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The influence of renewable and non-renewable energy on carbon emissions in Pakistan: evidence from stochastic impacts by regression on population, affluence, and technology model

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Like other developing countries, Pakistan faces one of the most serious challenges of how to mitigate carbon emissions while achieving sustainable development. Although, it is widely accepted that the rising trend of carbon emissions and the resulting negative effects of climate change on human activities have emerged as major issues in recent years, the environmental effectiveness needed to clean the environment and promote sustainability is often overlooked. Using the PLSM 2018–2019 survey, this study attempts to examine the household sector's renewable and non-renewable energy usage magnitude, and the share of renewable and non-renewable energy in Pakistan. Furthermore, this study examines the impact of income, household size, biomass, non-renewable energy, and clean energy on carbon emissions using the STIRPAT model. It is obvious from the empirical findings that the coefficient of income is positive, whereas the coefficient of income square is negative and statistically significant, which indicates that carbon emissions in the household sector increase at lower income levels, while decreasing as income increases. The household size shows that the population has a positive impact on carbon emissions. The impact of biomass, non-renewable, and clean energy is particularly appealing, as the household sector consumes more biomass and non-renewable energy, which stimulates carbon emissions to rise. In the rural sector, clean energy has a negative but statistically insignificant impact on carbon emissions, showing a greater reliance on biomass and non-renewable energy consumption. Lastly, it is suggested that reducing the use of non-renewable energy in the household sector while increasing the use of green energy could be a policy option for making the environment clean and sustainable.

KEYWORDS

renewable energy, non renewable energy, carbon emissions, STIRPAT, Pakistan

Introduction

Because of human influence on the natural environment, global surface temperature is rising at an unprecedented rate (Intergovernmental Panel Climate Change (IPCC, 2021). In recent decades, environmental degradation caused by greenhouse gases (GHGs) has been an essential issue in the global environmental debate (Seetanah et al., 2018; Işık et al., 2019; Amin et al., 2020a; Amin et al., 2020b; Amin et al., 2021a; Amin et al., 2022; Destek et al., 2022; Mitić et al., 2023; Ongan et al., 2023; Pata and Kartal, 2023; Simionescu et al., 2023). Carbon dioxide (CO_2) emissions account for about 75% of GHGs emissions and are a major determinant of global warming and other climatic extremes (Abbasi and Riaz, 2016; Amin et al., 2020a; Yousaf et al., 2022; Abbas et al., 2023). The major changes in the climatic system, such as the increasing intensity and frequency of hot extremes, heatwaves, precipitation, agricultural and ecological degradation, intense tropical cyclones, and the reduction of arctic ice cover, are posing an existential threat to the earth's ecosystems and biodiversity. The current IPCC, 2021 climate scenarios show that global warming will exceed 1.5°C–2°C during the twenty-first century unless serious efforts are made to mitigate CO_2 emissions and other GHGs emissions. Moreover, the rising global temperature and extreme heatwaves are deteriorating the productivity of food crops and increasing global food insecurity (Destek and Aslan, 2020; Okumus et al., 2021; Ameer et al., 2022; Ali et al., 2023; Bakry et al., 2023). The United Nations is stressing the adoption of the seventeen Sustainable Development Goals (SDGs) agenda for 2030, proposed in September 2015, to address the most pressing economic, environmental, and climatic issues in a more sustainable way. In line with the SDGs agenda, the United Nations is urging the adoption and development of green production technologies that can enhance overall productivity while reducing dependence on fossil fuels, which is a major source of CO_2 emissions. Moreover, the environmental concentration of CO_2 emissions has reached its highest level of 412.5 parts per million in 2020 (International Energy Agency, (IEA, 2021). Emerging markets and developing countries are the major contributors to CO_2 emissions, accounting for more than two-thirds of the global emissions (Aziz et al., 2020; IEA, 2021; Kartal et al., 2023; Ramzan et al., 2023). The most important contributor to CO_2 emissions is the consumption behavior of households, which is responsible for almost 72% of global greenhouse gas emissions (Dubois et al., 2019). Moreover, the adoption of green energy and technology at the household level can be the most effective policy intervention to achieve the sustainable economic growth plan as proposed by the United Nations.

Globally, Pakistan is the fifth most populous country, with more than 216.5 million people in 2019 and a total land area of 796,095 km_2 (Işık, 2010; Yousaf et al., 2021). Moreover, the current projection of the United Nations Population Division shows that the population could grow by more than 403 million by 2050. More than 60% of the total population lives in rural areas, where improving their living standards is extremely difficult. The lower *per capita* income along with higher energy prices induce rural households to use firewood (67% of total energy), dang cake biomass (26%), liquefied petroleum gas (12%), kerosene (2%), and coal (0.3%) for cooking, and heating. Similarly, firewood (67%) is preferred by urban households, followed by liquefied petroleum gas (18%), dang cake (13%), kerosene (1%), and coal (0.5%) (Pakistan Social and Living Standards Measurement (PSLM, 2018-19). It implies that firewood is the major source of energy for domestic households, especially rural households, for heating and cooking purposes, followed by dung cake. The major problem with the excessive demand for firewood is that it is responsible for massive deforestation and the destruction of forest ecosystems and biodiversity. Moreover, the burning of firewood and dung cake are major sources of CO_2 and sulfur dioxide (SO_2) emissions that have a greenhouse effect on the environment and severe health complications for exposed households. This argument is validated by the report of the World Air Quality Report (IQAir, 2021), which ranked the air quality of Pakistan as the second most polluted. To reduce dependence on firewood and other greenhouse gas emissions, attempts should be made at the household level to diversify energy toward clean renewable energy generated by solar power, wind power, and tidal power.

Pakistan's household sector, like other developing countries, uses both modern (for instance, electricity, gas, oil, and solar energy) and traditional (for example, firewood, dang cake, and agricultural leftovers) energy sources (Işık, 2010; Moeen et al., 2016; Işık et al., 2018; Aziz et al., 2020; Fakher et al., 2023). Electricity is used for lighting in rural houses, while it is used for lighting, cooling, cooking, and heating in the urban household sector. Only 58.65% of rural households have access to electricity, and households in the urban sector will have 100% access to electricity in 2019 (World Bank, 2021). In comparison to the industrial and commercial sectors, the percentage of energy consumption in the household sector has climbed significantly from 38.07 percent in March 2019 to 44.90 percent in March 2020, while the agriculture sector has experienced a fall. In terms of LPG usage, the household sector utilized 445,496 tons in 2019, with Punjab being the most significant consumer with 212,360 tons, followed by Khyber Pakhtunkhwa with 72,874 tons (Pakistan Economic Survey, 2019). According to the International Renewable Energy Agency (2021), traditional biomass energy is used by 105 million Pakistanis, with a volume of 8.2 Mtoe in 2015. Rural households use traditional energy sources more than urban households for cooking and heating. Because of its accessibility and affordability, firewood is the most common energy source for rural households (Jan et al., 2012; Moeen et al., 2016; Yousaf et al., 2021). However, 77% of households rely on firewood and dung cake energy sources (Yousaf et al., 2021). According to the World Bank (2021), Pakistani energy consumption in 2014 was 460.23 kg of oil equivalent (kg) per person, which was significantly higher. In Pakistan, people use a wide range of non-renewable and biomass energy sources at the household level. Yet, the carbon emissions from Pakistan's household sector's usage of non-renewable and green energy sources have not been properly investigated. There is relatively rare literature available on households (clean and non-renewable) energy use and related carbon emissions; only a few researchers (for instance, Rahut et al., 2019; Marzano et al., 2018; Işık et al., 2017; Adeyemi and Adereleye, 2016; Özcan et al., 2013; Chun-sheng et al., 2012; Nansaior et al., 2011) examined the rural-urban household's use of energy and its linkage with carbon emissions. The earlier studies did not take into account the magnitude of carbon emissions from clean and non-renewable energy sources, as well as income and

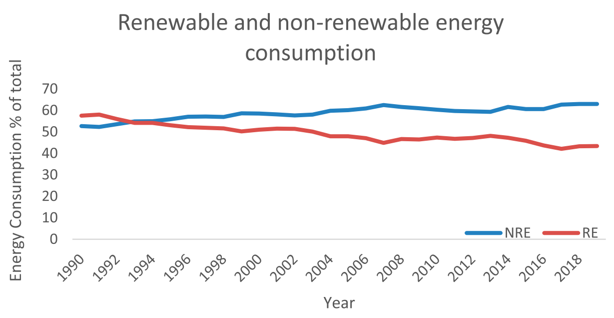

FIGURE 1
Renewable and non-renewable energy consumption in Pakistan (1990–2018).

clean energy, as factors influencing non-renewable and biomass energy choices in Pakistan. In addition, this research also examines the effects of income, family size, and clean energy on household sector choices for biomass and non-renewable energy sources by employing the STIRPAT model and accordingly proposes better policy implications based on the findings of the study. Furthermore, by using the Pakistan Social and Living Standards Measurements (PSLM, 2018–2019) survey, this study adds to the existing literature by exploring the household sector's biomass and non–renewable energy consumption magnitude as well as how much carbon is emitted from biomass and non-renewable energy sources in Pakistan. As it is obvious from Figure 1 that the share of non-renewable energy consumption is higher than that of renewable energy consumption, this situation is deemed harmful not only for human well-being but also for sustainable development. In addition, various models have been utilized in the literature for identifying the drivers of household sector energy consumption; for example; Azam and Ahmed (2015); Baiyegunhi and Hassan (2014); Mensah and Adu (2015),; Rahut et al. (2019) used multinomial logit; Irfan et al. (2018); Ngui et al. (2011) utilized a linear approximate almost ideal demand system; Chen et al. (2006); Damette et al. (2018) employed energy demand of utility maximization; Han et al. (2018) used a dynamic panel regression model; Heltberg (2005) used Engle curve; Huebner et al. (2016) used the regression model;; Wang and Yang (2019) used the STIRPAT model. In this study, we employ the stochastic impacts of regression on population, affluence, and technology (STIRPAT) model, which has several advantages over other methods, including simple model modification, partitioning and inclusion of indicators, and straightforward interpretation of results (Dietz et al., 2007; Hayden and Shandra, 2009; Zhou and Li, 2020).

The utilization of renewable or clean energy and taking substantial steps to prevent climate change's negative effects by the government will definitely promote sustainable development and a clean environment worldwide. More than 100 renewable and clean energy projects have been approved to achieve energy security, reducing reliance on non-renewable and dirty energy usage (Pakistan Economic Survey, 2019). According to the International Renewable Energy Agency (2018), major steps have been taken to provide clean energy to the household sector and lower dependence on non-renewable and biomass energy in rural areas. In this regard, solar home systems were established in 7,000 villages in Sindh and Balochistan, and 356 micro-hydropower projects were started in Khyber Pakhtunkhwa.

One thing that is evident from the debate above is that the Pakistani government is attempting to shift household energy usage away from dirty energy and toward renewable and clean energy sources. Yet, the impact of renewable and non-renewable energy use on climate change for rural and urban households has been overlooked in the existing literature. Similarly, the impact of biomass, non-renewable energy, and clean energy on carbon emissions at the household level in Pakistan has not been estimated. The literature on household sector energy consumption and associated carbon emissions is minimal, and the study of Yousaf et al. (2021) for Pakistan (at the aggregate level) has attempted to quantify it. Using the PSLM, 2018-19, this study adds to the existing literature by analyzing biomass and non-renewable energy; users of different sources of biomass and non-renewable energy; and associated carbon emissions for rural and urban households in Pakistan. In addition, this study evaluates the impact of income, household size, biomass, non-renewable, and clean energy on carbon emissions using the stochastic (ST) estimation of environmental impacts (I) by regression (R) on population (P), affluence (A) and technology (T) (STIRPAT) model.

Regarding the findings of the study, the coefficient of income is found to be positive, while the coefficient of income square is negative and statistically significant, which demonstrates that the household sector's carbon emissions increase at lower income levels, while decreasing as income increases. Furthermore, the household size indicates that the population has a direct influence on carbon emissions. While the impact of clean and non-renewable energy is particularly appealing, the household sector utilizes more clean and non-renewable energy, which ultimately causes environmental pollution (Kamran et al., 2023). In the rural sector, it is found that clean energy has an indirect and statistically insignificant impact on carbon emissions, demonstrating much reliance on biomass and non-renewable energy sources. Finally, it is suggested that increasing the utilization of clean energy and reducing the use of fossil fuels in the household sector could be a policy option for making the environment more sustainable.

In light of the above discussions, the first motivation of the present study is to explore the household sector's magnitude of renewable and non-renewable energy usage, and the share of renewable and non-renewable energy in Pakistan by using the PLSM 2018–2019 survey. Previously, researchers examined the economic and non-economic factors of environmental quality, such as, natural resources (Bekun et al., 2019; Danish et al., 2019; Joshua and Bekun, 2020; Farooq et al., 2023); financial development (Al-Mulali et al., 2015; Abbasi and Riaz, 2016; Amin et al., 2020a; Sadiq et al., 2022); foreign direct investment (Peng et al., 2016; Zhang and Zhou, 2016; Nguyen et al., 2021); trade (Farhani and Ozturk, 2015); globalization (Sadorsky, 2014; Destek, 2020); population (Begum et al., 2015; Mohsin et al., 2019). None of these studies examined the impact of income, household size, biomass, non-renewable energy, or clean energy on carbon emissions. The second motivation of the present study is to use stochastic (ST) estimation of environmental impacts (I) by regression (R) on population (P), affluence (A) and technology (T) (STIRPAT) model. Previously, several other common models

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have been employed to identify the determinants of household sector energy consumption. For instance, the multinomial logit model was employed by Azam and Ahmed (2015); Baiyegunhi and Hassan (2014); Mensah and Adu (2015),; Rahut et al. (2019); the linear approximate almost ideal demand system was utilized by Irfan et al. (2018); Ngui et al. (2011); the energy demand of utility maximization model was used by Chen et al. (2006); Damette et al. (2018); the dynamic panel regression model was employed by Han et al. (2018); while the regression model was used by Huebner et al. (2016). The motivation behind employing the STIRPAT model is threefold, for instance, it has easy model modification, variable partitioning, and interpretation of results. The third motivation for this study is that it focuses on Pakistan. Increased carbon emissions from the household's use of non-renewable and biomass energy have been assessed for a number of countries (see, for example; Soltani et al. (2019) for Iran; Goldstein et al. (2020) for the United States; Sinha and Shahbaz (2018) for the G-7 nations;; Xu et al. (2017) for China). Pakistan is an agricultural country, and biomass is a significant energy resource with a high potential for energy production. Agricultural leftovers, animal waste, municipal solid waste (MSW), and forest residues are all examples of the biomass resources generated in the agriculture, livestock, and forestry industries. Pakistan has started a number of initiatives for environmental sustainability, including the eco-system restoration initiative, the carbon market initiative, the clean green cities index, the clean green Pakistan movement, the ten billion trees tsunami program, seasonal tree planting campaigns, and the reduced emission from deforestation and forest degradation scheme. Due to these reasons, it is important to investigate this issue in Pakistan, which was previously ignored. The remainder of the study is organized as follows: Section 2 discusses the literature review. Section 3 discusses materials and methods, while Section 4 discusses results and discussions. The last section concludes the whole study with policy implications. Figure 2.

Literature review

Energy consumption and carbon emissions

In recent eras, the significance of energy consumption cannot be denied, as it is considered the backbone of the development of an economy and the source of social wellbeing in a country. Previously, Asumadu-Sarkodie and Owusu (2017) investigated the relationship between energy consumption, economic growth, and environmental quality in Senegal. Their findings demonstrate that energy consumption significantly increases pollution, while income has a detrimental effect on the environment. They suggested that the use of green energy may improve environmental quality. Saboori et al. (2017) investigated the relationships amid oil usage, income, and carbon emissions for three Asian countries during the period 1980–2013. According to their findings, China and Japan showed one-sided causality from oil consumption to economic growth, whereas South Korea's oil use is a main contributor to CO_2 emissions. Sulaiman and Abdul Rahim (2017) explored the relationship between energy use, income, and environmental degradation in Malaysia over the period 1975–2015. The findings showed that energy consumption and GDP contribute to increased CO_2 emissions.

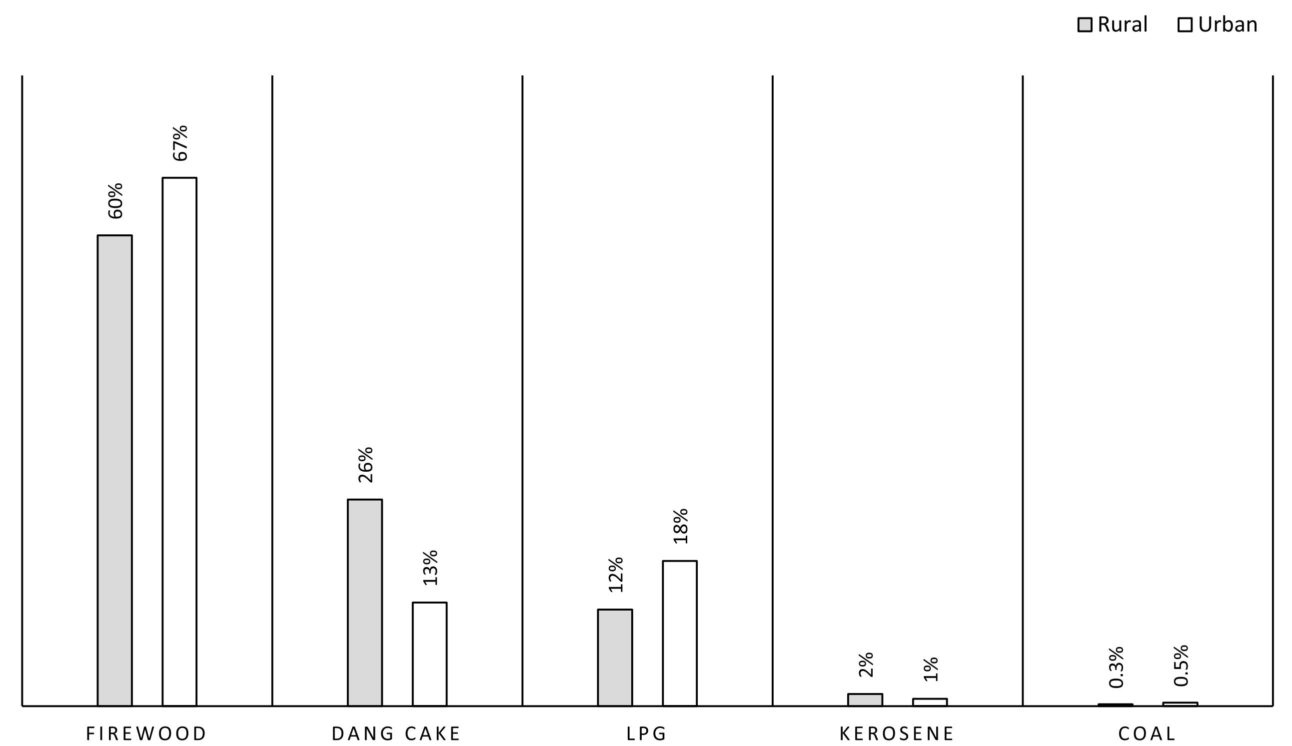

FIGURE 2
Users with different energy preferences in Pakistan (PSLM 2018-19 dataset).

Renewable and non-renewable energy consumption and carbon emissions

The utilization of green and renewable energy contributes to the environment's future safety. Additionally, it is crucial for sustainable development, which is only achievable with contemporary sources of energy. Shahbaz et al. (2012) found one-way causation from economic growth to carbon emissions, whereas energy consumption increases carbon emissions in the short and long term. They argue that green energy is required as an input to sustain economic growth, but that in Pakistan, all sectors are heavily reliant on dirty energy, resulting in rising carbon emissions. For 10 MENA countries, Farhani and Shahbaz (2014) examined the relationship between output, utilization of energy produced from green and non-green sources, and environmental pollution. They came to the conclusion that both green and non-green sources of electricity significantly contribute to stimulating CO_2 emissions. By utilizing data from 11 South American economies, Apergis and Payne (2015) found similar findings. For newly industrialized economies, Destek (2016) examined the linkage among clean energy use, and economic growth during 1971–2011. In his study, he focused on investigating the correlation among direct and indirect shocks of indicators. According to the findings, indirect shocks in clean energy usage cause direct shocks in *per capita* income in Mexico and Africa, whereas indirect shocks in clean energy usage cause indirect shocks in *per capita* income in India. Liu et al. (2017) investigated the relationship amid renewable energy, non-green agriculture, and environmental pollution in the BRICS economies. The investigation's findings proved that green energy contributes negatively to environmental degradation. Moreover, by utilizing the Toda Yamamoto econometric approach, Khan et al. (2018) found that the utilization of green energy considerably mitigates environmental pollution in Pakistan. According to the study's findings, the government should use more green energy in order to lower CO_2 emissions. Bhat (2018) found similar results for the BRICS economies over the period 1992–2016. His empirical findings demonstrate that using green energy may improve environmental quality in a country, so he suggested that the BRICS countries' policymakers implement such energy policies to promote sustainable development. For G-7 economies, Destek and Aslan (2017) studied the linkage among clean energy use, economic growth, and climate change from 1991 to 2014. In their study, they mainly focused on solar, wind, solar biomass, and hydroelectricity energy use. They found that the use of renewable energy sources contributes to cleaning the environment and promoting sustainable development around the globe. In addition, they found that hydroelectricity is the most effective type of renewable energy to diminish environmental contamination in sampled nations. Usman et al. (2022) investigated if nuclear and renewable energy reduce environmental pollution in Pakistan by employing the NARDL approach. Their analysis suggests that indirect variations in nuclear energy degrade the environment, while direct or indirect variations in clean energy significantly improves the quality of climate. They suggested to enhancing the utilization of nuclear and clean energy sources in Pakistan to promote a sustainable and clean environment. Abbasi et al. (2022) investigated the linkage among GDP, carbon emissions, and green and non-renewable energy from 1980–2018 by employing NARDL approach. Based on observations, energy production from fossil fuels significantly increases both long- and short-term CO_2 emissions; while using renewable energy sources temporarily increases CO_2 emissions. Their findings suggest that switching to renewable energy sources is critical to meeting environmental sustainability objectives and deters the use of fossil fuels. Furthermore, numerous studies have found no relationship between green energy and environmental degradation. For instance, for 25 OECD countries, Jebli et al. (2016) found no significant relationship between the use of green energy and CO_2 emissions. Bento and Moutinho (2016) failed to find any significant relationship between energy production from renewable sources and CO_2 emissions in Italy. For Thailand, Bootome et al. (2017) explored an unbiased correlation between environmental pollution and the use of renewable energy sources during the period 1971–2013. According to Saidi and Mbarek's (2016) analysis, there is no causal relationship between the use of green and nuclear energy in nine developed economies over the period 1990–2013. Riti et al. (2017) investigated the link between CO_2 emissions, financial development, and energy consumption in China. The study's findings showed that the Environmental Kuznets Curve's (EKC's) turning point was irregular; this irregularity can be attributed, among other things, to different variable selections and data sources used in separate analyses. In Greece, Isik et al. (2017) found that economic growth contributes to environmental degradation; Destek and Aslan (2017) studied the correlation among clean non-renewable energy usage for emerging nations from 1980 to 2012. They found that environmental measures aimed at reducing non-renewable energy usage may have a positive influence on enhancing economic growth in emerging economies. For the G-7 economies; Cai et al. (2018) investigated the relationship between green energy, economic growth, and carbon emissions. Out of seven countries, the authors only discovered cointegration in two (Japan and Germany). Furthermore, in Tunisia, Cherni and Jouini (2017) found that green energy can be utilized as an alternative to conventional energy to reduce CO_2 emissions. Furthermore, by examining the linkage among green and non-renewable energy usage, trade, economic growth, and ecological footprint, Destek and Sinha (2020) found that switching to clean energy sources improves environmental quality, whereas the usage of non-renewable energy has a detrimental influence on the environment. For G7 economies, Okumus et al. (2021) studied how renewable and non-renewable energy usage affect economic growth. They concluded that both indicators positively affect economic growth, but non-renewable energy use has a more significant effect on fostering economic growth as compared to the clean energy. The existing studies regarding CO_2 emissions and the household sector's energy consumption are summarized in Table 1. To the best of our knowledge, there is a dearth of literature on the topic of household non-renewable and biomass energy use and carbon emissions, as shown by the aforementioned discussion. Furthermore, there is no study available to take into account the carbon emissions from non-renewable and biomass energy sources, as well as income and clean energy, as key determinants of non-renewable and biomass energy choices in Pakistan. Accordingly, this study uses the Pakistan Social and Living Standards Measures to investigate the household sector's

TABLE 1 Summary of existing literature.

Author(s)	Country (ies)	Variables	Methodology	Findings
Abbasi et al. (2022)	China	GDP, carbon emissions, green and non-renewable energy	NARDL	They concluded that energy production from fossil fuels significantly increases both long- and short-term CO_2 emissions, while using renewable energy sources temporarily increases CO_2 emissions. Their findings suggest that switching to renewable energy sources is critical to meeting environmental sustainability objectives and deters the use of fossil fuels
Usman et al. (2022)	Pakistan	Carbon emissions, nuclear and renewable energy	NARDL	Their analysis suggests that indirect variations in nuclear energy degrade the environment, while direct or indirect variations in clean energy significantly improve the quality of climate. They suggested to enhancing the utilization of nuclear and clean energy sources in Pakistan to promote a sustainable and clean environment
Yousaf et al. (2021)	Pakistan	Firewood, LPG, coal, kerosene oil, dang-cake, income, household size, clean energy	Descriptive and STIRPAT model	Household income increases consumption of LPG, kerosene oil, firewood, and dang cake, while reducing coal consumption. Household size increases the consumption of biomass. Clean energy significantly and negatively affects LPG and firewood
Zou and Zhang (2020)	China	Energy consumption, economic growth, and CO_2 emissions	Spatial Durbin model	CO_2 emissions and energy consumption have a two-way causal relationship
Zheng et al. (2020)	China	Economic growth, population growth, energy intensity, carbon intensity, CO_2 emissions	Johansen cointegration	CO_2 emissions increase as a result of increased energy usage
Chontanawat (2020)	ASEAN	Energy consumption, CO_2 emissions and economic growth	Cointegration and causality model	Reduced energy usage contributes to improving environmental quality by lowering CO_2 emissions
Emir and Bekun (2019)	Romania	Energy intensity, CO_2 emissions, renewable energy, and economic growth	ARDL model and Toda-Yamamoto model	Bidirectional causality between energy intensity and economic growth as well as unidirectional causality between renewable energy usage and economic growth were found
Sarkodie and Strezov (2019)	Developing Countries	FDI, economic development, and energy consumption, CO_2 emissions	Quantile panel data regression	There is a positive impact of energy consumption on CO_2 emissions. EKC is valid for only China and Indonesia
Li et al. (2018)	China	CO_2 emissions and energy consumption	Johansen cointegration	CO_2 emissions are continuing to rise because of increased energy use
Sarkodie (2019)	Africa	Economic growth, CO_2 emissions	Panel regression and panel Ganger Causality	A U-shape relationship between economic growth and CO_2 emissions was found, which demonstrates that initially, economic growth mitigates CO_2 emissions while further economic growth contributes to increasing CO_2 emissions
Asumadu-Sarkodie and Owusu (2017)	Senegal	CO_2 emissions, electricity consumption, economic growth, financial development, industrialization, and urbanization	nonlinear iterative partial least squares (NIPALS) regression	Electricity consumption, financial development, and industrialization increase CO_2 emissions
Gul et al. (2015)	Malaysia	Energy consumption, CO_2 emissions	maximum entropy bootstrap (Meboot) approach	The findings support the unidirectional causality from energy consumption to CO_2 emissions
Salahuddin et al. (2015)	Gulf Cooperation Council Countries	Economic growth, electricity consumption, CO_2 emissions and financial development	dynamic ordinary least squares; fully modified ordinary least squares	Electricity consumption and economic growth have a positive long-run association with CO_2 emissions, whereas financial development negatively and significantly affects CO_2 emissions

(Continued on following page)

TABLE 1 (***Continued***) **Summary of existing literature.**

Author(s)	Country (ies)	Variables	Methodology	Findings
Jammazi and Aloui (2015)	GCC countries	Energy consumption, economic growth, and CO_2 emissions	wavelet approach	The findings confirm a unidirectional relationship among energy consumption and CO_2 emissions
Osabuohien et al. (2014)	Africa	CO_2 emissions, *per capita* income with control variables	Panel cointegration	The findings confirm a long-run relationship between CO_2 emissions and *per capita* income, including institutional factors and trade
Soltani et al. (2019)	India	Coal consumption, economic growth, trade openness and CO_2 emissions	ARDL model	The findings confirm the feedback hypothesis between coal consumption, and CO_2 emissions. Moreover, trade openness causes economic growth, coal consumption, and CO_2 emissions. The EKC hypothesis is valid both in the short-run and the long-run
Shahbaz et al. (2012); Nasir and Ur Rehman (2011)	Pakistan	CO_2 emissions, energy consumption, economic growth, and trade openness	Bound tests for cointegration and Ganger Causality	The findings confirm one-way causation from economic growth to CO_2 emissions. Energy consumption increases CO_2 emissions both in the short-run and long-run. The EKC hypothesis holds for CO_2 emissions and economic growth
Acaravci and Ozturk (2010)	Nineteen European countries	CO_2 emissions, energy consumption, and economic growth	ARDL model	There is a long-run relationship between CO_2 emissions, energy consumption, and real GDP *per capita*
Halicioglu (2009)	Turkey	CO_2 emissions, energy consumption, income, foreign trade	ARDL, Ganger Causality	The findings confirm the short-run and long-run relationship between energy consumption and CO_2 emissions. In addition, bi-directional Granger causality has been obtained between CO_2 emissions and commercial energy consumption

consumption of renewable and non-renewable energy sources, as well as the amount of carbon emitted from these sources, in an effort to fill this void and add to the existing literature. In addition, the STIRPAT model is employed to examine how various factors, such as family income, size, and access to clean energy, influence the non-renewable and biomass energy sources available to households, and policy recommendations are made in light of these results.

Material and method

Theoretical framework of STIRPAT model

Previously, different models have been utilized in the literature for identifying the drivers of household sector energy consumption; for example, Azam and Ahmed (2015), Baiyegunhi and Hassan (2014), Mensah and Adu (2015), and Rahut et al. (2019) used a multinomial logit; Irfan et al. (2018) and Ngui et al. (2011) utilized a linear approximate almost ideal demand system; Chen et al. (2006) and Damette et al. (2018) employed energy demand of utility maximization; Han et al. (2018) used dynamic panel regression model; Heltberg (2005) used the Engle curve; Huebner et al. (2016) used the regression model; and Wang and Yang (2019) used the STIRPAT model. In this study, we employ the stochastic impacts of regression on population, affluence, and technology (STIRPAT) model, which has several advantages over other methods, including simple model modification, partitioning and inclusion of indicators, and straightforward interpretation of results (Dietz et al., 2007; Hayden and Shandra, 2009; Zhou and Li, 2020).

STIRPAT is an extension of the IPAT model (Zhou and Li, 2020). Ehrlich and Holdren (1971) proposed the IPAT model, which consists of four variables, such as influence (I), population (P), affluence (A), and technology (T). According to Zhou and Li (2020), the fundamental IPAT model is as follows:

$$I = P \times A \times T \tag{1}$$

In Eq. 1 demonstrate environmental pollution, P represents population size, A stands for affluence, and T is technology.

The application of the IPAT model is minimal and contains some flaws because it assumes that the elasticity of each independent variable corresponds to 1, which oversimplifies the problems faced by our environment (Timma et al., 2016). Moreover, it does not allow non-monotonic and non-proportional changes in influencing factors. Consequently, Dietz and Rosa (2007) addressed this issue by converting IPAT into a stochastic form known as the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology), which is widely used to investigate environmental indicators more precisely and accurately. In the literature, numerous studies have employed the STIRPAT model, for instance (Shahbaz et al., 2012; Zhang and Lin, 2012; Wang et al., 2013; Roberts, 2014; Wang and Zhao, 2015; Sheng and Guo, 2016; Amin and Dogan, 2021b).

The STIRPAT model has several advantages; for instance, it not only allows each coefficient to be estimated as a parameter but also allows each factor to be appropriately decomposed, which means

TABLE 2 Variables description.

Variables	Construction	Unit value	Data source
logcarbon	It is constructed by following Yousaf et al. (2021) method of calculation and then taking logarithmic according to STIRPAT model	kg	PSLM 2018-19
logmexp	It is the log value of total expenditure made on all items by household as a proxy for income	Rs	PSLM 2018-19
Sqlogmexp	It is constructed by following York et al. (2003) as [logmexp-mean]^2 to reduce collinearity and then taking the log value according to the STIRPAT model while including it to check the effect of further growth in total expenditure on carbon emissions	kg	PSLM 2018-19
loghhsize	It is constructed as the sum of total household members and then takes a log value according to STIRPAT modeling while including a proxy for population effect on carbon emissions	number	PSLM 2018-19
logmqbiomass	It is the log value of quantity consumption of biomass (i.e., the sum of firewood and dang cake), while the log is taken according to the STIRPAT model while including carbon emissions	kg	PSLM 2018-19
logmqnonren	It is the log value of non-renewable energy consumption in households (i.e., the sum of LPG, kerosene oil, and coal), and the log is taken according to the STIRPAT model while including carbon emissions	kg	PSLM 2018-19
Proxgreen energy	It is dummy variable whose value is 1 in the case of households using clean energy options; otherwise it is 0 while including carbon emissions	dummy	PSLM 2018-19

that the new influencing factors can be added accurately to the STIRPAT framework. The STIRPAT model takes into consideration the basic environmental changes and analyzes of various indicators that may be most responsive to policies. Nowadays, the STIRPAT model has become one of the most famous, widely used, and classical theoretical models in environmental economics literature. The STIRPAT model is a stochastic model that helps with hypothesis testing; this model is equally suitable for time series, cross-sectional, and panel data; it studies the environmental influence of behavioral indicators such as population, affluence, and technology; and it accurately explains the sensitivity of the environment to the driving factors of carbon dioxide emissions. The model highlights that a country's environmental degradation depends on its population, economic development, and technology (York et al., 2003).

The basic form of the STIRPAT model is presented as follows:

$$I = aP^x A^y T^z e \tag{2}$$

In Equation 2, a is the intercept; x, y, and z represent the coefficients of environmental effects corresponding to P, A, and T, while e is the error term. In the STIRPAT model, in order to facilitate the calculations, all variables in Eq. 1 are usually converted to logarithmic form. After taking the log, Equ. (3) becomes,

$$lnI = \alpha_o + \alpha_1 lnP_i + \alpha_2 lnA_i + \alpha_3 lnT_i + e_i \tag{3}$$

In Equation 3, *I* indicate carbon emissions. Wang et al. (2013) and Zheng et al. (2020) used carbon emissions *per capita* and total carbon emissions to measure environmental quality. α_0 is a constant term, while α_1 depicts income elasticity, α_2 shows the household size effect on non-renewables and biomass energy consumption, α_3 shows the clean energy effect, and e_i is an error term.

To estimate the impact of various factors on CO_2 emissions, the STIRPAT model is presented below.

$$\begin{aligned} logCO_2 = &\beta_o + \beta_1 logincome_i + \beta_2 (logincome_i)^2 + \beta_3 clean\,energy_i \\ &+ \beta_3 loghhsize_i + e_i \end{aligned} \tag{4}$$

Since the coefficients of the drivers in Eq. 4 exhibit elasticities, this re-specification of the original STIRPAT model is known as the elasticity model.

$$\begin{aligned} logCO_2 = &\beta_o + \beta_1 logincome_i + \beta_2 (logincome_i)^2 + \beta_3 clean\,energy_i \\ &+ \beta_3 hhsize_i + \beta_3 logbiomass\,energy_i \\ &+ \beta_3 lognonrenwable\,energy_i + e_i \end{aligned} \tag{5}$$

Since both the regressand and regressors are logarithmic in Eq. 5, the coefficients β1 and β1 represent the income elasticity and the household size effect of non-renewable and biomass energy consumption, respectively; β1 represents the clean energy effect; β0 represents the constant term, while e_i represents the random terms for the chosen models.

Data

In this study, we used the Pakistan Social and Living Standards Measurements (PSLM) survey 2018–2019. PSLM 2018–2019 is the Pakistan Bureau of Statistics' household survey. This survey covers in-depth data on household income, expenditures on food and non-food commodities, demographics, education, health, and employment of households. There were a total of 248,000 households surveyed, with 65% from rural areas and 35% from urban areas. On the basis of positive consumption magnitude, the following sets of households were selected: 3,865 for LPG, 340 for kerosene, 331 for coal, 10636 for firewood, and 4,328 for dang cake. The survey data also included information on other factors, such as income, household size, and total spending on non-renewables and biomass energy consumption. The clean energy variable was employed as a proxy for technology; it was assigned a positive value if a family reported spending money on renewable sources like solar panels, geothermal heat pumps, or natural gas. The values 1 indicated positive expenditures, while 0 otherwise.

This study surveys the economic, demographic, and energy consumption factors that affect the household sector's CO_2 emissions. The sources of data and construction of variables are presented in Table 2.

Result and discussion

Users with biomass and non-renewable energy

The users of biomass and non-renewable energy are depicted in Figure 1. The result shows that most households in both sectors are associated with biomass (86% of rural users and 80% of urban users). A minor segment of households in rural (14%) and urban (20%) areas is associated with non-renewable energy. The most significant users related to biomass energy are similar to the findings of Jan et al. (2012) for rural households in Pakistan; Mislimshoeva et al. (2014) for Tajikistan; Rahut et al. (2014) for Bhutan; Behera et al. (2015) for South Africa; Baul et al. (2018) for Bangladesh; Dash et al. (2018) for India; Giri and Goswami (2018) for Nepal; Ravindra et al. (2019) for India;; Yousaf et al. (2021) for Pakistan. In the urban sector, households affiliated with non-renewable energy account for 20% of all households, higher than in the rural sector (14%). For example, Rahut et al. (2014) found that households in the urban region are more likely to be affiliated with non-renewable resources than those in the rural area in Bhutan; for households in India Ravindra et al. (2019) obtained that 75.5% of households in rural India are associated with biomass energy and 75.4% of urban households are users of LPG; Hou et al. (2017) for China obtained that 60% of households in rural areas and less than 5% of urban households use biomass as a source of energy for cooking; while according to Kumar et al. (2016), through various programs introduced by the Indian government for the adoption of clean energy, 65% of urban and 89% of rural households are connected to LPG.

On the contrary, other existing studies (for instance, Karimu, 2015; Mensah and Adu, 2015; Baul et al., 2018) found that various types of renewable and biomass fuels were utilized in homes, with the average non-renewable energy consumption per household per month being 14.41 kg. Coal, with 22.85 kg per household, was the most popular nonrenewable energy source, whereas kerosene only made up 4.08 L household1 month1. The average amount of biomass used was 155.64 kg per home per month. The most common amount of firewood used was 142.06 kg per family per month, whereas the most common amount of dang cake was 92.92 kg per household per month. It follows that people utilized many types of fossil fuels and biomass in their homes. The quantity of firewood used was the greatest, followed by that of ding cake, coal, LPG, and kerosene, in that order.

Users with different energy preference

The results depicted in Figure 3 show that firewood (60%) and dang cake (26%) are the first and second most preferred energy sources, followed by LPG (12%), kerosene (2%), and coal (0.3%) in the rural sector. In the case of the urban sector, firewood (67%) and LPG (18%) are the first and second most preferred energy sources, followed by dang cake (13%), kerosene (1%), and coal (0.5%). Our findings are congruent with those of Giri and Goswami (2018), as about 80% of households in Nepal use firewood and dang cake; Rahut et al. (2017) found that firewood is a major source of home fuel in Timor-Leste; and according to Baiyegunhi and Hassan (2014), 63.3% of Nigerian households rely on biomass, while 23% rely on kerosene; Mensah and Adu (2015) found that 40% of Ghana's households rely on biomass as a source of energy; 67% of Iranian households rely on biomass for cooking, whereas 20% of households are the users of dang cake and fuelwood as sources of energy for cooking; Behera et al. (2015) found that 98% of households in Bangladesh, 90% of households in Nepal, and 73% of households in India are associated with fuelwood consumption, whereas 75% of households in India, 50% in Nepal, and 47% in Bangladesh rely on the usage of dang cake; Ahmad and Wu (2022) concluded that with 17.8 GW and 16 GW, respectively, China and the United States led the world in bioenergy production. China, the United States, Brazil, Germany, and the United Kingdom were noted as the world leaders in creating bioelectricity at the time; while Özcan et al. (2013) reported that 48% of households use firewood and dang cake, while 40% use LPG and coal. Furthermore; Rahut et al. (2016) found that 79% of households in Bhutan rely on electricity, followed by LPG (67%), and firewood (47%); Karimu (2015) found that Ghanian households are the largest users of firewood (57%), and charcoal (29%). On the other hand, Nansaior et al. (2011) found that the usage of clean energy grows as families become more urbanized in Thailand, while for Ghanaian families, Karimu (2015) reported that 40% of rural households rely on renewable energy.

Magnitude of biomass and non-renewable energy

The magnitude of biomass and non-renewable energy in the household sector is reported in Table 3. The biomass consumption of rural users is 1711.85 tons per month, whereas urban users consume 201.32 tons per month. The average monthly biomass consumption is 0.13 and 0.10 tons, respectively. Among biomass components, rural users consume 1,333.18 tons of firewood per month, which is more than the 177.82 tons consumed by urban users. The average monthly firewood usage is 0.14 tons and 0.12 tons, and the dang cake consumption is 378.67 tons and 23.50 tons, respectively. The finding of biomass suggests that rural households are the most significant contributors to environmental deterioration, as they consume biomass in more significant quantities than urban households. Our findings are consistent with Irfan et al. (2018) for Pakistan; Ngui et al. (2011) for Kenya; Mensah and Adu (2015) for Ghana; Jingchao and Kotani (2012) for rural Beijing; Ravindra et al. (2019) and Dash et al. (2018) for India; Giri and Goswami (2018) for Nepal; Yousaf et al. (2021) for Pakistan; Ahmad and Wu (2022) for Bangladesh; and Rahut et al. (2017) Timor-Leste. Furthermore, the results are in line with those found by Rahut et al. (2017) who found that households use biomass, coal, and kerosene; Baiyegunhi and Hassan (2014) found that 63.3% of households were associated with biomass

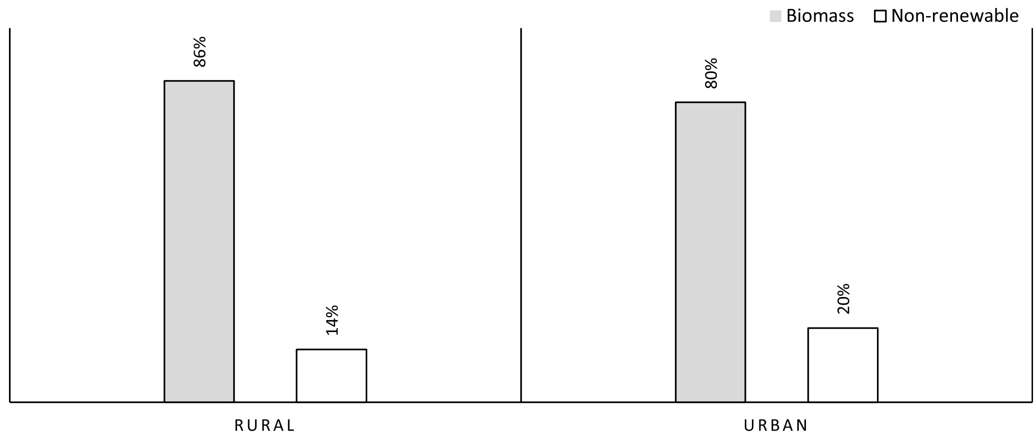

FIGURE 3
Households preferential use of biomass and non-renewable energy in Pakistan.

TABLE 3 Magnitude of biomass and non-renewable energy (tons month⁻¹).

	Rural		Urban	
	Total	Mean	Total	Mean
Firewood	1333.18	0.145	177.82	0.125
Dang Cake	378.67	0.093	23.5	0.084
Biomass	1711.85	0.128	201.32	0.104
LPG	14.08	0.007	3.35	0.009
Kerosene	0.621	0.002	0.042	0.002
Coal	3.3	0.084	0.28	0.028
Non-renewable	18.001	0.027	3.762	0.009

Source: Authors estimation while using the PSLM, 2018-19 dataset.
Note: Biomass consists of firewood and dang cake usage while non-renewable is the sum of LPG, kerosene, and coal.

usage and 23.0% with kerosene use at home; while Mensah and Adu (2015) concluded that more than 40% of households were involved with biomass energy. In detail, Mensah and Adu (2015) found that 40% of Ghana's households rely on biomass as a source of energy; 67% of Iranian households rely on biomass for cooking, whereas 20% of households are the users of dang cake and fuelwood sources of energy for cooking; Behera et al. (2015) found that 98% of households in Bangladesh, 90% of households in Nepal, and 73% of households in India are associated with fuelwood consumption, whereas 75% of households in India, 50% in Nepal, and 47% in Bangladesh rely on the usage of dang cake. Özcan et al. (2013) reported that 48% of households use firewood and dang cake, while 40% use LPG and coal. Furthermore, Rahut et al. (2016) found that 79% of households rely on electricity, followed by LPG (67%), and firewood (47%) in Bhutan. Karimu (2015) found that Ghanian households are the largest users of firewood (57%), and charcoal (29%).

Concerning the magnitude of non-renewable energy, rural households consume 18 tons of non-renewable energy per month, whereas 3.76 tons of non-renewable energy per month are consumed by households in the urban sector. The average monthly non-renewable consumption is 0.02 tons for rural households and 0.009 tons for urban households. Among the non-renewable sources, LPG is consumed by 14.08 tons per month by rural households and 3.35 tons per month by urban households. The total coal consumption is 3.30 tons and 0.28 tons per month, respectively. The finding of non-renewable consumption implies that rural households are the most significant contributors to environmental degradation, as they are the largest users of non-renewable consumption compared to urban users. Thus, non-renewable energy substitution programs, such as installing solar and electric energy in the household sector, could reduce carbon emissions associated with non-renewable energy. Previously, according to Nansaior et al. (2011), the usage of clean energy grows as families become more urbanized in Thailand, while for Ghanaian families, Karimu (2015) reported that 40% of rural households rely on non-renewable energy.

TABLE 4 Magnitude of carbon emissions (ton month^{-1}).

	Rural	Urban
	Total emissions	Total emissions
Firewood	40	5.33
Dang cake	298.01	18.49
Biomass	338.01	23.82
LPG	5.64	1.43
Kerosene	0.28	0.02
Coal	1.88	0.16
Non-renewable	7.8	1.61

Source: Author's estimation while using the PSLM, 2018-19 dataset.

Magnitude of carbon emissions

Table 4 shows the magnitude of carbon emissions from biomass and non-renewable energy use in the household sector. The carbon emissions associated with biomass in the rural sector are the highest, at 338.01 tons per month, compared to 23.82 tons per month in the urban sector. The contribution of dang cake in the rural sector is 298.01 tons per month, which is more than the 18.49 tons per month in the urban sector. The carbon emissions from firewood are 40 tons and 5.3 tons per month in the rural and urban sectors, respectively. LPG is the largest non-renewable contributor to non-renewables, with the most significant CO_2 emissions in the rural sector (5.64 tons) and in the urban sector is 1.43 tons every month. Our study findings are in line with those of Baul et al. (2018), who found that emissions from biomass energy use are 202.57 kg per household month-1, while overall emissions from non-renewable sources are 56.36 kg per household month-1 in Bangladesh.

Note: Households are selected on the basis of their positive quantity consumption of biomass and non-renewable energy. The number of rural households with biomass usage is 13275 and urban households are 1,689. The total number of rural and urban sector households with non-renewable are 2,175 and 418, respectively. Follow the studies of Baul et al. (2018); Danish et al. (2019); and Yousaf et al. (2021) for carbon emission factors.

Econometric analysis

The significance of income, household size, and energy consumption (as decomposed into clean energy, biomass, and non-renewable) in the household sector's carbon emissions is reported in Tables 5, 6. The study split t he econometric analysis into urban and rural household sectors for a better understanding. According to Table 5, column (2), there is an inverted-U relationship between emissions and income, confirming that a lower income level has a positive impact on carbon emissions and a higher income level has a negative effect. This is conceivable because urban households are more likely to limit their biomass and non-renewable energy use as their income rises, resulting in lower carbon emissions. The result of lower-income households having a positive impact on carbon emissions is consistent with Ala-Mantila et al. (2016); Fremstad et al. (2018). When clean energy alternatives are available, urban households substitute them for biomass and nonrenewable energy, resulting in a 0.36 percent reduction in carbon emissions. Each additional member increases carbon emissions by 0.26 percent, according to the coefficient for household size. This is acceptable since households with more members are more likely to consume dirty energy (such as biomass, kerosene, and coal), resulting in increased carbon emissions. The result in column (3) is based on the impact of biomass and non-renewable quantities, as well as household size, income, and clean energy, on CO_2 emissions. An inverted-U relationship between carbon emissions and income emerges even when energy variables are considered. It demonstrates that low-income households are more likely to consume dirty energy, resulting in increased carbon emissions, whereas households with higher incomes reduce carbon emissions. The coefficient associated with clean energy is insignificant, indicating that, given the availability of biomass and non-renewable options, households are likely to replace clean energy. Household size is one of the key factors with a positive and statistically significant impact, with each additional member resulting in a 0.15 percent increase in carbon emissions. Biomass and non-renewable energy have a positive and statistically significant impact on carbon emissions. A 1% increase in biomass results in a 1.33 percent rise in carbon emissions, which is higher than a 1% increase in non-renewable carbon emissions (i.e., 0.43 percent). This is conceivable because the household sector consumes biomass in more significant quantities than the commercial

TABLE 5 Determinants of carbon emissions (urban sector).

	(1)	(3)
	LOGSUMCARBONBN	LOGSUMCARBONBN
logmexp	2.129***	1.682**
	(0.748)	(0.83)
SQLogincome	−0.109**	−0.153***
	(0.052)	(0.058)
proxelecgas	−0.362**	−0.161
	(0.141)	(0.124)
Loghhsize	0.268***	0.158**
	(0.075)	(0.067)
logmqbiomass		1.333***
		(0.107)
logmqnonren		0.434***
		(0.049)
cons	−12.569***	−13.235***
	(2.686)	(3.006)
Observations	1,495	1,495
R-squared	0.13	0.272
Adj R^2	0.127	0.269
F-stat	62.57	79.553

Robust standard errors are in parentheses.
***$p < .01$, **$p < .05$, *$p < .1$.

TABLE 6 Determinants of carbon emissions (rural sector).

	(1)	(3)
	Logsumcarbonbn	Logsumcarbonbn
lonmexp	4.077***	3.99***
	(0.302)	(0.29)
SQLogincome	−.254***	−0.308***
	(0.021)	(0.02)
proxelecgas	−0.221	−0.172
	(0.152)	(0.147)
Loghhszie	0.419***	0.337***
	(0.036)	(0.035)
logmqbiomass		1.156***
		(0.043)
logmqnonren		0.252***
		(0.021)
constant	−18.538***	−20.49***
	(1.093)	(1.052)
Observations	10797	10797
R-squared	0.076	0.163
Adj R^2	0.076	
F-stat	203.757	277.696

Robust standard errors are in parentheses.
***$p < .01$, **$p < .05$, *$p < .1$.

sector; thus, the higher the biomass consumption, the higher the carbon emissions.

These outcomes are consistent with those of Hossain (2020) for Bangladesh, who concluded that income is positively associated with household energy consumption; Sarker et al. (2020) found rural regions may benefit economically from adopting biogas regardless of plant size. On the other hand, the findings of Özcan et al. (2013) demonstrate that income has a negative influence on firewood and kerosene, which is consistent with our result that income has a positive impact on both energy choices. The results of Baiyegunhi and Hassan's (2014) research on kerosene are comparable to the positive impact obtained on kerosene in Nigeria. Furthermore, Karimu (2015) found that the influence of income and household size on LPG is similar to our findings. Mensah and Adu (2015) observed a similar impact of household size on wood consumption in Ghana as we did; Mottaleb et al. (2017) reported a favorable influence of biomass and kerosene usage in Bangladesh households.

On the contrary, the existing studies (see, Jingchao and Kotani, 2012; Li et al., 2016; Baul et al., 2018; Damette et al., 2018; Goldstein et al., 2020) explored that the residential sector consumes the most biomass energy, with the main fuels being firewood and dang cake. Among non-renewable and biomass energy options, dang cake has the highest carbon footprint, followed by coal, and LPG has the lowest. The income impact reveals that the household sector considers LPG, kerosene, firewood, and dang cake necessary, but coal is a substandard item. The household size coefficient reveals that big households utilize firewood and dang cake, while small households use LPG and kerosene. As a result, household use of non-renewable and biomass energy drops in reaction to increases in clean energy.

Table 6 shows the importance of the determinants in the carbon emissions of rural households. Column (2) confirms the existence of an inverted U-shaped relationship between carbon emissions and income. This may be plausible since low-income households consume biomass and non-renewable energy in the rural sector, which they reduce when their income rises, resulting in fewer carbon emissions. Clean energy has a negative and statistically insignificant impact, confirming that there may be availability, accessibility, and affordability barriers to clean energy adoption. The negative impact shows that as clean energy options expand, the rural sector's reliance on biomass and non-renewable energy sources decreases, resulting in decreased carbon emissions. The coefficient associated with household size is positive and statistically significant. It shows that an additional member leads to an increase in carbon emissions of 0.41 percent. As a result, a population reduction program would reduce household size, lowering carbon emissions. Households with more crowded members would consume more biomass and non-renewable resources, resulting in an increase in carbon emissions. When biomass and non-renewables are added as additional variables, the result in column (3) supports an inverted U-relationship between carbon emissions and income. This is a positive sign because higher-income households negatively influence CO_2 emissions. The impact of clean energy is still negative and statistically insignificant, indicating that households have a low relationship with clean energy usage. However, increased clean energy choices would lower the amount of carbon emitted by rural households because of biomass and non-renewable energy usage. According to the household size effect, every additional member increases carbon emissions by 0.33%. The coefficients related to biomass and non-renewable energy positively affect CO_2 emissions in the rural sector. Furthermore, an increase in biomass energy consumption has the greatest impact, resulting in a 1.15 percent increase in carbon emissions for every 1% increase in biomass consumption. At the same time, a 1% increase in non-renewable energy usage results in a 0.25% rise in carbon emissions. These are achievable because, as previously discussed (see, Baul et al., 2018; Rahut et al., 2019; Wang and Yang, 2019), households in the rural sector consume biomass in more significant quantities than non-renewable energy. Our findings reflect the global scenario, in which recent increases in carbon emissions have been attributed to the developing world's household sector. Thus, the incredible rise in carbon emissions is associated with low income, household size, and the consumption of biomass and nonrenewable energy. In Pakistan, the household sector is primarily dependent on biomass and non-renewable energy. This study urges Pakistan to switch the household sector from biomass and non-renewable energy sources to clean energy choices. Also, speeding up economic growth and keeping the population down could be used as policy tools to mitigate carbon emissions in a country.

Conclusion and policy recommendations

In developing countries, the household sector is primarily reliant on biomass and non-renewable energy as crucial domestic energy

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sources. The heavy dependency on energy consumption is attributed to a positive association with CO_2 emissions. This study, on the other hand, investigated how much renewable and non-renewable energy households use and how much carbon dioxide is released as a result.

Using the STIRPAT model, an econometric analysis was performed to examine the impact of income, household size, green and biomass energy, and non-renewable energy on the household sector's carbon emissions. The study was decomposed into rural and urban sectors for better understanding. The findings of this study reveal that biomass energy is used by the majority of rural (86%) and urban (80%) households, while a small percentage of households use non-renewable energy. Firewood users are the most prevalent among biomass consumers, accounting for 67 percent of urban and 60 percent of rural households. The amount of biomass and non-renewable energy consumed reveals that both urban and rural households consume a lot of biomass, with firewood being the most significant contributor, followed by dang cake. The average monthly use of firewood in the urban sector is 0.12 tons, while in the rural sector, it is 0.14 tons per household. In both sectors, the average monthly consumption of dang cake is about the same. The average monthly amount of LPG consumed in the non-renewable sector is between 0.007 and 0.010 tons per household, whereas the average monthly amount of kerosene consumed in each sector is 0.002 tons per household. The average monthly coal consumption per household in the rural sector is 0.08 tons, which is higher than the 0.02 tons consumed per household in the urban sector. The results of carbon emissions show that emissions from biomass use are the most dominant, with rural households contributing 338.01 tons per month and urban households contributing 23.83 tons per month. Among biomass, emissions from the use of dang cake are higher (i.e., 18.49 tons per month for urban households and 298.01 tons per month for rural households) than those from firewood (i.e., 5.33 tons per month for urban households and 40 tons per month for rural households). LPG usage emits the greatest non-renewable emissions, with urban and rural households emitting 1.43 and 5.64 tons per month, respectively. The econometric findings confirm an inverted-U relationship between carbon emissions and income, suggesting that the increasing pace of growth reduces the household sector's carbon emissions. The positive and statistically significant influence of household size on carbon emissions shows that population control policies would lower emissions. The negative impact of clean energy means that CO_2 emissions will be reduced if households adopt more clean energy choices. The positive coefficients for biomass and non-renewable energy show that reducing biomass and non-renewable energy would lower CO_2 emissions.

The study's final recommendation is to pursue clean energy provision at the household level and reduce non-renewable energy consumption without sacrificing environmental quality. Thus, it is crucial to switch from the residential sector's usage of non-renewable energy to sustainable or clean energy. Also, increasing household income and reducing household size may both be viable policy options for lowering the consumption of non-renewable energy in Pakistan. The study recommends that clean energy provision at the household level be implemented without sacrificing environmental quality by decreasing consumption of non-renewable and biomass energy. Since sustainable energy is so important, it is imperative that the residential sector make the switch from using non-renewable and biomass sources of energy. Renewable energy sources are one possibility. Increasing personal disposable income and shrinking family sizes may also be viable policy options for cutting down on the usa of nonrenewable and biomass sources of energy.

Furthermore, based on the data from our study, we came up with a number of policy implications that could help clean energy sources in Pakistan. The results of this study show that the energy sector can cut carbon emissions via energy advancements, which could be done by spending money on research and development. This will finally help reduce the intensity of energy use and, as a result, the amount of CO_2 that is released into the air. Using green energy can also reduce damage to the environment and help Pakistan grow its economy towards sustainable development. So, it is better for Pakistan to make coal use more efficient, look into non-renewable energy sources that produce goods with added value, and use more renewable energy sources. Policymakers in the sample country want people to spend money on research and development (R&D) to protect the environment and use energy efficiently.

This study has some limitations, and some potential future directions are suggested. First, carbon emissions are used as the regressand in this study. Whereas, renewable energy production needs to be identified as a regressand in future studies, and its association with selected variables must be investigated. Second, future researchers may employ additional econometric models, such as the environmental Kuznets curve (EKC). Third, this study only investigated the linear relationship between variables, however, in the future, researchers may also investigate the asymmetric relationship as well. In addition, the empirical analysis of the research encourages a comparable study for other developing and developed economies worldwide.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: will be provided on demand. Requests to access these datasets should be directed to dr.yousaf@luawms.edu.pk.

Author contributions

AA: data curation, writing original draft; NY: supervision, and arranged funding; HY: data analysis, and wrote results; SP: review and editing; CI: reviewed the whole manuscript; MA: proofread the manuscript; SA: visualization. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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