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Sustainable pathways for attaining net zero emissions in selected South Asian countries: role of green energy market and pricing

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Due to the ongoing challenges posed by climate change and environmental degradation, developing nations are pursuing initiatives to mitigate carbon emissions at net zero and achieve sustainability objectives. To attain these objectives, it is necessary to shift from conventional energy sources to green energy sources. This research paper examines the dynamic role of the green energy market and green energy pricing in sustainable pathways for attaining net-zero emissions in South Asian countries including India, Malaysia, Pakistan, and Bangladesh. The study utilizes the dynamic Autoregressive Distributed Lag simulations (DARDLS) technique and panel data spanning from 1990 to 2018. The findings reveal a positive correlation between the green energy market and sustainable development in the short run, with reverse effects in the long run. Furthermore, there is an inverse relationship between green energy prices, net-zero emissions, and sustainable development emissions in the short run, which strengthens over time. Based on the results, the study suggests that South Asia is a region that is especially susceptible to the impacts of climate change. Therefore, the governments of these countries should consider implementing favourable policies to support sustainable development, including providing financial assistance, offering subsidies for green energy technology, reducing tariffs, and establishing strong sustainability frameworks and government regulations.

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Introduction

Attaining net zero emissions is essential to ensure a sustainable future and meet the energy and environmental targets stated in SDGs (Davis et al. 2018; Vats and Mathur, 2022). According to Climate scientists, the rising temperatures on Earth are the main reason for climate change (Liu et al. 2018), and carbon emissions are the primary culprit behind this rising temperature (IPCC, 2014). To address this issue, several international entities and global societies have undertaken efforts, such as the Kyoto Protocol, the United Nations Climate Change Conferences (COP 26), the Paris Agreement, and the United Nations' Sustainable Development Goals (SDGs), to establish deliberate objectives and implementation strategies. The Intergovernmental Panel on Climate Change (IPCC) published a special report in 2018, which stated that to limit global warming to 1.5 °C, a reduction of approximately 45% in global net human-caused CO2 emissions from 2010 levels would be necessary by 2030. Additionally, achieving net zero emissions by around 2050 would also be required to meet this target. Despite the ambitious climate change goals and countless pathways for net zero emissions, the literature currently lacks comprehensive studies that identify sustainable pathways for South Asian economies to achieve net zero emissions. The attainment of net-zero emissions is an imperative objective in order to reduce the impacts of climate change and restrict the rise in global temperatures. The process entails achieving equilibrium between the quantity of greenhouse gases released into the atmosphere and the quantity that is either sequestered or compensated for, leading to a net emissions level of zero. To achieve this objective, it is imperative to pursue several sustainable pathways and solutions throughout numerous sectors of the economy.

The term "Net zero emission" refers to the state in which all human-generated emissions are balanced by carbon removal from the atmosphere through a process called Net Carbon reduction. It is widely recognized that there is a symmetric and significant relationship between global temperature and CO2 emissions. The addition of additional CO2 will have an impact on future warming (Arora and Mishra, 2021). As a result, achieving net zero emissions has become a critical objective for energy and emissions policies worldwide due to its increasing significance. The global agenda is now focused on achieving net zero emissions by 2050, commonly known as the NZE Scenario. These scenarios aim to integrate two of the UN2030 agenda's critical objectives for sustainable development: ensuring universal access to modern energy services by 2030 (SDG 7) and taking action to address climate change (SDG 13). Hence, achieving these goals requires a transformation in energy sources from traditional to green energy, which is aligned with the sustainable development goals. In conclusion, Net Zero emission is possible by utilizing green energy (NASEM, 2023). Transitioning from the use of fossil fuels, namely coal, oil, and natural gas, to the adoption of renewable energy sources, including wind, solar, hydro, and geothermal power, is imperative. To ensure the dependability and stability of the grid, it is recommended to make investments in modern energy storage technology. The objective is to enhance the energy efficiency of pre-existing buildings and infrastructure through retrofitting measures. Advocate for the adoption and utilization of energy-efficient appliances, transportation, and industrial processes. The implementation of smart grid technologies is essential for enhancing energy management capabilities. The attainment of net-zero emissions is a critical objective in the context of mitigating climate change and securing a sustainable trajectory for our planet. To achieve this objective, it is imperative to adopt a comprehensive approach encompassing a range of techniques and approaches that span multiple sectors within society. Transitioning from the use of fossil fuels to the adoption of renewable energy sources, including solar, wind, and hydroelectric power, is imperative. This entails the expansion of infrastructure for renewable energy, enhancement of energy efficiency, and allocation of resources towards the development of energy storage systems. The attainment of net-zero emissions is a multifaceted and enduring undertaking, yet it is imperative for properly addressing the challenge of climate change. The achievement of desired outcomes necessitates the active participation, unwavering dedication, and concerted efforts of individuals, communities, corporations, and governmental entities.

Concerns over climate change and the need for environmentally friendly solutions have grown globally in recent years, particularly in the green energy market. The green energy market involves the supply, demand, and pricing of sustainable energy sources. The Global Energy Climate (GEC) model's partial equilibrium illustrates the transformation of primary energy throughout the energy supply chain to meet energy service demand while maintaining stable energy prices (IEA report, 2022). Green energy pricing refers to the cost of energy produced from renewable and sustainable sources, and several factors can influence it, including input factor cost, government regulations, energy supply and demand shocks, market structure and trade regulations (Sharif et al. 2023). The objective of green energy pricing is to make renewable energy affordable and accessible while encouraging the transition from fossil fuels to a sustainable and low-carbon energy system. The incorporation of sustainable pricing in the green energy market has the potential to achieve sustainable development goals such as reducing carbon emissions and mitigating climate change. Advocate for the widespread use of electric vehicles (EVs) and allocate resources towards the development and enhancement of charging infrastructure. Promote the use of public transportation, cycling, and pedestrian modes of mobility. Transition towards the utilization of sustainable aviation fuels and delve into the realm of electric aircraft. The adoption and deployment of carbon capture and storage (CCS) technology should be pursued. The imperative lies in transitioning towards the utilization of green hydrogen and the electrification of industrial processes. One potential strategy to mitigate environmental impact is the reduction of emissions in heavy industries, such as steel and cement production. Implement carbon pricing mechanisms such as carbon taxes or cap-and-trade systems. Establish unambiguous targets and regulations for reducing emissions. It is recommended to implement a system of incentives and subsidies to promote the adoption and utilization of renewable energy sources and low-carbon technologies.

This study aims to explore sustainable pathways to achieve net zero emissions in South Asia. South Asia is chosen as a case study due to its prominent position in the fight against climate change. The region's economies are highly vulnerable to climate change impacts and account for the largest share of global greenhouse gas emissions (ABDI Report 2023), comprising 44% of global emissions in 2022. India is the world's third-largest emitter, contributing 7% to global emissions, followed by Pakistan (0.9%), Bangladesh (3.83%), and Malaysia (3.44%) (Global Carbon Atlas, 2023). These emission trends have significant implications for the region's future development path and the global fight against climate change. To date, 55 countries, including India and Malaysia, have committed to national net-zero emissions targets, with India pledging to achieve net-zero emissions by 2070 and Malaysia by 2050. Pakistan and Bangladesh have submitted proposals to achieve net zero emissions by 2050 (ECIU, 2023). However, current policies and the use of existing energy resources will not suffice to meet the Paris targets and may lead to excessive costs. Short-term commitments made by these countries are also insufficient to control climate change. Hence, achieving net zero at a sustainable cost will require significant changes in the energy market, including transitioning to green and sustainable energy sources, which can effectively reduce emissions and mitigate climate change impacts. The attainment of net-zero emissions presents a varied and intricate task necessitating a synchronized endeavour involving governmental bodies, corporations, communities, and individuals. The process encompasses not only the mitigation of emissions but also the active extraction of carbon dioxide from the Earth's atmosphere. The implementation of sustainable strategies aimed at achieving net-zero emissions is of utmost importance in addressing the challenges posed by climate change and safeguarding the environment for future cohorts. Net zero emissions, or carbon neutrality, refers to a condition wherein the quantity of greenhouse gases released into the environment is counterbalanced by an identical quantity being eliminated. Put simply, we maintain a carbon balance in the atmosphere by neither adding more carbon nor removing less carbon than what is already present. This does not imply a complete absence of greenhouse gas emissions. Instead, this implies that the emissions are being counterbalanced through the implementation of diverse carbon removal methods, including carbon capture and storage, reforestation, and the use of carbon sinks such as oceans and forests.

The scientific basis for achieving net zero emissions is grounded in a comprehensive comprehension of the greenhouse effect and the pivotal function of carbon dioxide and other greenhouse gases in the phenomenon of global warming. Greenhouse gases are responsible for the retention of thermal energy within the Earth's atmosphere, resulting in an increase in global temperatures, commonly referred to as the phenomenon of global warming. To mitigate the increase in temperature, it is imperative to cease the addition of greenhouse gases to the atmosphere beyond the capacity of their removal, hence necessitating the achievement of net zero emissions. The attainment of net zero emissions is of utmost importance in the context of climate change mitigation as it directly targets the fundamental underlying issue, namely the surplus of greenhouse gases present in the Earth's atmosphere. Implementing this approach is considered the most efficacious method to mitigate the escalation of global temperatures and mitigate the adverse consequences of climate change. According to the Intergovernmental Panel on Climate Change (IPCC), to achieve the objective of the Paris Agreement to restrict global warming to 1.5 °C, it is imperative to attain a state of 'net zero' global human-induced carbon dioxide emissions by approximately 2050. Numerous nations and corporations have acknowledged the significance of this objective and have made firm commitments to achieve net zero aims. As an illustration, the European Union has made a firm commitment to achieving carbon neutrality by the year 2050. Furthermore, some member nations within the European Union have established their targets for achieving net zero emissions. Likewise, prominent corporations such as Microsoft, Amazon, and Unilever have made commitments to attain carbon neutrality within the forthcoming decades. These agreements serve as evidence of the increasing acknowledgement of the pressing need for climate action and the crucial significance of achieving net zero emissions in addressing this issue. The objective of achieving net zero emissions is not a standalone aspiration. The concept in question is inherently interconnected with the overarching framework of the Sustainable Development Goals (SDGs). The attainment of net zero emissions makes a significant contribution to the overall realization of the Sustainable Development Goals (SDGs) through several direct and indirect means.

Net zero initiatives play a significant role in advancing the objectives of Sustainable Development Goal 13, which pertains to Climate Action, through their direct contribution to the mitigation of climate change. Through the mitigation of greenhouse gas emissions, it is possible to curtail the phenomenon of global warming, thus mitigating the adverse consequences of climate change, including but not limited to extreme weather phenomena, escalating sea levels, and the depletion of biodiversity. Furthermore, the implementation of net zero methods has the potential to indirectly support the other Sustainable Development Goals (SDGs). As an illustration, the adoption of renewable energy sources as a means to mitigate emissions (SDG 7, Affordable and Clean Energy) has the potential to generate employment opportunities and foster economic advancement (SDG 8, Decent Work and Economic Growth). In a similar vein, the implementation of sustainable farming methods that effectively capture carbon can play a significant role in achieving net zero emissions. Moreover, these practices have the potential to enhance food security, aligning with the objectives of Sustainable Development Goal 2, which aims to eradicate hunger. Additionally, they can contribute to the sustainable utilization of terrestrial ecosystems, supporting the aspirations of Sustainable Development Goal 15, which focuses on preserving life on land. Nevertheless, it is crucial to acknowledge that the endeavour to achieve net zero emissions must be undertaken in a manner that upholds principles of fairness and equality. This entails ensuring that the shift towards a low-carbon economy neither amplifies pre-existing disparities nor gives rise to novel ones. This aligns with the objectives outlined in Sustainable Development Goal 10, which focuses on the reduction of inequalities, as well as Sustainable Development Goal 16, which aims to promote peace, justice, and the establishment of strong institutions. Several case studies exemplify the favourable impacts of net zero activities on the Sustainable Development Goals (SDGs). As an example, the municipality of Copenhagen in Denmark has made a firm commitment to achieve carbon neutrality by the year 2025. The municipality's all-encompassing climate strategy encompasses a range of strategies, including enhancing the energy efficiency of structures, augmenting the adoption of renewable energy sources, and advocating for sustainable modes of transportation. These initiatives not only serve to decrease emissions but also yield additional advantages, including the enhancement of air quality (SDG 3, Good Health and Well-being), the generation of green employment opportunities (SDG 8), and the promotion of a more habitable and sustainable urban environment (SDG 11, Sustainable Cities and Communities). Therefore, the pursuit of achieving net zero emissions is an essential component of the worldwide endeavour to attain the Sustainable Development Goals (SDGs). This strategy effectively tackles the pressing issue of climate change while simultaneously making significant contributions to various other objectives, including clean energy, economic development, food security, and the establishment of sustainable cities. Hence, it is a strategic approach that warrants our whole endorsement and dedication.

Previous literature (Jia et al. 2023; Sarkodie and Strezov 2018; Alam, et al. 2016; Shahbaz, et al. 2015; Sharma et al. 2021) has extensively studied the economies of South Asia. However, most of the literature focuses on individual countries and may not provide a holistic view of the region. To address this gap, this panel study analyzed the data of selected economies of South Asia including India, Pakistan, Bangladesh, and Malaysia. Of these, two countries have already submitted pledges for net-zero emission targets, while Pakistan and Bangladesh have submitted their proposals to be part of the net-zero emission scenario by 2030. The justification for achieving net-zero emissions is based on the imperative to reduce the consequences of climate change and guarantee the long-term viability of the Earth as a livable environment for present and future cohorts. The principal motivator for the pursuit of net-zero emissions is to alleviate the impacts of climate change. The rise in global temperatures is attributed to the escalation of greenhouse gases, particularly carbon dioxide, in the atmosphere as a result of anthropogenic activities such as the combustion of fossil fuels, deforestation, and industrial operations. These consequences give rise to a variety of detrimental effects, encompassing heightened frequency and intensity of extreme weather phenomena, escalating sea levels, and disturbances to ecological systems. In summary, the justification for achieving net-zero emissions is complex, embracing various aspects such as mitigating climate change, conserving the environment, promoting public health, creating economic possibilities, fostering global collaboration, and ensuring the long-term viability of our planet. The aforementioned statement signifies a collaborative endeavour aimed at addressing a significant contemporary concern. This study reflected two primary contributions to the existing literature. Firstly, it provides a novel analysis of the sustainable pathway for achieving net-zero emissions for the combined economies of South Asia. Secondly, the study incorporates the dynamic role of the green energy market and green energy pricing as measures of achieving net-zero emissions. To holistically investigate sustainable development in South Asia, the study employs dynamic Autoregressive Distributed Lag simulations (DARDLS) for the dataset spanning from 1990–2018 followed by the studies of Chen et al. 2023).

The subsequent sections of this paper are organized as follows: In Section 2, we review the existing literature on modeling sustainable low-carbon pathways for South Asian economies. Section 3 describes the data methodology adopted for the study. In Section 4, we present and analyze the modelling results and discuss the significance of our findings. Finally, in Section 5, we summarize the key findings of the study, acknowledge its limitations, and provide suggestions for future research.

Literature review

In light of the persistent problems of climate change and environmental degradation, numerous countries are implementing measures to mitigate carbon emissions and reach long-term net-zero goals. According to recent research, developing countries are making headway towards sustainable development by leveraging the potential of green energy resources (Ahuja and Tatsutani, 2009). Nevertheless, the outlook for South Asian economies is less positive. This section of the paper aims to provide a critical analysis of the literature on sustainable strategies for attaining net-zero emissions by investigating the interplay between the green energy market, green energy pricing and sustainability.

Net zero emission and sustainable development. Numerous studies have been conducted on achieving Net Zero Emissions (NZE) and its contribution to sustainable development across various economic sectors (Zuo et al. 2012; Gupta et al. 2020; Jain and Jain, 2017; Chen et al. 2023). The majority of these studies have reported a positive correlation between NZE and sustainability and have identified several sustainable pathways to achieve the NZE scenario by 2050 but missed out on the negative associations, which highlights the significant gap for this current study. For example, Roche (2023) proposed the use of energy and production efficiency to aid decarbonization in Africa. Li and Haneklaus (2022) suggested three ways India could achieve NZE, including accelerating the utilization of renewable energy sources, introducing clean energy technologies, and developing a carbon trading market. Klaaßen and Steffen (2023) found that investing in green technology could identify the NZE-SDG nexus, while Setiawan and Setiyo (2022) proposed the production of green diesel as a measure of net zero emissions. Drouet et al. (2021) introduced the variable of climate risk, which has a negative nexus with NZE. Additionally, Sofuoğlu and Kirikkaleli (2023) analyzed used material footprint (MF) as an essential pathway for achieving NZE targets and sustainable development goals for EURO-26 countries. Furthermore, Filipović et al. (2022) introduced the perspective that a successful transition to climate neutrality can be sustainable only if citizens are fully committed and the link between the two goals of achieving NZE and sustainable development is clearly understood. Apart from the existing literature, in this study, we used the green energy market and green energy pricing as measures to attain NZE. These variables build on the existing literature; the green energy market is an augmented transition energy model of the existing GCE model, which is a data-intensive model of the market that considers energy demand, supply, and energy price integration sensitivities (IEA, 2022). The convergence of net-zero emissions and sustainable development is a significant and dynamic subject in the scholarly discourse. There is a growing acknowledgement among researchers, politicians, and organizations that the attainment of net-zero emissions is not solely a climate-related endeavour, but rather an essential component of sustainable development. Climate action is a prominent objective under the United Nations' 2030 Agenda for Sustainable Development, specifically outlined as Goal 13. Numerous scholarly publications and reports extensively examine the correlation between attaining net-zero emissions and the overarching objectives of the Sustainable Development Goals (SDGs), thereby making a significant contribution towards fostering a sustainable future. Several notable sources for additional reading and investigation in this field encompass papers and publications authored by esteemed institutions such as the United Nations, the World Bank, and the Intergovernmental Panel on Climate Change (IPCC). Furthermore, scholarly journals specializing in the disciplines of sustainability, environmental science, climate change, and development studies consistently disseminate research about this subject matter. It is of utmost significance to refer to contemporary sources, given the dynamic nature of the net-zero emissions and sustainable development domain.

Hypothesis 1: *existence of significant and positive correlation between achieving net zero emissions and promoting sustainable development*.

Green energy market and sustainable development. According to (Bhowmik et al. 2020), the term "green energy" describes sources of energy that produce minimal environmental impact, in contrast to conventional energy sources. In recent times, policymakers have been paying significant attention to the implementation of the green energy market. (Bie et al. 2023) elaborated that the green energy market has been identified as having two primary objectives: Firstly, to ensure a consistent supply of energy sources for all generations. Secondly, to fulfil the global demand for energy by employing carbon techniques, while keeping the prices as low as possible to make clean and affordable energy accessible to all (Aktar, et al. 2020). Moreover, numerous studies have identified green technology innovation as a key driver of the green energy market (Anwar et al. 2021; Shan et al. 2021; Adebayo et al. 2023). These studies have concluded that the green energy market cannot achieve net zero emissions and energy sustainability without the adoption of green technology innovation. They also underscore the need for continued investment in green technology and the development of the green energy market to achieve energy and environmental sustainability. Hence, following the studies mentioned above, this current study also adopts green technology innovation as a proxy variable for the green energy market.

According to studies conducted by (Sen and Ganguly 2017; Sharif et al. 2023; Zhao et al. 2022), the production and consumption of green energy have the potential to facilitate sustainable development and address environmental degradation. A significant body of literature has shown a positive relationship between the green energy market (GEM) and sustainable development, with the studies (Ha and Byrne, 2019; Kaygusuz, 2012); Li et al. 2023; Sutrisno, et al. 2021; Sobocińska, 2022; Salvarli and Mustafa, 2020) highlighting this nexus. For Instance: (ha and Byrne, 2019) investigated the nexus between GEM and sustainable development through the Korean Green Growth Initiative (KGGI) and suggested that GEM has the potential to create job opportunities, reduce poverty, address environmental degradation, and achieve sustainable development. Similarly, (Kaygusuz, 2012) identified the nexus and recommended that a financial, institutional, and technology framework is needed in developing economies to enhance access to modern energy services at the local and regional levels. Likewise, (Li et al. 2023) explained that GEM generates job opportunities and reduces income inequality, leading to sustainable development in resource-based regions. Additionally, (Sutrisno et al. 2021) argued that sustainable energy is a dominant concern for many economies and that GEM expansion creates opportunities for green energy suppliers, helping to achieve carbon removal scenarios. Furthermore (Tiwari et al. 2022) found that green energy bonds are an effective investment channel and play a significant role in GEM and sustainable development. However, some studies have reported negative associations, such as (Sobocińska, 2022), who identified that consumer behaviour could affect GEM adversely, and high investment costs in GEM could lead to a decline in energy demand, negatively impacting sustainability in Poland. In the end, (Aktar et al. 2020) have highlighted the barriers in the green energy market that hinder the deployment of sustainable energy and limit the ability to achieve net zero emissions. These barriers include complex legal regulations, insufficient funds, and limited competition in the market. Green financing refers to the process of augmenting the magnitude of financial resources, originating from various sectors such as banking, micro-credit, insurance, and investment, to direct them towards sustainable development objectives. An essential aspect of this endeavour is enhancing the management of environmental and social risks, pursuing possibilities that yield both favourable financial returns and environmental advantages, and fostering heightened accountability. The promotion of green financing can be facilitated by implementing modifications to the regulatory frameworks of countries. This includes the harmonization of public financial incentives and the augmentation of green financing across various sectors. Additionally, aligning the decision-making process of public sector financing with the environmental aspect of the Sustainable Development Goals can contribute to this endeavour. Furthermore, increasing investments in clean and green technologies, as well as providing financing for sustainable natural resource-based green economies and climate-smart blue economies, can be instrumental in advancing green financing. Another avenue to explore is the heightened utilization of green bonds, among other potential strategies.

Several studies have highlighted the GEM-SD nexus in South Asian economies (Kumar et al. 2023; Fulton et al. 2017; Asif, 2009; Foo, 2015; Das et al. 2020). However, South Asian economies made significant progress in transitioning towards green energy and achieving their sustainable development goals (Pandey and Asif, 2022; Shukla, et al. 2017; Salem and Kinab, 2015). However, despite these advancements in the energy market, some South Asian economies are still facing challenges in accessing modern energy resources to achieve a balance between their environment and economy (Guo et al. 2020).

Hypothesis 2: The green energy market possesses a Positive and significant impact on Sustainable development:

Green energy pricing and sustainable development. The extensive literature on the relationship between green energy prices and sustainable development compelled policymakers and academics to attain net zero emissions. Traditional energy sources have been associated with environmental damage, leading to the development of sustainable and eco-friendly green energy sources. The recent literature has shown a substantial and negative correlation between sustainable development and green energy pricing. Various factors related to this nexus include; tariffs, government regulations, energy demand, consumer willingness to pay, input prices, and market uncertainty, which act as moderators in the GEP and Sustainability nexus and pose challenges in achieving the goal of net zero emission (Sotnyk et al. 2021; Trujillo-Baute, et al. 2018; Traber and Kemfert, 2009). Specifically, (Sotnyk et al. 2021) examined the role of tariffs in the nexus of green energy pricing and sustainability in Brazil and found that additional tariffs led to imbalances in pricing policies, resulting in disproportionate development of green energy capacities and threatening the sustainable development of the sector. Similarly, (Trujillo-Baute et al. 2018) investigated the impact of energy regulation on sustainable development and found that rising energy prices caused by regulations hindered the achievement of sustainable development goals in the EU energy industry. (Traber and Kemfert, 2009) analyzed the effect of policy on German green energy prices and showed that prices were negatively related to sustainable development, and policy intervention created difficulties in achieving the goal of net carbon removal. In addition, (Knapp et al. 2020; Tiwari et al. 2021) found that consumers are generally unwilling to pay a premium for green energy, which includes the prices of certificates and bonds, and this can have a long-term impact on the green energy market. (Karatayev and Clarke, 2016) have also indicated that the high-risk business environment and market uncertainty contribute to high energy prices and decrease sustainable development in Kazakhstan. Furthermore, several studies have shown a decline in green energy prices positively contributes to sustainable development (Bergman and Eyre, 2011; Zarnikau, 2003; Shahzad et al. 2023). Hence, it has been suggested by Karataayev and Clarke, that addressing high premium prices, implementing low energy tariffs, and reducing excess supply and production of green energy with an efficient regulatory and legal framework can help keep green energy prices low and achieve sustainable development goals, ultimately contributing to net-zero emissions. Climate change has become the prominent political and economic issue of the current century and is expected to maintain its significance in the foreseeable future. Governments, investors, businesses, and private individuals across the globe are increasingly engaging in initiatives aimed at addressing the climate challenge, with a particular focus on the implementation of de-carbonization strategies. The transition towards a low-carbon or green economy necessitates substantial amounts of new capital investment, particularly in the realm of green financing. This financial support is crucial for facilitating initiatives that reduce greenhouse gas (GHG) emissions and aid businesses in adapting to the impacts of climate change. It is imperative to comprehend the concept of green finance and its significance. The tally of nations declaring commitments to attain net zero emissions in the forthcoming decades is steadily increasing. However, the commitments made by countries thus far, even if they are completely realized, are insufficient in meeting the requirements to establish a state where global energy-related carbon dioxide emissions reach net zero by 2050. Consequently, these commitments also fail to provide the world with a reasonable probability of limiting the increase in global temperature to 1.5 °C. This unique analysis represents the inaugural and all-encompassing examination of the strategies required to achieve a net zero energy system by the year 2050. It aims to ensure the stability and affordability of energy sources, facilitate universal access to energy, and foster resilient economic growth. The proposed approach outlines a financially efficient and economically advantageous trajectory, leading to the establishment of a sustainable and robust energy sector mostly reliant on renewable sources such as solar and wind, as opposed to fossil fuels. The research additionally investigates significant issues about the roles of bioenergy, carbon capture, and behavioural changes in achieving a state of net zero.

Hypothesis 1: *Green energy prices have a significant and inverse relationship with sustainable development*

The attainment of net-zero emissions presents a diverse and intricate problem that necessitates substantial progress in both theoretical and practical domains. It is imperative to acknowledge that the state of research and knowledge in this particular sector may have changed after the year 2020. The following are several theoretical and practical research gaps that were pertinent as of the most recent update: The objective is to enhance the efficiency and cost-effectiveness of carbon capture technologies. This study aims to investigate innovative materials and methodologies for the effective capture and sequestration of carbon dioxide originating from diverse sources. The existing practical gap. This study aims to execute and evaluate the viability, scalability, and environmental consequences of implementing extensive carbon capture and storage (CCS) initiatives. Examine the comprehension of CCS technologies among the general public and evaluate their level of adoption. The present discourse is around the exploration of theoretical frameworks that facilitate the seamless integration of intermittent renewable energy sources into pre-existing energy systems. The objective is to devise sophisticated energy storage solutions that can ensure a dependable and consistent supply of renewable energy. This study aims to implement and conduct a performance analysis of smart grids and energy storage technologies. This study aims to examine the social and economic ramifications associated with the move towards renewable energy sources. This study aims to construct comprehensive models that facilitate the transition towards sustainable transport, encompassing a range of transport modalities. This study aims to investigate the viability and potential consequences of developing technologies, including electric and hydrogen-powered automobiles. This study aims to execute and evaluate the efficacy of sustainable transport solutions at a significant magnitude. Examine the necessary infrastructure prerequisites and sociocultural behavioural modifications required for achieving extensive acceptance and utilization. This paper aims to propose theoretical frameworks that can facilitate effective international collaboration in the context of climate change mitigation. Examine systems aimed at achieving a fair distribution of responsibilities among states. Addressing these theoretical and practical gaps necessitates the establishment of interdisciplinary collaboration, the use of innovative research methodologies, and the ongoing commitment of the scientific community, policymakers, and industrial partners.

Results

Model and data set. This research paper scrutinizes the dynamic role of the green energy market and green energy pricing for sustainable pathways for attaining net zero emissions in selected South Asian Countries (i.e., India, Pakistan, Malaysia and Bangladesh) via empirical equation modelled as follows:

$$lnSUS_t = \theta_0 + \theta_1 lnNZE_t + \theta_2 lnGEM_t + \theta_3 lnGEP_t + e_t, \qquad (1)$$

where t, ln, CAE, GTI, FD, TO, θ_0, θ_1 to θ_3 and e_t represent time, natural logarithm, sustainability, net zero emissions, green energy market and green energy pricing, constant term, coefficients of the explanatory variables, and the error term, respectively. Depending on data availability for selected countries, annual data spanning the period from 1990 to 2018 are used in the paper. Different from the existing literature, this research paper utilizes green energy marketing and green energy pricing as a measure of net zero emissions instead of traditional marketing and pricing policies and strategies. As discussed by Rahman et al. (2022) and Ahmad and Wu (2022) lower (higher) carbon intensity signifies higher (lower) carbon emission. In contrast to both CO_2 emissions and traditional energy marketing and pricing, green energy pricing and marketing allow determining the complete and comprehensive sustainable and net zero emissions. This critical feature of both GEM and GEP makes them a suitable indicator for sustainable development (Mohammed et al. 2023).

Based on the study conducted by Habiba et al. (2022), the registered patents in environment-related technologies were obtained from the database of the Organization for Economic Co-operation and Development (OECD) (https://stats.oecd.org)are used as a proxy for green energy market and pricing. To represent sustainable development (SD), the sustainable development index downloaded from the sustainable development index database of the sustainable development organization is used (de Haan et al. 2022). Finally, as in the paper of Su et al. (2022), the proportion of the sum of exports and imports (i.e., trade) to GEM gathered from WTI is used for green energy pricing (GEP). All variables are transformed into natural logarithms to minimize data variability and possible impacts of heteroscedasticity.

Methodology. The empirical investigation in the paper employs dynamic Autoregressive Distributed Lag simulations (DARDLS) methodology developed by Jordan and Philips (2018). The DARDLS approach is an enhanced version of the conventional ARDL method introduced by Pesaran et al. (2001). Suppose the mused includes complex specifications (i.e., multiple lags, first differences, and lagged first differences). In that case, it is difficult to interpret the explanatory variables' short- and long-term impacts on the dependent variable with the traditional ARDL. On the other hand, the DARDLS approach simulates, forecasts, and finally visualizes the effects of the possible counterfactual shock in an explanatory variable at a specific time horizon on the dependent variable by holding other explanatory variables constant through dynamic stochastic simulation techniques. This approach also provides numerical results to make statistical inferences about the graphs. Dynamic Autoregressive Distributed Lag models are frequently employed in the fields of econometrics and statistics to examine the temporal evolution of variables and investigate their interrelationships. These models enhance the conventional autoregressive distributed lag (ADL) models by incorporating the capability to capture dynamic interactions among variables. DADL models are valuable tools for examining the impact of one or more independent variables on a dependent variable, considering both short-term and long-term impacts. These models take into account the lagged values of both the dependent and independent variables. Hence, the DARDLS approach allows us to examine both the short- and long-term impacts of positive and negative shocks in the explanatory variables on the dependent variable (Jordan and Philips, 2018; Danish and Ulucak, 2022; Emenekwe et al. 2022; Xiang and Solaymani, 2022).

The DARDLS model of the paper in error correction form is as follows:

$$\begin{aligned}\Delta lnSUS_t = \alpha_0 + \varphi_0 lnSUS_{t-1} + \delta_1 \Delta lnNZE_t \\ + \varphi_1 lnNZE_{t-1} + \delta_2 \Delta lnGEM_t \\ + \varphi_2 lnGEM_{t-1} + \delta_3 \Delta lnGEP_t + \varphi_3 lnGEP_{t-1} + e_t\end{aligned} \qquad (2)$$

Table 1 Unit root tests results.

	ADF		PP	
Variables	Level	First difference	Level	First difference
SUS	−0.434	−4.832***	0.074	−3.843***
NZE	−2.783*	−6.843***	−6.142***	−4.943***
GEM	−0.845	−5.943***	−0.832	−6.832***
GEP	−2.483	−5.834***	−3.832	−4.451***

Symbols "***" and "*" represent significant at 1% and 10% levels, respectively.

Table 2 Bounds test results.

		10%		5%		1%	
Estimated model	F-statistic	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
SUS = f(gti, fd, to)	11.054 ***	4.04	5.83	4.54	4.05	5.65	6.08

I(0) and I(1) are the critical values of the lower and upper bounds, respectively. Symbol "***" denotes significant at a 1% level.

Where Δ, α_0, δ_1 to δ_3, φ_0 to φ_3 and stand for difference operator, constant term of the estimation, short-run coefficients, long-run coefficients, and error term of the model, respectively.

Empirical results

For the DARDLS results to be valid, the integration order of the variables to be used should be at most one (Khan et al. 2020b), and there must be a cointegration relationship between the relevant variables (Olasehinde-Williams and Oshodi, 2021). For this reason, first, the integration orders of the study variables are scrutinized by employing two conventional unit root tests, namely Augmented Dickey-Fuller (Dickey and Fuller, 1979) and Phillips-Perron (Phillips and Perron, 1988). The process entails making decisions regarding the arrangement of autoregressive and distributed lag terms, in addition to other parameters such as seasonal components, trend components, or structural breaks. To estimate the parameters of the DADL model, one can utilize statistical software or programming languages such as R or Python, as well as specialized econometric software packages like EViews or STATA. The estimation of model parameters is commonly performed using techniques such as ordinary least squares (OLS) or maximum likelihood estimation (MLE). Evaluate the adequacy of the model's fit and ascertain its adherence to the assumptions of the DADL model, including the absence of autocorrelation in the residuals. The simulation results should be analyzed to develop conclusions regarding the relationships between variables and the potential impacts of various scenarios on the dependent variable. The results of the unit root tests in Table 1 ensure that the integration orders of all study variables are at most one.

Second, the cointegration relationship between the study variables is examined by utilizing the modified Pesaran et al. (2001) bounds test with Kripfganz and Schneider's (2020) critical values instead of the critical values of Pesaran et al. (2001). The critical values of Kripfganz and Schneider (2020) are preferred in this study since these values ensure more robust and reliable outputs, especially for small sample sizes, as in this paper (Danish and Ulucak, 2020). The bounds test results in Table 2 verify the cointegration relationship between the study variables. The findings obtained from both unit root and bounds tests reveal that the results of the DARDLS analysis using the study variables will be valid. Unit root tests and limits tests often employ statistical methodologies in the field of econometrics and time series analysis to evaluate the stationarity of a given time series. These tests are utilized to ascertain whether a time series exhibits trend-stationarity or difference-stationarity, which is crucial for accurate modelling and forecasting purposes. The Augmented Dickey-Fuller (ADF) test is well recognized as a prominent unit root test in the field. The purpose of this test is to evaluate the null hypothesis that a given time series possesses a unit root, which implies that the series is non-stationary. If the calculated test statistic deviates sufficiently from the predetermined critical value, it is appropriate to reject the null hypothesis and infer that the time series exhibits stationarity. In contrast to the ADF test, which examines the existence of a unit root, the KPSS test assesses the existence of a deterministic trend inside a stationary process. The null hypothesis of stationarity is assumed, and if the test statistic is above the critical value, the null hypothesis would be rejected, leading to the conclusion that the time series is not stationary.

Finally, the dynamic role of green energy marketing, green energy pricing, and net zero emission on sustainable development in selected South Asian countries is scrutinized by utilizing the DARDLS approach. This approach will allow us to see the short- and long-term impacts of the possible positive and negative shocks in green energy marketing, green energy pricing, and net zero emission on sustainable development at a specific time horizon. The establishment of appropriate pricing mechanisms for green energy and the pursuit of net-zero emissions are essential factors in advancing sustainable development and effectively tackling the pressing global issues associated with climate change and environmental degradation. The concept of green energy pricing pertains to the financial valuation of electricity produced from renewable and low-carbon energy sources, including wind, solar, hydroelectric, and geothermal power. The objective is to enhance the economic viability of renewable energy sources, thereby establishing their competitiveness with, or potential to surpass, fossil fuels in terms of cost (Tiwari et al. 2023). The cost of green energy carries significant consequences for the advancement of sustainable development. Reducing the financial burden associated with green energy enhances its affordability and widens its reach, encompassing a diverse range of individuals and enterprises. The implementation of cost-effective sustainable energy sources has the potential to mitigate energy poverty and enhance the overall well-being of numerous individuals, particularly those residing in developing areas. Figures 1–3 and Table 3 illustrate the graphs and numerical results of the DARDLS, respectively.

Figure 1 exhibits that a positive (negative) change in green energy marketing decreases (increases) sustainable development in the short term, but this effect is reversed in the long term. The outputs in Table 3 show that the long-run effect is statistically significant, while the short-run effect is not.

Figure 2 depicts a positive (negative) change in green energy pricing that slightly increases (decreases) sustainability in the short run, while this effect is much more in the long run. The results in Table 3 indicate that while the long-run effect is statistically significant, the short-run effect is not.

The graphs in Fig. 3 and the outputs in Table 3 together illustrate that a positive (negative) change in net zero emissions statistically significantly reduces (increases) sustainable development both in the short- and long-run.

DARDLS findings reveal that green energy marketing and green energy pricing have a favourable impact on net zero emissions in the long run, while net zero emissions increase sustainable development in both the short- and long-run in selected countries.

Several diagnostic tests need to be performed to determine the reliability of the DARDLS findings. The outputs of the diagnostic

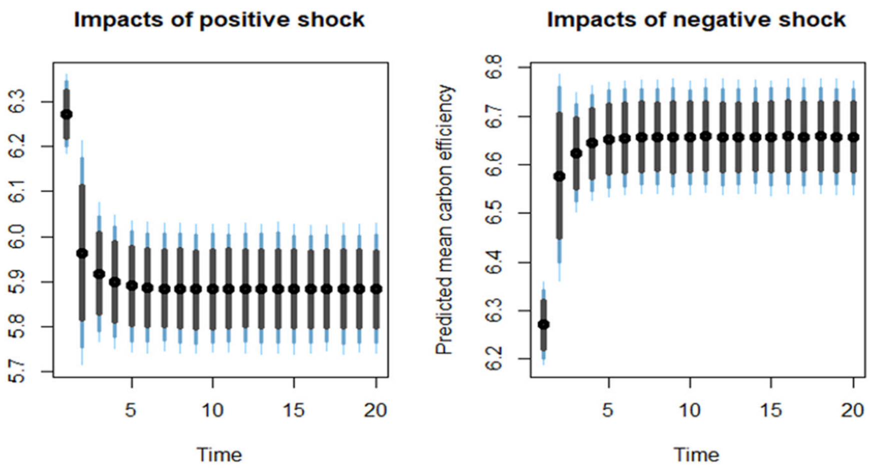

Fig. 1 Positive and Negative shocks of energy marketing on carbon efficiency. A shock of ± 1% in green energy marketing and its role on carbon efficiency as a sustainable development.

Table 3 Numerical results of the DARDLS.

Variables	Coefficient	Std. error	t-Statistic	Prob.
Constant	5.540***	0.381	7.043	0.001
SUS_{t-1}	−0.534***	0.201	−6.843	0.000
ΔNZE_t	−0.045	0.054	−2.843	0.831
ΔGEM_t	0.005	0.822	0.043	0.382
ΔGEP_t	−0.482**	0.932	−3.832	0.034
NZE_{t-1}	0.493***	0.043	4.543	0.005
GEM_{t-1}	0.820**	0.184	3.831	0.032
GEP_{t-1}	−0.341**	0.382	−3.843	0.011

Symbols "***" and "**" indicate significant at 1% and 5% levels, respectively.

tests performed are shown in Table 4 the outputs show that the study model is stable and free of any serial correlation, ARCH, heteroscedasticity, misspecification, and non-normality problems; therefore, the DARDLS findings are reliable.

ARCH (Autoregressive Conditional Heteroskedasticity) models belong to a category of time series models that are employed to examine and resolve concerns associated with heteroscedasticity, misspecification, and non-normality in financial and econometric data. Issue: Heteroscedasticity manifests when the variability of the residual terms in a time series or regression model deviates from being constant across different data. Put simply, the data's variability fluctuates over time, hence contradicting the concept of homoscedasticity. The purpose of ARCH models is to effectively capture and model the volatility that varies over time. This is achieved by incorporating lagged error terms into the model to address the autocorrelation present in the squared residuals. ARCH models can discern the dynamic nature of volatility patterns and offer improved estimations and predictions. ARCH models are a useful tool for identifying and rectifying misspecification problems associated with heteroscedasticity. By integrating the autoregressive conditional heteroskedasticity framework into the model, researchers provide a more adaptable depiction of the volatility in the data, hence enhancing the model's accuracy and mitigating potential errors in specification.

Conclusion and policy implications

This study presents a comprehensive review of existing literature and empirical methodology to identify viable strategies for achieving net zero emissions in selected South Asian economies, namely India, Malaysia, Pakistan, and Bangladesh. The region's significance stems from its large population and high emission levels, rendering the path to achieving net zero emissions arduous and costly. Traditional energy sources such as coal, gas, oil, and electricity that are heavily relied upon by South Asian economies result in severe environmental damage. Additionally, the changing weather patterns brought about by climate change pose a substantial threat to nations such as India, Bangladesh, and Pakistan. Thus, South Asian countries must establish internal net-zero targets no later than 2050. The ultimate goal for all countries, regardless of their level of development or availability of energy resources, is to achieve an affordable, safe, and sustainable energy future. However, the South Asian region is facing difficulties in transitioning from conventional energy to green energy. In response, countries in the region have initiated carbon removal programs and pledged to achieve net zero emissions. The study used the DARDLS simulation technique and its findings support the proposed hypothesis and demonstrate a positive correlation between the green energy market and sustainable development in the short run, and reverse effects in the long run. Additionally, there is an inverse relationship among green energy prices, net zero emissions and sustainable development emissions in the short run, and this effect becomes stronger in the long run. In other words, an increase (decrease) in green energy prices would lead to a decrease (increase) in sustainable development. The study also suggests that despite the high demand for energy in the region and the recognition of the terms "green energy market" and "green energy prices," the lack of a centralized green energy market, green innovation, and concerns for energy security hinder the achievement of green energy sustainability and market establishment. Nevertheless, the reliability and availability of green energy for achieving net zero emissions are critical for consolidating sustainable gains.

The exploration of sustainable approaches for achieving net zero emissions yields substantial theoretical advancements across diverse academic disciplines and domains of inquiry. The advancement of sustainable strategies aimed at achieving net zero emissions makes a valuable contribution to the theoretical frameworks around climate change mitigation. This aids academics and policymakers in gaining a deeper comprehension of the methods, policies, and activities that are necessary for effectively mitigating climate change. The incorporation of sustainability concepts, technology, economics, policy, and social sciences into pathways aiming for net zero emissions serves as a prime illustration of the interdisciplinary character inherent in this discipline. The promotion of collaboration among academics is

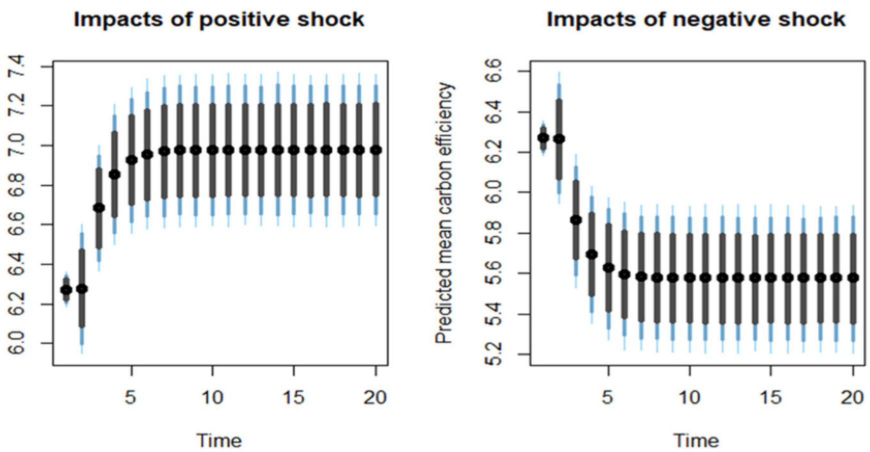

Fig. 2 Positive and Negative shocks of green energy pricing on sustainable development. A shock of ± 1% in green energy pricing and its role on sustainable development in the form of carbon efficiency.

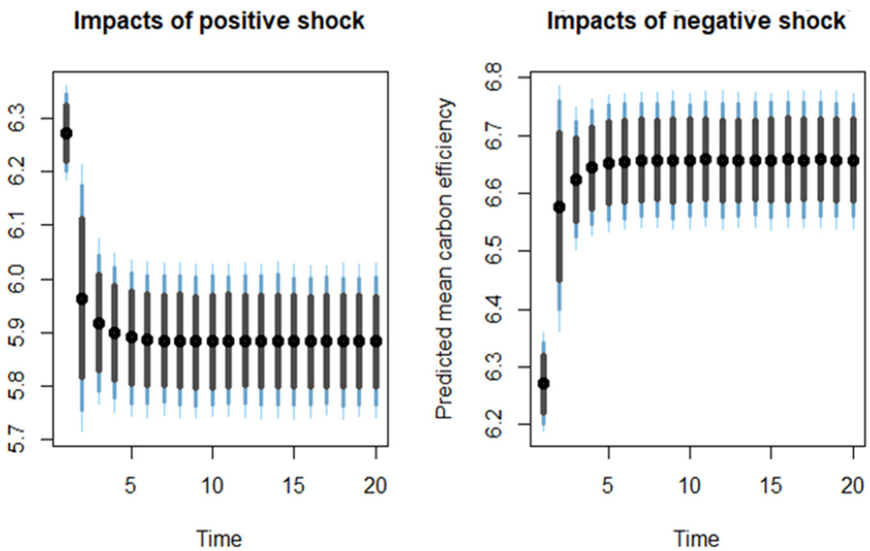

Fig. 3 Positive and Negative shocks of net zero emissions on sustainable development. A shock of ± 1% in net zero emissions and its role on sustainable development in the form of carbon efficiency.

Table 4 Results of diagnostic tests.

Tests	*p*-values
Breusch Godfrey Lagrange Multiplier	0.734
ARCH	0.480
Breusch Pagan Godfrey	0.372
Ramsey RESET	0.840
Jarque-Bera	0.739

encouraged to foster the development of comprehensive and integrated strategies for addressing climate change. The integration of various Sustainable Development Goals (SDGs) set by the United Nations is a common practice in theoretical research on sustainable pathways. This study investigates the correlation between the attainment of net zero emissions and the advancement of broader Sustainable Development Goals (SDGs), thereby illustrating the interdependence of various sustainability concerns. The understanding of why specific pathways are selected and the potential for their alteration is facilitated by the significant role played by the concept of path dependency. Theoretical contributions in this domain facilitate the elucidation of the historical, institutional, and technological determinants that exert an influence on the process of decision-making. In general, the theoretical contributions about sustainable paths towards achieving net zero emissions serve to enhance our comprehension of the intricate and diverse obstacles and prospects linked to the shift towards a sustainable, low-carbon trajectory. These theories serve as a foundation for both scholarly inquiry and practical decision-making in several domains.

The endeavour to achieve net-zero emissions encompasses a broader scope beyond being solely a strategy aimed at mitigating climate change (Ozkan et al. 2023; Zou et al. 2023; Tiwari et al. 2023). The aforementioned pathway serves as a means to attain the Sustainable Development Goals (SDGs) and foster a future that is both sustainable and resilient for all individuals. By actively pursuing the goal of achieving net-zero emissions, individuals and organizations can make a direct and meaningful contribution to the United Nations Sustainable Development Goal 13, which focuses on Climate Action. Moreover, this endeavour can also have indirect positive impacts on various other Sustainable Development Goals, such as SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 2

(Zero Hunger), and SDG 11 (Sustainable Cities and Communities), among others. Nevertheless, the attainment of net-zero emissions is not devoid of obstacles. The implementation of such changes necessitates substantial modifications in technological, economic, policy, and sociological domains. However, these constraints also give rise to chances for innovation, expansion, and the emergence of leadership. By embracing these opportunities, individuals and organizations may effectively address the difficulties and expedite the transition towards achieving net-zero emissions. As we progress, corporations, governments, and individuals must demonstrate their dedication to achieving net-zero targets. Business enterprises can achieve this objective by embracing sustainable methodologies, allocating resources towards renewable energy sources, and fostering the development of novel technology. Governments can achieve this objective through the implementation of policies and regulations that provide support, investment in sustainable infrastructure, and setting a precedent through their actions. Individuals can contribute to this cause by actively decreasing their carbon footprint, campaigning for climate action, and adopting sustainable choices in their day-to-day activities. In summary, the responsibility for shaping the future of sustainable development and climate action lies within our control. By actively pursuing the goal of achieving net-zero emissions, we have the potential to cultivate a future characterized by sustainability, resilience, equity, and inclusivity. The prospect of a future that can be transmitted to subsequent generations instils a sense of pride. Let us wholeheartedly embrace the challenge at hand, grab the available opportunities, and demonstrate unwavering commitment towards the attainment of net-zero emissions. The present moment necessitates immediate action.

Moreover, to ensure net zero emissions in this decade, South Asian economies should consider the following policies such as (1) deploying green energy technology like green technology innovations on an urgent basis to reduce global emissions towards net zero emissions. (2) Allocating a green budget for the energy sector and increasing funding for green energy development at all levels, especially for the local community welfare. (3) Supporting investment in green energy expansion and subsidizing the green energy market by establishing fiscal assistance plans and providing credit deductions on loans and tariffs. (4) Increasing the availability of credit as a priority sector and encouraging greater participation by commercial banks. (5) Utilizing a hybrid configuration of two or more resources, including conventional sources and storage devices, to achieve a reliable system. Regulatory authorities should formulate the necessary standards and regulations for hybrid systems. (6) Fostering awareness of green energy among communities and focusing on their social-cultural practices to promote sustainability. More likely, governments and associated stakeholders of selected countries should design some standing policies and strategies in line with reducing carbon emissions and ecological footprint via green innovations, eco-friendly products, pricing and marketing models. Additionally, active participation of local communities is detrimental to achieving net zero emissions and sustainable development as these are real and moral stakeholders, therefore, central, state and local government policies must be designed by keeping locals at the Centre of focus. Future research has the potential to enhance the existing literature in several ways. Firstly, this study has proposed sustainable pathways for selected South Asian economies, which could be extended to the entire region and utilized for comparative analysis. Secondly, although ARDL techniques have been employed and long and short-term price shocks have been identified, alternative techniques could be incorporated based on the research objectives. Thirdly, the study could be broadened by integrating the supply and demand aspects of green energy at the domestic level.

The pricing of green energy and the objective of attaining net-zero emissions are essential factors in advancing sustainable development and tackling worldwide issues associated with climate change and environmental deterioration. The concept of green energy pricing pertains to the financial valuation of electricity derived from renewable and low-carbon energy sources, including wind, solar, hydroelectric, and geothermal power. The objective is to enhance the economic competitiveness of clean energy sources, aiming to achieve cost parity or even cost superiority over fossil fuels. The cost of green energy carries several consequences for the advancement of sustainable development. By ensuring that clean energy becomes economically viable, there is a higher likelihood that both individuals and businesses will transition to renewable energy sources. This transformation serves to decrease the release of greenhouse gases, alleviating the effects of climate change and its negative consequences on both ecosystems and human societies. The green energy industry frequently facilitates the generation of employment opportunities, particularly in the domains of manufacture, installation, and maintenance of renewable energy systems. This phenomenon plays a significant role in fostering economic expansion and ensuring employment security, hence bolstering the pursuit of sustainable development objectives. The use of a variety of renewable energy sources that are domestically accessible contributes to the enhancement of energy security and diminishes reliance on imported fossil fuels. The implementation of this strategy has the potential to enhance the stability of energy markets and mitigate the susceptibility to price swings.

The green energy market and pricing are key factors in facilitating the transition towards a future characterized by net-zero emissions. An efficiently operating green energy market offers financial motivations for the generation and utilization of sustainable energy sources. Various mechanisms, such as feed-in tariffs, renewable energy certificates, and power purchase agreements, have the potential to incentivize and promote investment in projects related to renewable energy. The determination of pricing for renewable energy sources significantly impacts the decision-making process about investments. The decreasing cost of renewable technologies and their increasing competitiveness with conventional fossil fuels might incentivize a transition towards cleaner energy sources through market dynamics. The implementation of carbon pricing, such as the utilization of carbon taxes or cap-and-trade systems, serves to internalize the external expenses associated with carbon emissions. This creates a monetary motivation for both enterprises and individuals to decrease their carbon emissions and allocate resources towards more environmentally friendly solutions. In brief, the implementation of a robust green energy market and pricing mechanism has the potential to facilitate the shift towards achieving net-zero emissions. This can be accomplished by various means, such as stimulating the production of renewable energy, fostering innovation, internalizing external costs, ensuring market adaptability, attracting financial investments, and shaping consumer preferences. The strategy encompasses various dimensions; wherein economic incentives are harmonized with objectives of environmental sustainability. Policymakers, corporations, and consumers each have significant roles in influencing and engaging in these markets to attain a sustainable and environmentally friendly future with reduced carbon emissions. The establishment of sustainable pathways is of utmost importance in the pursuit of achieving net-zero emissions, as they offer a structured approach to making well-informed decisions and implementing policies that contribute to enduring environmental, social, and economic sustainability. Sustainable paths encompass a holistic approach to planning that incorporates diverse sectors, including energy, transportation, agriculture, and industry. The adoption of a comprehensive approach is needed to effectively discover and analyse the interconnections and compromises necessary to attain reductions in emissions throughout the entirety of the economy. Governments, corporations, and research institutions all have a significant role to play in establishing incentives that promote the advancement and widespread use of breakthrough technologies that are in line with sustainable trajectories. This may encompass the allocation of resources towards research and development, the provision of tax incentives, and the implementation of regulations that foster a conducive environment. In brief, sustainable pathways offer a systematic framework for attaining a state of net-zero emissions. This is accomplished through the facilitation of comprehensive planning, the stimulation of technology advancements, the provision of guidance for policy formulation, the promotion of circular economy principles, the cultivation of behavioural modifications, and the reinforcement of resilience. The successful implementation of these paths necessitates the establishment of collaborative efforts among governmental bodies, corporations, communities, and research institutions to develop a sustainable and resilient trajectory for the future.

Data availability

Data has been shared.

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Author contributions

ST: Data curation, software, data estimations, revisions. SB: Introduction, Literature analysis. TS: Discussion, Conclusion, supervision. US: Policy Implications, Revisions, Initial Draft and Resources.

Competing interests

All authors have approved and agreed with the submission to this journal. The current work has not been published and is not under consideration for publication elsewhere. Moreover, there is no conflict of interest for this study.

Ethical approval

The authors approved that this study has not involved any human participants, their data or biological material.

Informed consent

Other than authors, present study does not need any consent from elsewhere.

Additional information

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