


Adoption of Solar Energy Sources and Sustainable Performance for Environment in Power Sector of Pakistan: An Empirical Analysis Based on Mediation Model of Green Innovation

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ARTICLE INFO	ABSTRACT
<p>Article History: Received: December 12, 2025 Revised: January 25, 2026 Accepted: February 08, 2026 Available Online: February 20, 2026</p>	<p><i>The expression renewable energy has drawn considerable interest in recent years owing to the loss of certain energy assets from ongoing use and the pollution caused by fossil fuel usage. The present circumstances make the use of energy from renewable sources a complex process driven by many societal considerations. The purpose of the study is to look at the effect of solar energy adoption on the sustainable environmental performance of the general public sector in Pakistan. Furthermore, green innovation mediates the link of solar energy and sustainable environmental performance. The study used an empirical approach to gather data via a questionnaire administered to employees of grade 17 and above, including the upper management in the electricity industry. The data analysis of the research was carried out using the SPSS program to assess all hypotheses. The analysis's findings indicated that the deployment of solar energy enhances sustainable environmental performance. Also, green innovation plays a partly mediating function between solar energy and sustainable environmental performance. The investigation is crucial for government tasks and may be used extensively for the Pakistani power industry overall uses in business and industry, as well as for mitigating harmful emissions.</i></p>
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Introduction

The adoption of solar energy relates to the usage and embrace of green energy sources, such as solar power, in lieu of non-renewable resources like fossil fuels. Green innovation encompasses all forms of innovation that contribute to the development of critical goods, services, or operations focused on mitigating environmental hazards, impacts, and degradation, while maximizing the efficient use of renewable resources within the energy sector. Renewable energy is acquiring

relevance for politicians and decision-makers (Chu & Meisen et al 2011). Such innovations may play a pivotal role in today's setting by facilitating the optimal and effective usage of natural resources to enhance them for human well-being. Furthermore, such novel forms of creativity, innovation, and the integration of new alterations in items and manufacturing processes may facilitate sustainable development and environmental conservation.

Solar energy is also vital for keeping life on Earth. Solar energy is increasingly recognized as a viable alternative to oil and gas. It is considered to be an ecologically sustainable energy source since to its direct origin from solar radiation (Jäger et al. 2014). Solar energy is the most likely means of supplying projected energy needs in developing countries. Also, solar energy offers new jobs, reduces pollution, and improves environmental conditions (Kabiretal., 2018). In focusing on the adoption of renewable energy, sustainability is paramount as it caters for a shortage of conventional sources. This switch results to environmental enhancement through cost reduction, with efficient impacts for sustainable development (Said et al., 2022). The ongoing use of renewable energy technology might diminish carbon dioxide emissions and enhance public understanding of climate change implications (Kumar et al., 2020). Data analysis demonstrates that investments in clean energy sources boost environmental protection and facilitate energy conservation (Ganda et al., 2019). The study reveals a correlation of solar energy, green innovation, and sustainable environmental performance in the Pakistani public sector.

Literature Review and Hypotheses

Solar Energy Adoption and Environmentally Sustainable Performance

The majority of countries worldwide count on fossil fuels to produce and supply electrical energy. The finite accessibility of fossil fuels causes the discussion of renewable energy as an attractive substitute a prominent focus of current research in science. The use of renewable energy are growing more significant for policymakers, scientists, and other researchers (Chu & Meisen et al 2011). Based on figures from the Environmental Protection Agency, solar power is described as energy created by direct sunlight. Solar energy is also crucial to sustaining life on the Earth. Solar energy is increasingly being recognized as a viable alternative to oil and gas. It is considered to be an ecologically sustainable energy source since it is derived directly from the sun (Jäger et al. 2014). Solar energy is one of the most recognized sources of power globally, since advancements in solar technology have enabled the acquisition of electricity at competitive rates (Honrubia-Escribano et al., 2018). Solar photovoltaic (PV) technology is growing in popularity as an achievable choice for power generation. Solar energy is the most potential method for fulfilling future energy needs in nations that are emerging. In addition, solar energy provides additional jobs, reduces pollution, and boosts environmental conditions (Kabir et al., 2018).

According to Gisha (2017), fifty percent of Palestine's renewable energy stems from solar electricity, while the remaining fifty percent originates from bioenergy and other means. Solar photovoltaics is the leading strategy for achieving effective environmental sustainability in subsequent investments. Furthermore, due to Palestine's reception of considerable solar radiation, solar energy has contributed to alleviating energy poverty and boosting economic growth tied to the populace's quality of life (Hilal and Nassar, 2018). This renewable energy source is superior for some as it never produces solid or liquid garbage during operations. Though some dust and tiny pollutants may lower the efficiency of photovoltaic panels, periodic water usage is required for their maintenance to ensure optimal performance. Everyone perceives the environment as a widespread ecological problem today, and harnessing solar energy for electricity generation may drastically alleviate the results of carbon dioxide emissions on the environment. In light of that event, government ought to put in necessary precautions and adopt policies any assistance produced renewable energy and safeguards for the environment (Fayaz et al., 2022). There is a

deficiency in knowing the interactions of sustainable development and the use of renewable energy sources (Owusu and Asumadu Sarkodie et al., 2016).

Prioritizing the use of renewable energy is essential, as ecological sustainability serves as an essential element in compensating for the depletion of conventional sources. This shift contributes to ecological enhancement through cost reduction, thereby resulting in substantial advantages for the future (Said et al., 2022). The adoption of renewable energy technologies in developing nations has substantially improved job possibilities for the populace, stimulating sustainable social achievement while driving economic growth at an adequate rate (Arroyo and Miguel et al., 2020). The usage of renewable energy is also prevalent in ensuring environmental sustainability. It also reduces pollutant production and enhances network productivity (Franzitta et al., 2013). The ongoing use of renewable energy technology might diminish greenhouse gases emissions and enhance public understanding of climate change implications (Kumar et al., 2020).

The adoption of green energy technologies demands an aggressive focus on sustainability from both physical and economic perspectives, particularly due to the substantial costs associated with such devices (Garrido et al., 2020). Brodny and Tutak et al. (2020) assert that each nation globally are currently contributing to the usage of renewable energy sources as a means to enhance ecological sustainability. The adoption of renewable energy is vital for improving sustainable performance on all social, economic, and ecological aspects by addressing harmful emissions and stimulating beneficial economic development through the application of innovative technologies designed for renewable energy integration (Xu and Liu et al., 2019). A growing number of companies prioritize sustainability and involvement in the creation of energy from renewable sources by installing solar panels on their premises (Strielkowski et al., 2021). Ahn et al. (2020) demonstrated that organizations that can managing ecological sustainability may enhance their financial value and reduce waste by embracing renewable energy sources. The regular use of clean sources of energy is intended for sustainable aims. The substantial efficiency of energy generation significantly influences the modern techniques now in use. The use of energy from renewable sources can act as a robust strategy for sustainable development inside a nation. likewise, the use of green energy sources may be more advantageous for the environment and support growth by cutting energy prices.

H1: SEA has positive relative on ESP

Mediating of Green Innovation

The correlation between innovative green technologies and carbon emissions has been a significant subject of investigation, mostly divided into two research domains: The primary consideration is the helpful effects of green technology innovation in mitigating environmental changes and its positive influence on advancing technology via new energy solutions. Conversely, advancements in technology and research pertaining to investment opportunities may significantly decrease carbon emissions. Advancements in environmentally friendly technologies and environmental legislation have alleviated the effects of CO₂ emissions and bolstered environmental integrity. A plethora of studies have examined the relationship between technical progress and carbon emissions. The empirical findings have been inconsistent. Ganda et al. (2018) examined the environmental variables influencing the economies of the Organization for Economic Co-operation and Development (OECD) from 2000 to 2014. Statistical research demonstrates that investments in renewable energy sources bolster environmental protection and facilitate energy conservation. Ganda et al. (2019) evaluated the correlation between technological innovations (TI) and carbon emissions in OECD countries using the Generalized Method of Moments (GMM) from 2000 to 2014. Their results confirmed that technological progress greatly damages the environment and showed that OECD nations may improve environmental quality by investing in information

technology. The impact of public-private partnership investments in the energy and tech industries on China's consumption-based carbon emissions (CBE) from 1990 to 2017. The unit root testing used Generalized Least Squares (GLS) methods, whereas Maki co-integration tests and other models like FMOLS, DOLS, CCR, and FDC were applied in the study. The study's results illustrate the co-integrating relationships across elements, demonstrating a tendency towards an elevated level of CBE over time. Additionally, Fernandez et al. (2018) used the Ordinary Least Squares (OLS) method to analyze the impact of research and development (R&D) expenditures overall carbon dioxide emissions in the United States, the European Union, and China from 1994 to 2013.

Their study indicates that R&D spending are beneficial for mitigating emissions in the United States and the European Union. The escalating scientific and technological expenditures in China are leading to heightened carbon emissions. The empirical research approaches revealed that policymakers augmented expenditures on R&D, especially in the private sector and for governmental allocations, to foster innovative technologies, since new advancements successfully lessen environmental changes. The relationship between spending on research and development and the environment for 19 OECD countries from 2003 to 2015. Their analysis revealed three unique methodologies: STIRPAT, OLS, and GMM. The findings showed how R&D spending significantly influenced the reduction of CO2 emissions. This report argued that the restriction of energy R&D spending must be firmly enforced to decrease energy intensity and carbon emissions. (Kirikkaleli et al., 2023) advocated for eco-friendly technologies which promoted the decrease of greenhouse gas emissions in Denmark.

H2: The SEA has positive relative on GI

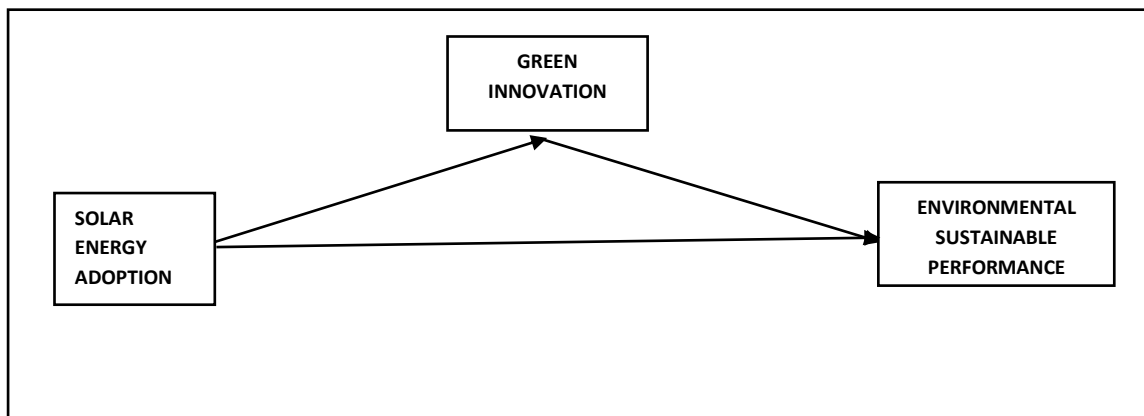
H3: The GI has positive relative on ESP

H4: SEA has positively mediated on ESP through GI

Table. 2.1: Variables

Variables of Research Model	
Solar Energy Adoption	Independent Variable
Green Innovation	Mediator
Environmentally Sustainable Performance	Dependent Variable

Figure 2.1: Conceptual Model



Methodology

The study investigates the influence of solar energy on the sustainable environmental performance of Pakistan's public sector. It also includes a single mediator: the use of green innovation. The queries addressed in English were basic for personnel of grade 17 or above. The surveys were administered to individuals employed in government-owned enterprises in Pakistan. Initially, 550 questionnaires were given out, however only 350 were returned. The complete questionnaire has 19 questions encompassing population density, solar energy, sustainable environmental performance, and green innovation. Demographic data including elements that involve gender, age, marital status, and level of education. The methodological ways and analysis techniques are derived by past studies on energy sector and multi-disciplinary papers conducted by (F, Saddique & N, Mushtaq et .al, 2020 to 2026).

Table.3.1 Variables, No. of Items, Sample Items and Reference

Variables	Item	Variables Measured By
Solar Energy Adoption	5	El-Khozondar, H et al., 2018
Green Innovation	6	Saleh, Yahya et al., 2023
Environmental Sustainable Performance	4	Saleh, Yahya et al., 2023

Table: 3.2. Sample Distribution

	Characters	F	%
Gender	Male	308	88
	Female	42	12
Ages	16-25	82	23.4
	26-35	122	34.9
	35-45	95	27.1
	46-55	51	14.6
Education	Bachelor	49	14.0
	Master	60	17.1
	M.Phil	143	40.9
	Ph.D	87	24.9
	Other	11	3.1
Marital Status	Married	167	47.7
	Single	183	52.3

Explanation: According to above Table 3.2, the total of respondents to the questionnaires was 550, of which 350 were collected in which, male is 308 (88%) and female are 42 (12%). The respondents' age was classified into four groups. The majority of respondents were between the age of 26 and 35 years 122 (34.9%), followed by 46-55 years 51 (14.6%) and below 25 years 82 (23.4%). The other participant's ages were between 35-45 years, 95 (27.1%). Based on the qualification, its category is in four groups, in which the majority of the respondents were M.Phil. 143 (40.90%) and a small number other (3.11%). Based on marital status married are 167 (47.7%) and single are 183 (53.3)

Table 3.3 Reliability Analysis

Variable	No of Items	Cronbach's Alpha
Solar Energy Adoption	5	0.836
Green Innovation	6	0.868
Environmental Sustainable Performance	4	0.767

Explanation: The reliability test of each scale was examined using Cronbach's alpha. See table 3.3. All the above values are higher than 0.70, which indicates that the measurements were accurate and acceptable enough for future research.

Correlation Analysis: Pearson Correlation analysis is used to assess stable associations and examine techniques for dependency between two sums. Estimates of connectivity range from negative one to positive. They consider -0.5 to -0.3 and 0.3 to 0.5 is shown a straight and high association. furthermore, -0.3 to -0.1 and 0.1 or 0.3 is low/delicate shown association. When the connection of the estimate is zero, it means no link between factors.

Correlation Analysis Table:

Table 3.4 Correlations

		AGE	GENEDER	EDUCATION	MARITAL STATUS	M_SEA	M_GI	M_ESP
AGE	Pearson Correlation	1	.123*	.072	.623**	-.023	-.006	-.088
	Sig. (2-tailed)		.022	.177	.000	.674	.908	.102
	N	350	350	350	350	350	350	350
GENEDER	Pearson Correlation	.123*	1	.094	.035	-.067	-.082	-.066
	Sig. (2-tailed)	.022		.080	.520	.211	.124	.220
	N	350	350	350	350	350	350	350
EDUCATION	Pearson Correlation	.072	.094	1	.003	.048	-.072	-.073
	Sig. (2-tailed)	.177	.080		.949	.370	.177	.170
	N	350	350	350	350	350	350	350
MARITAL STATUS	Pearson Correlation	.623**	.035	.003	1	-.077	-.061	-.155**
	Sig. (2-tailed)	.000	.520	.949		.152	.257	.004
	N	350	350	350	350	350	350	350
M_SEA	Pearson Correlation	-.023	-.067	.048	-.077	1	.404**	.125*
	Sig. (2-tailed)	.674	.211	.370	.152		.000	.019
	N	350	350	350	350	350	350	350
M_GI	Pearson Correlation	-.006	-.082	-.072	-.061	.404**	1	.168**
	Sig. (2-tailed)	.908	.124	.177	.257	.000		.002
	N	350	350	350	350	350	350	350
M_ESP	Pearson Correlation	-.088	-.066	-.073	-.155**	.125*	.168**	1
	Sig. (2-tailed)	.102	.220	.170	.004	.019	.002	
	N	350	350	350	350	350	350	350

*. Correlation is significant at the 0.05 level (2-tailed).

** . Correlation is significant at the 0.01 level (2-tailed).

Explanation:

In Table 3.4, illustrates the association between factors in this study. Solar Energy Adoption is significantly and correlated with green innovation ($r=0.404$, $p=0.00$), and green innovation is moderately and significantly correlated with environmentally sustainable performance ($r=0.168$, $p=.000$), In addition, the association between environment sustainable performance is strong and statistically significant ($r = 0.125$, $p =.000$).

Regression Analysis:

Table 3.3.1. Model between SEA and ESP

Variable	R ²	B	t	Sig
SEA	0.016	0.118	2.356	0.010

Dependent Variable: ESP. *p < 0.05.

Explanation: In table 3.3.1, demonstrates the basic regression analysis performed to determine the impact of solar energy on environment sustainable performance. The model is fit since the ANOVA sig value is $0.00 < 0.05$. The R-squared value of 0.016 indicates that a one-unit change in solar energy will result in a 1.6% difference in sustainable environment performance. Hence, hypothesis 1 is supported.

Table 3.3.2. Model between SEA and GI

Variable	R ²	B	t	Sig
SEA	0.163	0.398	8.245	0.000

Dependent variable: GI, *p < 0.05.

Explanation: Table # 3.3.2. displays the basic regression analysis performed to determine the impact of solar energy on green innovation. The ANOVA sig value is $0.00 < 0.05$, showing the appropriate model. The R-squared value of 0.163 indicates that a one-unit change in solar energy will result in a 16.3% difference in green innovation. The coefficient's sig value is.000. Hence, hypothesis 2 is accepted.

Table 3.3.3. Model between GI and ESP

Variable	R ²	B	t	Sig
GI	0.028	0.155	3.173	0.002

Dependent Variable: ESP, *p < 0.05.

Explanation: Table 3.3.3 displays the basic regression analysis performed to determine the impact of green innovation on sustainable environmental performance. The ANOVA sig value is $0.00 < 0.05$, showing the appropriate model. The R-squared value of 0.028 indicates that a one-unit change in green innovation is result in a 2.8% difference in environmental sustainable performance. The coefficient's sig value is.000. Hence, hypothesis 3 is accepted

Mediation Analysis:

Table 3.5.4: Mediation analysis using through Bootstrap

Relationships	β	P	Bootstraps @		Hypotheses
			95% LL	UL	
<i>SEA → GI → ESP</i>					
Direct effect	0.065	***	0.05	0.178	
Indirect effect	0.129	***	0.24	0.231	

Note: SEA=, GI=, ESP=, ***p<0.01

Explanation: The variable mediating hypothesis was evaluated using 1000 bootstraps with a confidence range of 95% and with upper and lower limits established. The role of green innovation as a mediator associated between solar energy and sustainable environment performance, the indirect effect (0.129, LL = 0.24, UL = 0.231, P 0.01) was smaller than the direct consequence ($\beta = 0.065$, P 0.01), and there was no “0” value between upper and lower limits, therefore, Hypothesis H4 is accepted.

Discussion

At the conclusion of the research, the following main suggestions are summarized to tackle the challenges within the energy sector and the impact of adopting renewable sources on the environmental sustainability performance of the energy sector. Three distinct time frame policies have been addressed in the "Way Forward" section. It is vital for implementing short-, medium-, and long-term policy actions in their genuine form. A renewable adoption regulatory is suggested, it would oversee the execution of all short-, medium-, and future policy issues. It is essential to cultivate a culture for the adoption of renewable energy sources within the general sector of power generating. The bureaucratic obstacles in this process must be eradicated, since they unnecessarily extend the workflow.

The use of renewable sources necessitates the cessation of power theft, and actions must be implemented for the complete recovery of overdue and continuing income. One component of the trillions of rupees in circular debt is electricity theft inside the grid. The rapid establishment of a "circular debt retirement fund" is essential to solve the critical issue of circular debt. Funding may be provided by financial institutions or a consortium with federal government guarantees. Subsidies impose a significant burden on treasuries and must be eliminated entirely via the implementation of short-term and medium-term initiatives. Disputes between the federal and provincial governments must be handled, and political agreement must be established, particularly with renewable projects. The proportion of renewable energy sources must be augmented in the energy mix, and more resources should also be harnessed. We must investigate the extensive solar belt and accessible wind corridors for increased generation of power.

Regional coordination must be improved, and existing agreements such as the TAPI, Pak-Qatar, and Iran-Pakistan energy projects need completion. The existing structure of the energy power industry is very complicated, resulting in unnecessary obstacles. It is necessary to consolidate several renewable energy ministries and authorities into a single ministry to enhance operational efficiency. Upgrading the existing transmission and distribution network for renewable energy sources is necessary to reduce inefficiencies. The fundamental problem is in line losses, as the increased generation in the power sector fails to reach end customers due to the inadequacy of the

present transmission infrastructure. In the energy industry, public-private partnerships should be strengthened, particularly in the renewable energy domain. The inadequate security conditions at renewable energy producing sites need improvement, particularly for new extraction and exploration activities. New renewable energy generating projects must be developed and performed alongside current power projects, all of which need to be completed within the designated timeframe.

This research is distinctive in nature. This research investigates the determinants influencing energy power production and its role in the economic development of Pakistan. The research assists in identifying issues related to the adoption of renewable energy production from solar and wind sources operating in Pakistan. This research addresses the information gap about possible issues in the extensively discussed renewable energy generating sectors and their impact on the sustainable environment and economic development of the nation. Significantly, a comprehensive analysis has never been undertaken in the renewable power generating industry in Pakistan. The study's results, suggestions, and policy contributions may significantly enhance the current literature, particularly in the domain of Renewable Energy Finance and Renewable Energy Economics. The whole framework of the research is very beneficial for policymakers, energy industry specialists, and stakeholders in both government and commercial sectors in their short-, medium-, and long-term planning.

The model developed for analyzing hurdles in each renewable energy source will provide policymakers with a novel perspective on the challenges of power production in the country. This investigation will also provide substantial support for the optimal energy mix equation. The research is very beneficial for industries, enterprises, households, and individual customers. The paper further presents methodological insights for future research. The comprehensive survey questionnaire developed for the study, together with the conceptual research framework defined, has not been before used and may enhance the current body of knowledge. A comprehensive and methodical analysis of the energy sector's challenges and obstacles has been presented using statistical models that have not been before investigated. By tackling the issues mentioned in each energy generating sector, energy emergencies may be mitigated by increased power production from the relevant sources.

The study findings may contribute to the financial sustainability of the nation's economy. The research indicates that the nation's energy power production is hindered by many issues, and if they are adequately handled, the energy crisis may be mitigated or managed to a tolerable extent.

Conclusions

It is important to explicitly acknowledge future research deficiencies after the completion of the present study. The research focuses on the production of energy from renewable resources and the related challenges within the energy sectors. The study examined sustainable power generating sources, energy production, and their correlation with environmental sustainability performance in the Pakistani power industry. Various models have been investigated that may be applicable for testing in other developing nations. The potential for energy production from tidal sources remains largely unexplored. The research might be expanded to examine the possibilities of energy production from other renewable sources on the sustainable economic growth of Pakistan.

The study may be broadened by include several sectors, such as the services industry, to get complete results. The research findings may also be validated by testing them in other developing nations. This research has highlighted numerous elements that might affect the adoption of renewable energy sources in Pakistan's environmental sustainability performance within the electricity industry. Nevertheless, supplementary elements, like the perceived utility of the

payback time for renewable energy sources (RES) and the potential negative effects of RES, may have been identified and included into the model of this research. This study did not account for characteristics such as industry type, business experience, size, and other moderating factors related to renewable energy sources and environmental sustainability performance. Furthermore, the potential effect of this on the interactions across coexisting paradigms is an intriguing study subject for future investigations.

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