWh in 2000, 8.65 TWh in 2020 and 32.09 TWh in 2040), the agriculture sector (5.60 TWh in 2000, 9.75 TWh in 2020 and 30.09 TWh in 2040) and the commercial sector (3 TWh in 2000, 7.87 TWh in 2020 and 20.16 TWh in 2040), respectively.

Energy production status of Pakistan from the year 2000 to 2040 is given in Figure 5. Energy production from hydro sources is 27.48 TWh in 2000, 37.43 TWh in 2020 and 223.32 TWh in 2040. Coal produces 0.20 TWh in 2000, 25.97 TWh in 2020 and 17.64 TWh in 2040. Natural gas produces 39.02 TWh in 2000, 47.24 TWh in 2020 and 7.43 TWh in 2040. Oil produces 12.27 TWh in 2000, 8.16 TWh in 2020 and 4.01 TWh in 2040. Nuclear produces 1.61 TWh in 2000, 9.70 TWh in 2020 and 5.12 TWh in 2040. Wind, solar and biomass start producing electricity from the year 2015. Energy production from wind sources is 0.46 TWh in 2015, 38.46 TWh in 2030 and 155.36 TWh in 2040. Solar produces 0.03 TWh in 2015, 7.88 TWh in 2030 and 60.07 TWh in 2040. Biomass produces 0.31 TWh in 2015, 13.97 TWh in 2030 and 91.20 TWh in 2040, respectively.

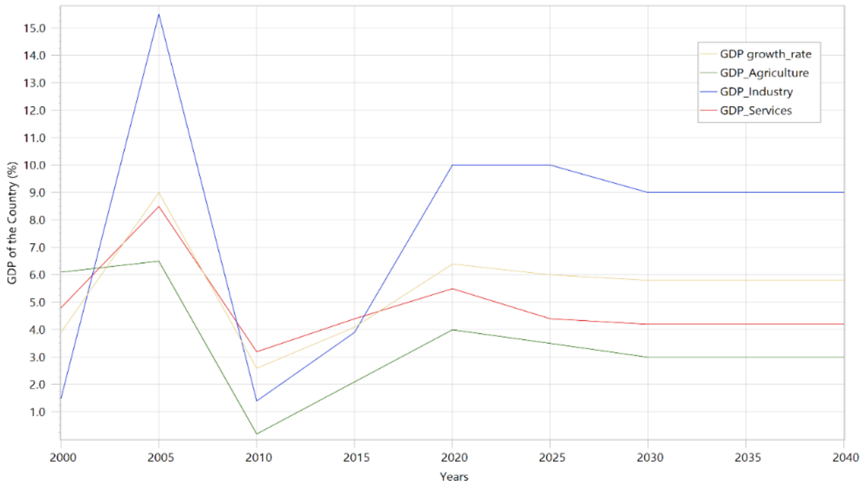

Figure 2. Sectorial growth rates of GDP in Pakistan from the year 2000 to 2040.

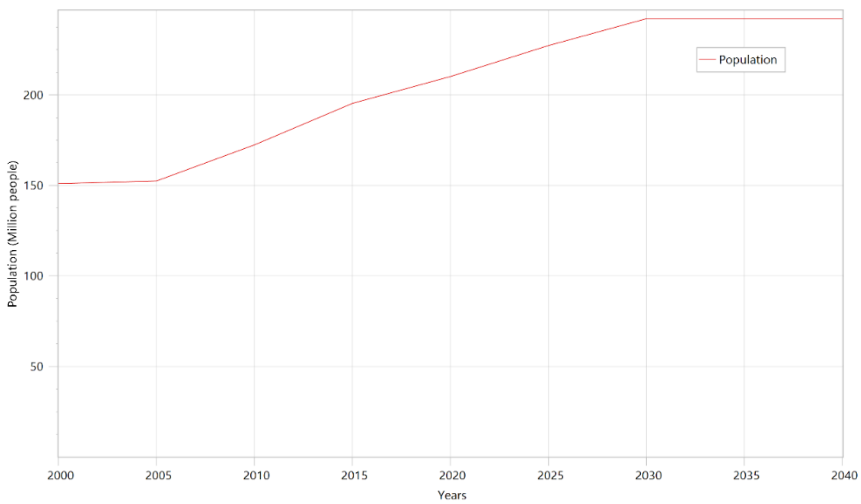

Figure 3. Population of Pakistan from the year 2000 to 2040.

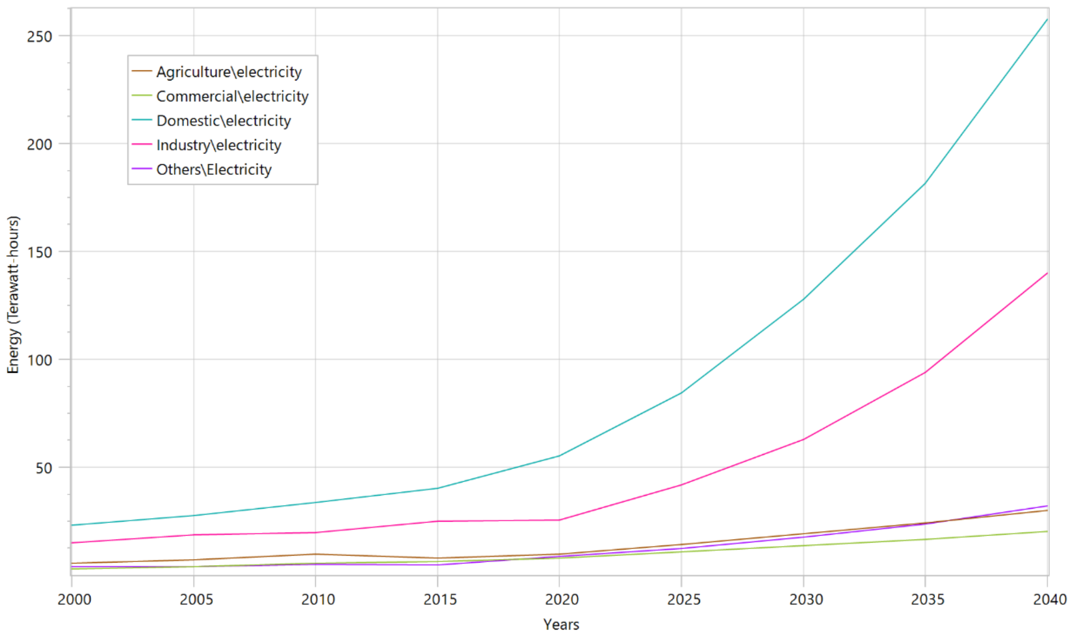

Figure 4. Energy demand of Pakistan from the year 2000 to 2040.

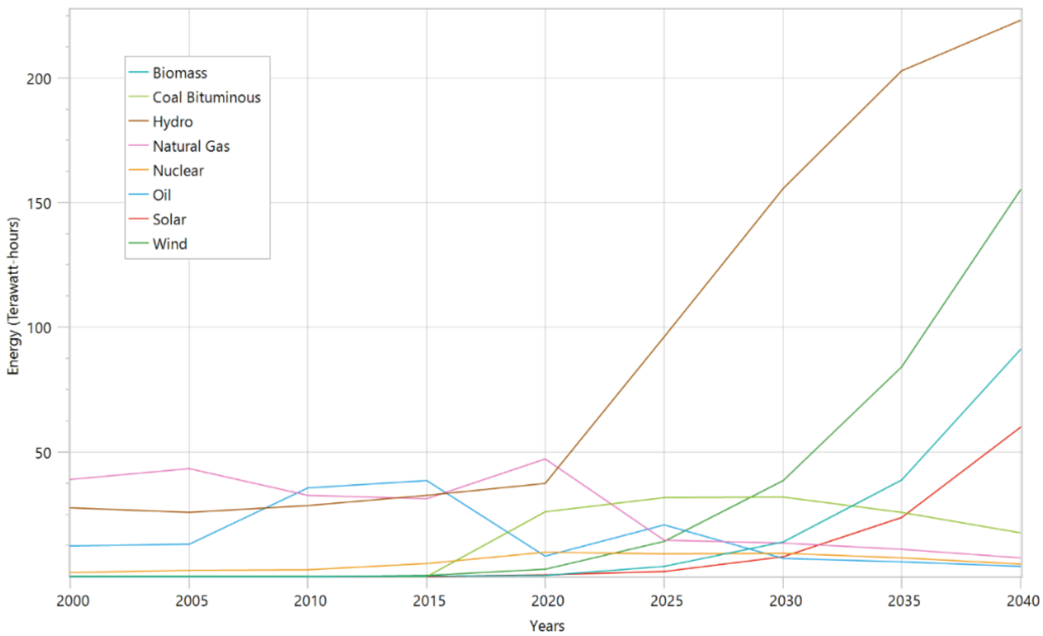

Figure 5. Energy production of Pakistan from the year 2000 to 2040.

CO_2 emissions are also forecasted over the study period 2021 to 2040, with input from the emissions from the year 2000 to 2020. CO_2 emissions for fossil assets are given in Figure 6. CO_2 emissions for coal are 0.19 million metric tons in 2000, 24.85 million metric tons in 2020 and 16.88 million metric tons in 2040. CO_2 emissions for natural gas are 17.05 million metric tons in 2000, 20.64

million metric tons in 2020 and 3.25 million metric tons in 2040. CO_2 emissions for furnace oil are 6.30 million metric tons in 2000, 4.19 million metric tons in 2020 and 2.06 million metric tons in 2040. Energy production of 564.16 TWh is enough to meet the energy demand of 480.10 TWh with CO_2 emissions of 22.19 million metric tons, having a population of 242.1 million people and GDP growth rate of 5.8%, in the year 2040. REP is 535.07 TWh, which can be utilized fully for meeting ED of the country for the year 2040. If full REP is exploited, then almost zero emissions will be produced, so there is a direct relationship between REP and CE. However, ED is directly related to the PP and GDP of the country.

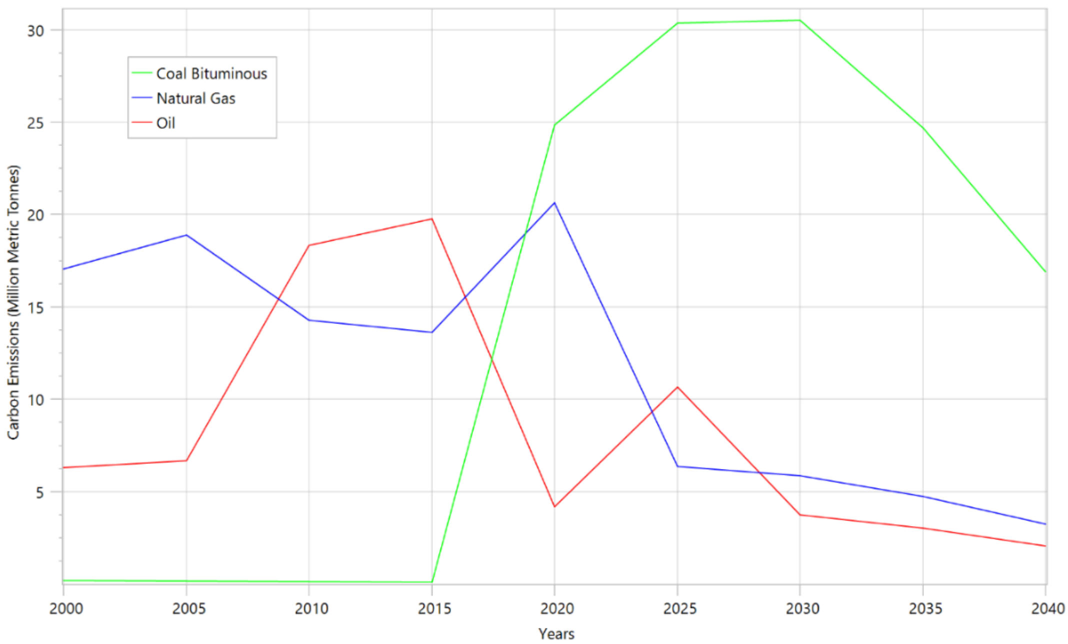

Figure 6. Carbon emissions of Pakistan from the year 2000 to 2040.

Some of the other research, as shown in Table 1, suggests a link between economic factors and CO_2 emissions, but none of the studies incorporated all the techno-economic factors. However, this study focused on the unidirectional causality among all techno-economic factors including GDP, PP, ED, REP and CE at the national level.

Table 1. Studies on unidirectional causality among GDP, PP, ED, REP and CE at the global level.

Country and Ref	Method and study period	Variables and causality among variables
South Africa [38]	ARDL method, 1971 to 2017	Economic growth reverses the environmental degradation
BRICS [39]	Panel Co-integration method (PC), 1992 to 2013	Use of renewable sources reduces CO_2 emissions and vice versa
China [40]	Granger Causality Analysis (GCA) method, 1952 to 2012	Feedback hypothesis between GDP and CO_2 emissions and causality of unidirectional nature is found between GDP and renewables
Thailand [41]	PC and GCA models, 1971 to 2013	GDP increases the use of fossil fuels and CO_2 emissions
25 Asian Countries [42]	GMM model, 1990 to 2015	Renewables reduce the CO_2 emissions and depleting of fossil fuels
74 Nations [43]	Westerlund Bootstrap Co-integration (WBC) model, 1990 to 2015	Positive and negative impacts of fossil fuels and renewables were identified
65 Countries [44]	Panel Data Analysis (PDA) model, 1960 to 2003	GDP has no effect on the degradation of the environment
24 MENA Countries [45]	Panel Vector Autoregressive (PVA) model, 1980 to 2015	Unidirectional causality of renewables with environment and GDP
Sweden [46]	Dynamic Ordinary Least Square (OLS) method, 1970 to 1997	Causality of unidirectional nature is found between GDP and CO_2 emissions
France [47]	ARDL method, 1960 to 2000	Causality of unidirectional nature is found between GDP and CO_2 emissions
China [48]	PVA method, 1960 to 2007	Unidirectional causality between electricity and CO_2 emissions
Pakistan [49]	ARDL method, 1971 to 2008	Unidirectional causality of CO_2 emissions with GDP, population and trade
India [50]	ARDL method, 1971 to 2008	Unidirectional causality of CO_2 emissions with GDP, and electricity use
United Arab Emirates [51]	ARDL and PVA method, 1975 to 2011	Causality of unidirectional nature is found between CO_2 emissions and GDP, electricity use and urbanization
Algeria [52]	ARDL method, 1971 to 2009	Unidirectional causality of CO_2 emissions with GDP, and population
Malaysia [53]	Meboot method, 1975 to 2013	Unidirectional causality of CO_2 emissions with electricity use
Italy [54]	PVA method, 1970 to 2006	Unidirectional causality of CO_2 emissions with GDP and electricity use
Pakistan (This study)	LEAP® model, 2021 to 2040	Unidirectional causality among gross domestic product, population within the country, energy demand, renewable energy production and CO_2 emissions at the national level.

5. Discussion: Study limitations, policy implications and future research directions

The main aim of this study was to increase the share of renewables and decrease the share of fossil fuels with appropriate unidirectional causality among techno-economic factors such as gross domestic product, population within the country, energy demand, renewable energy production and CO_2 emissions at the national level. The adoption of policy volatility in the biomass, hydro, wind and solar market given the abrupt changes in unidirectional causality of techno-economic factors in many countries in recent years [55–57]. The need for improved accuracy in volatility forecasting for renewable energy capacity and techno-economic factors is evident in the increasing implementation of investment decision-making methodologies that move away from static discounted cash-flow techniques, towards non-static models that include the value of flexibility in the decision-making process, such as real options [58,59]. In order to accurately harness green energy through a potential investment using these methodologies, a reliable estimate of the volatility of the future cash flows is essential [60]. Uncertainty in the electricity prices, greater cost of green energy projects implementation and greater fluctuations of dollar rate would affect the policy implications for renewable investment decisions in biomass, hydro, wind and solar [61,62]. We used biomass, hydro, wind and solar renewable energy credits as a proxy for policy uncertainty and applied our analysis to Pakistan's electric network. We used the LEAP® model to model the volatility of the biomass, hydro, wind and solar sources of uncertainty over a study period of 2022 to 2050. By focusing on the increased share of biomass, hydro, wind and solar sources in the total energy mix and also through the computation of unidirectional causality of techno-economic factors for renewable energy policy, we reached several important conclusions. First, by implementing a LEAP® model, we were able to obtain superior forecasts for a greater share of green energy for policy volatility. Second, a unidirectional causality among techno-economic factors compared to the majority of individual models, with results that are robust to a smaller sample range. Our findings were that individual models under-predict volatility. While several previous studies, as shown in Table 1, consider only one green energy source and forecast few techno-economic parameters, this is the first study, to our knowledge, that finds the unidirectional causality among all techno-economic factors such as gross domestic product, population within the country, energy demand, renewable energy production and CO_2 emissions at the national level for green energy policy volatility which considers the biomass, hydro, wind and solar sources.

Our study has important implications for both policymakers and investors. We have shown that there is significant need for development of sustainable green energy policy. Despite the rapid decline in the cost of solar, wind and other renewable technologies, recent reports suggest that investment in renewable energy is slowing. Traditionally, in order to attract investment in renewable energy, policy supports are introduced to make such investment attractive and competitive with non-renewable energy sources. Consequently, a large part of the return investors receive is based on the revenue generated from these policy supports. In markets that use wind, biomass, hydro and solar renewable energy credits, these credits provide a large incentive for investment. Due to the reliance on such policy supports to drive the investors' return, uncertainty that these incentives will persist over the lifetime of the investment will be factored into the investors' required rate of return. Previous examples of abrupt and significant policy changes from around the world suggest that investors are absolutely correct to be concerned about policy instability. When more uncertainty exists, the investment will be perceived to be riskier. As a result, higher policy volatility will lead to a higher risk premium and hence a higher cost of capital for renewable energy projects. This will lead to lower investment in such projects, slowing the move towards alternatives to fossil fuels. Governments around the world have been unveiling incredibly ambitious strategies for combating climate change, the majority of which include plans to significantly increase the amount of energy sources from renewables. For example, Ireland plans to generate 70% of electricity from renewable sources by 2030, while Spain has targeted 100% generation from renewables by 2050. Canada plans to phase out coal by 2030 and triple renewable energy generation over the same time period, and the United Kingdom has planned to achieve a 57% reduction in greenhouse gas emissions over 1990 levels. Each of these countries has also unveiled a series of policies to assist in achieving these ambitions. What is clear is that implementing appropriate policy is essential, and the stability of policy is of considerable importance in order to attract sufficient investment to achieve these targets. For policymakers, it is clear that in order to move towards reaching CO_2 emissions reduction targets, keeping policy uncertainty to a minimum will foster further investment in solar, wind, biomass and hydro by reducing perceived risk and attracting more capital at a lower required rate of return.

One potential tool for policymakers to reduce policy uncertainty, in the case of Pakistan, uncertainty in the electricity prices, greater cost of green energy projects implementation and greater fluctuations of dollar rate, is setting a price ceiling and a price floor in order to reduce the large volatility in Pakistan. In Pakistan, there should be a penalty for non-compliance with the biomass, hydro, wind and solar renewable energy credits system called the Alternative Compliance Payment (ACP). The ACP sets the maximum amount of incentive receivable for the particular year, and if the price goes above the ACP, suppliers will simply pay the penalty price. However, there is currently no price floor in the biomass, hydro, wind and solar renewable energy credits market, leaving investors exposed to downside price uncertainty. Inserting a price floor could ensure a minimum biomass, hydro, wind and solar renewable energy credits inflow. For potential investors, we have identified improved forecasts for the major sources of uncertainty surrounding investment in green energy projects, namely, electricity price uncertainty, uncertainty in implementation of green energy projects and dollar rate uncertainty. This information can be combined and incorporated into real options valuation, allowing for a more accurate valuation of green energy projects. Alternatively, investors can utilize the volatility estimate to alter the discount rate of the investment. The discount rate applicable to projects can change over time as the risks facing a firm change. Investors could express the discount rate as a function of volatility, so that in periods of high volatility, the discount rate can be increased to reflect the higher risk, and vice versa.

6. Conclusions

This study explored the unidirectional causality among the gross domestic product, population within the country, energy demand, renewable energy production and CO_2 emissions using the Low Emissions Analysis Platform (LEAP®) software. We have discussed and provided a set of recommendations in this paper, and we have applied this framework to the instance of Pakistan. Pakistan is a developing country in South Asia with less developed economy. The country is facing an electricity shortfall since 2004, and a huge dependence on imported fossil fuels has increased the problem of environmental degradation. Also, the cost of imported fossil fuels has been raised. To overcome these issues, this study has developed a de-carbonization plan for achieving net zero emissions by incorporating the alternative and renewable energy policy which was announced by the

Government of Pakistan. The goal of this policy is to increase the 30% capacity of green energy in total energy mix by 2030. In this regard, LEAP® software depicts the pattern of renewable energy generation over the period 2021 to 2040 for reducing the carbon emissions based on the techno-economic factors. The results revealed that Pakistan, with a population of 242.1 million people and a GDP growth rate of 5.8%, can consume 480.10 TWh of energy against the energy production of 564.16 TWh with CO_2 emissions of 22.19 million metric tons in 2040. The share of green energy production from domestic energy sources can contribute 535.07 TWh units in the total energy mix, which is greater than energy demand till 2040 with net zero contribution of carbon emissions. Energy demand is directly related to the population and GDP of the country, while renewable utilization is inversely proportional to carbon emissions. The declining trend of carbon emissions in Pakistan would help to achieve net zero emissions targets by mid-century. This technique would bring prosperity in the development of a clean, green and sustainable environment.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Bennich T, Weitz N, Carlsen H (2020) Deciphering the scientific literature on SDG interactions: A review and reading guide. *Sci Total Environ* 728: 138405. https://doi.org/10.1016/j.scitotenv.2020.138405
2. Breuer A, Janetschek H, Malerba D (2019) Translating sustainable development goal (SDG) interdependencies into policy advice. *Sustainability* 11: 2092. https://doi.org/10.3390/su11072092
3. Leal Filho W, Azeiteiro U, Alves F, et al. (2018) Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG). *Int J Sustainable Dev World Ecol* 25: 131–142. https://doi.org/10.1080/13504509.2017.1342103
4. Campbell BM, Hansen J, Rioux J, et al. (2018) Urgent action to combat climate change and its impacts (SDG 13): Transforming agriculture and food systems. *Curr Opin Environ Sustainability* 34: 13–20. https://doi.org/10.1016/j.cosust.2018.06.005
5. Schmidt-Traub G, Kroll C, Teksoz K, et al. (2017) National baselines for the sustainable development goals assessed in the SDG index and dashboards. *Nat Geosci* 10: 547–555. https://doi.org/10.1038/NGEO2985
6. Diaz-Sarachaga JM, Jato-Espino D, Castro-Fresno D (2018) Is the Sustainable Development Goals (SDG) index an adequate framework to measure the progress of the 2030 Agenda? *Sustainable Dev* 26: 663–671. https://doi.org/10.1002/sd.1735

7. Shahbaz M, Sharma R, Sinha A, et al. (2021) Analyzing nonlinear impact of economic growth drivers on CO_2 emissions: Designing an SDG framework for India. *Energy Pol* 148: 111965. https://doi.org/10.1016/j.enpol.2020.111965
8. Raza MA, Khatri KL, Rafique K, et al. (2021) Harnessing electrical power from hybrid biomass-solid waste energy resources for microgrids in underdeveloped and developing countries. *Eng Technol Appl Sci Res* 11: 7257–7261. https://doi.org/10.48084/etasr.4177
9. Shahbaz MS, Kazi AG, Othman B, et al. (2019) Identification, assessment and mitigation of environment side risks for Malaysian manufacturing. *Eng Technol Appl Sci Res* 9: 3851–3857. https://doi.org/10.48084/etasr.2529
10. Sinha A, Sengupta T, Kalugina O, et al. (2020) Does distribution of energy innovation impact distribution of income: A quantile-based SDG modeling approach. *Technol Forecasting Social Change* 160: 120224. https://doi.org/10.1016/j.techfore.2020.120224
11. Awan A, Bilgili F (2022) Energy poverty trends and determinants in Pakistan: Empirical evidence from eight waves of HIES 1998–2019. *Renewable Sustainable Energy Rev* 158: 112157. https://doi.org/10.1016/j.rser.2022.112157
12. Hassan M, Khan Afridi M, Irfan Khan M (2019) Energy policies and environmental security: A multi-criteria analysis of energy policies of Pakistan. *Int J Green Energy* 16: 510–519. https://doi.org/10.1080/15435075.2019.1593177
13. Raza MA, Khatri KL, Haque MIU, et al. (2022) Holistic and scientific approach to the development of sustainable energy policy framework for energy security in Pakistan. *Energy Rep* 8: 4282–4302. https://doi.org/10.1016/j.egyr.2022.03.044
14. Raza MA, Khatri KL, Memon MA, et al. (2022) Exploitation of Thar coal field for power generation in Pakistan: A way forward to sustainable energy future. *Energy Explor Exploit.* 40: 1173–1196. https://doi.org/10.1177/01445987221082190
15. Raza MA, Khatri KL, Israr A, et al. (2022) Energy demand and production forecasting in Pakistan. *Energy Strat Rev* 39: 100788. https://doi.org/10.1016/j.esr.2021.100788
16. Raza MA, Khatri KL, Hussain A (2022) Transition from fossilized to defossilized energy system in Pakistan. *Renewable Energy* 190: 19–29. https://doi.org/10.1016/j.renene.2022.03.059
17. Raza MA, Khatri KL, Akbar S, et al. (2021) Towards improving technical performance of a 747 MW thermal power plant. *Quaid-E-Awam Uni Res J Eng Sci Technol Nawabshah* 19: 104–111. https://doi.org/10.52584/QRJ.1901.15
18. Abbasi SA, Harijan K, Khan MWA, et al. (2021) Long-term optimal power generation pathways for Pakistan. *Energy Sci Eng* 9: 2252–2267. https://doi.org/10.1002/ese3.981
19. Palconit EV, Villanueva JR, Enano N, et al. (2021) Resource assessment of tidal stream power in Pakiputan Strait, Davao Gulf, Philippines. *Eng Technol Appl Sci Res* 11: 7233–7239. https://doi.org/10.48084/etasr.3853
20. Pao H-T, Tsai C-M (2011) Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. *Energy* 36: 2450–2458. https://doi.org/10.1016/j.energy.2011.01.032
21. Saboori B, Sulaiman J (2013) Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. *Energy Pol* 60: 892–905. https://doi.org/10.1016/j.enpol.2013.05.099
22. Pao H-T, Yu H-C, Yang Y-H (2011) Modeling the CO_2 emissions, energy use, and economic growth in Russia. *Energy* 36: 5094–5100. https://doi.org/10.1016/j.energy.2011.06.004

23. Nasir M, Rehman FU (2011) Environmental Kuznets curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy* 39: 1857–1864. https://doi.org/10.1016/j.enpol.2011.01.025
24. Wang SS, Zhou DQ, Zhou P, et al. (2011) CO_2 emissions, energy consumption and economic growth in China: A panel data analysis. *Energy Policy* 39: 4870–4875. https://doi.org/10.1016/j.enpol.2011.06.032
25. Hao Y, Liu Y, Weng J-H, et al. (2016) Does the Environmental Kuznets Curve for coal consumption in China exist? New evidence from spatial econometric analysis. *Energy* 114: 1214–1223. https://doi.org/10.1016/j.energy.2016.08.075
26. Saboori B, Sulaiman J, Mohd S (2012) Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the environmental Kuznets curve. *Energy Policy* 51: 184–191. https://doi.org/10.1016/j.enpol.2012.08.065
27. Ozturk I, Acaravci A (2010) CO_2 emissions, energy consumption and economic growth in Turkey. *Renewable Sustainable Energy Rev* 14: 3220–3225. https://doi.org/10.1016/j.rser.2010.07.005
28. Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. *Energy Econo* 36: 262–267. https://doi.org/10.1016/j.eneco.2012.08.025
29. Apergis N, Payne JE (2010) The emissions, energy consumption, and growth nexus: evidence from the commonwealth of independent states. *Energy Policy* 38: 650–655. https://doi.org/10.1016/j.enpol.2009.08.029
30. Jaunky VC (2011) The CO_2 emissions-income nexus: Evidence from rich countries. *Energy Policy* 39: 1228–1240. https://doi.org/10.1016/j.enpol.2010.11.050
31. Acaravci A, Ozturk I (2010) On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy* 35: 5412–5420. https://doi.org/10.1016/j.energy.2010.07.009
32. Saboori B, Sulaiman J (2013) CO_2 emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: A cointegration approach. *Energy* 55: 813–822. https://doi.org/10.1016/j.energy.2013.04.038
33. Zaman K, Shahbaz M, Loganathan N, et al. (2016) Tourism development, energy consumption and Environmental Kuznets Curve: Trivariate analysis in the panel of developed and developing countries. *Tourism Manage* 54: 275–283. https://doi.org/10.1016/j.tourman.2015.12.001
34. Shahbaz M, Mutascu M, Azim P (2013) Environmental Kuznets curve in Romania and the role of energy consumption. *Renewable Sustainable Energy Rev* 18: 165–173. https://doi.org/10.1016/j.rser.2012.10.012
35. Tiwari AK, Shahbaz M, Hye QMA (2013) The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. *Renewable Sustainable Energy Rev* 18: 519–527. https://doi.org/10.1016/j.rser.2012.10.031
36. Yavuz NÇ (2014) CO_2 emission, energy consumption, and economic growth for Turkey: evidence from a cointegration test with a structural break. *Energy Sources, Part B: Economics, Planning, Policy* 9: 229–235. https://doi.org/10.1080/15567249.2011.567222
37. Akbostancı E, Türüt-Aşık S, Tunç Gİ (2009) The relationship between income and environment in Turkey: is there an environmental Kuznets curve? *Energy Policy* 37: 861–867. https://doi.org/10.1016/j.enpol.2008.09.088

38. Nathaniel S, Nwodo O, Adediran A, et al. (2019) Ecological footprint, urbanization, and energy consumption in South Africa: Including the excluded. *Environ Sci Pollut Res* 26: 27168–27179. https://doi.org/10.1007/s11356-019-05924-2
39. Liu X, Zhang S, Bae J (2017) The impact of renewable energy and agriculture on carbon dioxide emissions: investigating the environmental Kuznets curve in four selected ASEAN countries. *J Cleaner Produc* 164: 1239–1247. https://doi.org/10.1016/j.jclepro.2017.07.086
40. Long X, Naminse EY, Du J, et al. (2015) Nonrenewable energy, renewable energy, carbon dioxide emissions and economic growth in China from 1952 to 2012. *Renewable Sustainable Energy Rev* 52: 680–688. https://doi.org/10.1016/j.rser.2015.07.176
41. Boontome P, Therdyothin A, Chontanawat J (2017) Investigating the causal relationship between non-renewable and renewable energy consumption, CO_2 emissions and economic growth in Thailand. *Energy Procedia* 138: 925–930. https://doi.org/10.1016/j.egypro.2017.10.141
42. Hanif I, Aziz B, Chaudhry IS (2019) Carbon emissions across the spectrum of renewable and nonrenewable energy use in developing economies of Asia. *Renewable Energy* 143: 586–595. https://doi.org/10.1016/j.renene.2019.05.032
43. Sharif A, Raza SA, Ozturk I, et al. (2019) The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. *Renewable Energy* 133: 685–691. https://doi.org/10.1016/j.renene.2018.10.052
44. Jorgenson AK, Clark B (2011) Societies consuming nature: A panel study of the ecological footprints of nations, 1960–2003. *Social Sci Res* 40: 226–244. https://doi.org/10.1016/j.ssresearch.2010.09.004
45. Charfeddine L, Kahia M (2019) Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis. *Renewable Energy* 139: 198–213. https://doi.org/10.1016/j.renene.2019.01.010
46. Lindmark M (2002) An EKC-pattern in historical perspective: Carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870–1997. *Ecol Econ* 42: 333–347. https://doi.org/10.1016/S0921-8009(02)00108-8
47. Ang JB (2007) CO_2 emissions, energy consumption, and output in France. *Energy Policy* 35: 4772–4778. https://doi.org/10.1016/j.enpol.2007.03.032
48. Zhang X-P, Cheng X-M (2009) Energy consumption, carbon emissions, and economic growth in China. *Ecol Econ* 68: 2706–2712. https://doi.org/10.1016/j.ecolecon.2009.05.011
49. Ahmed K, Long W (2012) Environmental Kuznets curve and Pakistan: an empirical analysis. *Proc Econo Finance* 1: 4–13. https://doi.org/10.1016/S2212-5671(12)00003-2
50. Kanjilal K, Ghosh S (2013) Environmental Kuznet's curve for India: Evidence from tests for cointegration with unknown structuralbreaks. *Energy Policy* 56: 509–515. https://doi.org/10.1016/j.enpol.2013.01.015
51. Shahbaz M, Sbia R, Hamdi H, et al. (2014) Economic growth, electricity consumption, urbanization and environmental degradation relationship in United Arab Emirates. *Ecol Indic* 45: 622–631. https://doi.org/10.1016/j.ecolind.2014.05.022
52. Lacheheb M, Rahim ASA, Sirag A (2015) Economic growth and CO_2 emissions: Investigating the environmental Kuznets curve hypothesis in Algeria. *Int J Energy Econ Policy* 5: 1125–1132.

53. Gul S, Zou X, Hassan CH, et al. (2015) Causal nexus between energy consumption and carbon dioxide emission for Malaysia using maximum entropy bootstrap approach. *Environ Sci Pollut Res* 22: 19773–19785. https://doi.org/10.1007/s11356-015-5185-0
54. Magazzino C (2016) The relationship between CO_2 emissions, energy consumption and economic growth in Italy. *Int J Sustainable Energy* 35: 844–857. https://doi.org/10.1080/14786451.2014.953160
55. Abbasi K, Jiao Z, Shahbaz M, et al. (2020) Asymmetric impact of renewable and non-renewable energy on economic growth in Pakistan: New evidence from a nonlinear analysis. *Energy Explorat Exploit* 38: 1946–1967. https://doi.org/10.1177/0144598720946496
56. Abbasi KR, Abbas J, Tufail M (2021) Revisiting electricity consumption, price, and real GDP: A modified sectoral level analysis from Pakistan. *Energy Policy* 149: 112087. https://doi.org/10.1016/j.enpol.2020.112087
57. Abbasi KR, Hussain K, Haddad AM, et al. (2022) The role of financial development and technological innovation towards sustainable development in Pakistan: fresh insights from consumption and territory-based emissions. *Technol Forecast Social Change* 176: 121444. https://doi.org/10.1016/j.techfore.2021.121444
58. Abbasi KR, Hussain K, Radulescu M, et al. (2022) Asymmetric impact of renewable and non-renewable energy on the industrial sector in Pakistan: fresh evidence from Bayesian and non-linear ARDL. *Renewable Energy* 187: 944–957. https://doi.org/10.1016/j.renene.2022.02.012
59. Abbasi KR, Shahbaz M, Jiao Z, et al. (2021) How energy consumption, industrial growth, urbanization, and CO_2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. *Energy* 221: 119793. https://doi.org/10.1016/j.energy.2021.119793
60. Raza MA, Aman MM, Abro AG, et al. (2022) Challenges and potentials of implementing a smart grid for Pakistan's Electric Network. *Energy Strategy Rev* 43: 100941. https://doi.org/10.1016/j.esr.2022.100941
61. Raza MA, Aman MM, Rajpar AH, et al. (2022) Towards achieving 100% renewable energy supply for sustainable climate change in Pakistan. *Sustainability* 14: 16547. https://doi.org/10.3390/su142416547
62. Qureshi AH, Raza MA, Aman M, et al. (2022) Energy demand projection and economy nexus of Pakistan. *Quaid-E-Awam Uni Res J Eng Sci Technol Nawabshah* 20: 138–144. https://doi.org/10.52584/QRJ.2001.17