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RESEARCH ARTICLE

Investigating household sector's non-renewables, biomass energy consumption and carbon emissions for Pakistan

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Abstract

Concerns over the observed rising trend towards carbon emissions and the resulting adverse effects of climate change on human activities are the main challenges facing human beings. This study examines household sector's non-renewables and biomass energy consumption magnitude and how much carbon is emitted from non-renewable and biomass energy in Pakistan by using the PSLM 2018–2019 survey. In addition, using STIRPAT model, this study investigates the effect of income, household size, and clean energy on non-renewables and biomass energy choices of the household sector. The results show that 77% of households rely on the consumption of biomass energy. An average household uses firewood at the largest magnitude of 142.06 kg month^{-1} and kerosene usage at the smallest magnitude of 4.08 kg month^{-1} among non-renewables and biomass energy choices. The largest contributor to carbon on average is dang cake and its magnitude of carbon emissions is 0.87 tons household^{-1} year^{-1} followed by coal with a magnitude of 0.76 tons household^{-1} year^{-1}. LPG is the lowest contributor to carbon and its carbon emission magnitude is 0.04 tons household^{-1} year^{-1}. The income impact finding indicates that LPG, kerosene, firewood, and dang cake are necessities, whereas coal is an inferior commodity. The coefficient of household size indicates that large household uses firewood and dang cake, and small one uses LPG and kerosene. As such, households prefer to reduce non-renewable and biomass consumption by increasing clean energy. Therefore, the study suggests that to reduce non-renewable and biomass energy consumption and follow clean energy provision at household level without compromising on environmental quality. The rise in household income and reducing household size could also be a valid policy option for reducing the non-renewable and biomass energy consumption.

Keywords Non-renewables energy · Biomass energy · Carbon emissions · STIRPAT · Pakistan

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Introduction

The concern about the increase in the carbon emissions trend and the associated adverse impact of climate change on human activities has attracted policy makers and researchers worldwide. Not that long ago, the fundamental survival of mankind was dependent, entirely, or partially, on the availability of biomass energy for heating and cooking. But modern industrialized communities have transitioned from traditional biomass to fossil fuel and updated the energy sources. Biomass, such as animal dung and agricultural wastes, are extremely likely to produce bioenergy with a lower greenhouse gas contribution. It is an economically sustainable and efficient method of producing energy (Iqbal et al. 2018). Biomass energy is renewable energy produced from some organic substance (Amer and Daim 2011). In both developed and developing countries, biomass is now a minor source of energy. It has been replaced by fossil fuel such as coal, oil, and natural gas (Klass 1998). Though the developing countries transitioned from biomass to fossil fuel; however, not much have changed in Third World countries. About 2.8 billion low income and most marginalized people are using biomass, dung, firewood, and charcoal sources, representing 55% of global wood harvest and 9% of primary energy supply. Nearly 1 billion people rely on petroleum lamps and other polluting tools to light their houses (Bailis et al. 2015; WHO 2016). For the poor, access to biomass such as charcoal and firewood for cooking and heating is important.

With a population of nearly 216.5 million in 2019, Pakistan is the 5th most populous country in the world, with a total land area of 796,095 km^2. The current projections suggest that the population of Pakistan will continue to grow with approximately 403 million population in 2050 (United Nations Population Division. World Population Prospects 2019).[1] Over 63%[2] of population is in rural regions and having constraints in the way of improving living standards. These constraints induce rural households' particular and urban households in general to use biomass energy resources for cooking and heating. According to the International Energy Agency (IEA 2019), more than 2.8 million households do not have access to clean fuel energy and 14% of world population do not have electricity connection for cooking and heating.

Increasing carbon emissions from household sector's non-renewable and biomass energy consumption has been evaluated for various countries (see, for instance, for Iran (Soltani et al. 2019); for USA (Goldstein et al. 2020); for G-7 countries (Sinha and Shahbaz 2018); for China (L. Xu et al. 2017)). Pakistan is predominantly an agricultural region; biomass is one of the important energy resources with tremendous energy generation potential. Biomass resources produced in the agriculture livestock and forest sectors include agricultural residues, animal waste, municipal solid waste (MSW), and forest residues. Pakistan possesses the ability to manage 15 million biogas plants successfully (Iqbal et al. 2018). The government of Pakistan is trying to switch household sector's energy consumption from dirty fuel-wood choices to clean energy such as natural gas, solar, and electricity to mitigate the carbon emissions. For environmental sustainability, Pakistan has initiated different programs, for example, eco-system restoration initiative, carbon market initiative, clean green cities index, clean green Pakistan movement, ten billion trees tsunami program, seasonal tree planting campaigns, and reduced emission from deforestation and forest degradation scheme (Governement of Pakistan 2019). To enhance environment for clean energy sources, several other programs, for example, alternative and renewable energy policy 2019; solar and wind system installation; and construction of dams for electricity generation were also initiated (Governement of Pakistan 2019).

The households use different variety of non-renewables and biomass fuels for domestic purposes in Pakistan. However, carbon emissions from the non-renewable and biomass energy consumption of the household sector in Pakistan have not yet been adequately addressed or quantified. The literature on the household (non-renewable and biomass) energy consumption and associated carbon emissions is very limited and few studies such as Rahut et al. (2019) have attempted to survey the issue in Pakistan. However, the previous studies failed to consider the magnitude of carbon emissions from non-renewable and biomass and income and clean energy as drivers of non-renewable and biomass energy choices in case of Pakistan. To fill this gap and contribute to the existing literature, this study tries to explore the household sector's non-renewables and biomass energy consumption magnitude and how much carbon is emitted from non-renewable and biomass in Pakistan by using the Pakistan Social and Living Standards Measurements (PSLM) 2018–2019 survey. Furthermore, using STIRPAT model, this study surveys the impact of income, household size, and clean energy on household sector's non-renewables and biomass energy choices and suggests policy options based on the study findings.

The study is organized as follows: "Literature review" presents a literature review; "Material and method" covers the material and method used to calculate the carbon emissions of the household sector and an econometric survey using STIRPAT modeling; "Results and discussion" presents results and discussions; and "Conclusion and policy implications" focuses on conclusions and policy implications.

Literature review

A large and growing body of literature has investigated the share of household and the magnitudes of non-renewable and biomass energy consumption on household sector energy choices for domestic purposes. For example, using field survey 2013, Sharma (2019) found that the dominant form of energy choice for domestic purposes in the case of Nepal the firewood and LPG shares are 84% and 9%, respectively, in total household sector energy consumption. Using the Nepal Living Standard Survey 2010–2011, Giri and Goswami (2018) show that more than 50% of total households use fuel wood and more than 20% use LPG as energy choices for domestic purposes. Besides, households associated with kerosene consumption are 0.8%. They further illustrate that about 70% of households depend on non-renewable and biomass energy choices. Baul et al. (2018) show that the mean consumption of non-renewable is 166.03 kWh $household^{-1}$

[1] https://population.un.org/wpp/Publications/Files/WPP2019_DataBooklet.pdf

[2] Source: World Bank World Development Indicators (WDI) https://databank.worldbank.org/source/world-development-indicators/Type/TABLE/preview/on Accessed October 23, 2020.

month^{-1} and the magnitude of biomass energy consumption is 1087.79 kWh household^{-1} month^{-1} in the study area of Bangladesh. Among non-renewable energy categories, LPG and kerosene accounted for 22.48 kWh and 12.83 kWh household^{-1} month^{-1}, respectively. The largest contributor to biomass energy is firewood which accounted for 693.79 kWh household^{-1} month^{-1}, and the dang cake accounted for 29.72 kWh household^{-1} month^{-1}. In the same vein, Damette et al. (2018) for French households estimate the proportion of households which use wood as energy source and the results show that only 1.6% households associated with wood usage, with its average consumption is 616.8 kWh household^{-1}. The proportion of households with fuel oil is 14.26% with average consumption of fuel oil that is 1325 kWh household^{-1}, more than double than wood consumption. Rahut et al. (2017a, b), using Timor-Leste Living Standards 2007 survey data, shows that 85.3% and 74.9% are households associated with fuel wood and kerosene consumption. The budget allocations to fuel wood and kerosene energy choices are 58.8% and 31.8%, respectively. Similarly, Adeyemi and Adereleye (2016) from the field survey 2016 of Ondo state, Nigeria, found that share of household associated with kerosene is 45% and household associated with firewood is 43%. Rahut et al. (2014) in the case of Bhutan show that more than 60% of households use non-renewable and biomass. The shares of households associated with non-renewable and biomass are 22.2% and 42.3%, respectively. The household budget allocations to firewood, kerosene, and gas in Bhutanese currency are 570.92, 38.95, and 131.54 month^{-1}, respectively. Jingchao and Kotani (2012) estimate consumption of non-renewable and biomass for the case of rural Beijing. The results show that among non-renewable coal is the largest consumption category, with its daily consumption that is 1.83 kg and daily consumption of LPG is 0.08 kg household^{-1}. Among biomass, fuel wood accounted for 0.33 kg, and crop residue daily consumption is 0.10 kg household^{-1}. Households are likely to consume coal in largest magnitude due to the fact that its price is lower than that from other non-renewable and biomass energy choices. Akpalu et al. (2011) investigate the share of household sector's energy choice for domestic purposes while using the Ghana Living Standards 1998–1999 survey. They found that 3.22 L of kerosene and 2.97 kg of firewood are used by Ghana households, respectively. Using questionnaire survey data on household energy consumption in China, Ngui et al. (2011) found that cooling, heating, cooking, and lighting have contributed 87.87% household's total energy used. Ngui et al. (2011) estimate energy consumption in the case of Kenyan households. The consumption of kerosene is the highest among energy choices, 185.53 kWh, followed by fuel wood 174.32 kWh, LPG 139.39 kWh, and charcoal 74.57 kWh^{-1} month^{-1}. Kerosene, fuel wood, LPG, and charcoal have a budget allocation of 13.41%, 12.62%, 10.09%, and 5.39%, respectively. Miah et al. (2009) investigate the percentage of families associated with non-renewable and biomass energy sources. They also investigate the magnitude of biomass fuel consumption in Bangladesh. The results show that about 53% families associated with the consumption of biomass (i.e., wood and kerosene), and only 5% families use gas. The average biomass consumption is 4.24 tons family^{-1} year^{-1}. Shittu et al. (2004) investigate the household sector budget allocation to biomass, kerosene, gas, and other four energy consumption categories while using primary data for Nigeria. They found that 36% of household sector budget allocates on energy consumption categories.

For regional carbon emission comparison, Goldstein et al. (2020) found that Western emits lowest emissions than from Central region in USA from used of residential fossil fuels. Li et al. (2016) used household carbon emission survey and found that carbon intensity, income, weather, and urbanization are factor accountable towards higher per capita carbon emissions. They identified that about 88% households' lives in Northwest China emit 0.39 to 2.58 tons carbon. Baul et al. (2018) in the study area of Bangladesh estimate the magnitude of carbon emission of the non-renewable and biomass. The total carbon emissions from non-renewable are 56.36 kg household^{-1} month^{-1}. The contributions from LPG and kerosene are 5.42 kg and 3.82 kg household^{-1} month^{-1}, respectively. The total emissions from the use of biomass 202.57 kg household^{-1} month^{-1}, with the largest contribution that is 192.03 kg household^{-1} month^{-1} from firewood.

In addition, Chun-sheng et al. (2012) examined urban-rural household energy consumption choices and associated carbon emissions. They found that urban households consume fossil fuels while rural households' energy used depends upon fossil and biomass energy choices. Households live in China's rural regions that emit higher carbon than those live in urban regions. Furthermore, Rahut et al. (2019) found that households live in rural regions that prefer to consume firewood, dung cake, and agricultural waste in large magnitude, while prefer to consume tiny magnitude of clean energy. Households having human capital, financial assets, and more educated in term of heads prefer to consume LPG as cooking fuel in Pakistan. According to region concern, Nansaior et al. (2011) found that urbanization has negative impact on dirty energy consumption and has positive impact on clean energy choices. However, the net effect of urbanization on energy usage is positive which illustrates that total energy consumption increases with urbanization for domestic purposes in Thailand. Marzano et al. (2018) used data from the 2007 Timor-Leste Living Standards survey to investigate household energy consumption determinants. The findings show that in the case of fuel wood, the coefficient associated with households is positive and is negatively associated with kerosene. They show that the larger the size of the household, the greater the availability of household labor to gather fuel wood, thereby increasing fuel wood while reducing the consumption of kerosene. Adeyemi and Adereleye (2016) show that the coefficient associated with household income is positive and statistically significant for kerosene, meaning that as households' income increases, they are likely to increase kerosene consumption. For kerosene, the coefficient associated with household size is negative, meaning that the greater the household size, the lower the kerosene consumption in the case of Ondo state, Nigeria.

Özcan et al. (2013) used the Turkey's household level data 2005–2006 survey and multinomial logit model to analyze the impact of income and living standards on demand of dirty and clean energy. They found that an increase in household's income leads to increase coal and natural gas demand, while increase in income with living standards leads to increase household sector's electricity demand in Turkey. By using cross-sectional data from 2010 to 2011 and multinomial logit model, Baiyegunhi and Hassan (2014) estimated the socioeconomic factor's impact on cooking fuel choices. They found that education and income are the determinants for positive impact on clean energy, but household size has negative impact on adoption of clean energy for cooking in Nigeria. According to demographic, socioeconomic, and household dwelling characteristics, Huang (2015) found that households' member type, income, occupied space, and multi floor houses have also significant impact on electricity consumption in Taiwan. Damette et al. (2018), using French household data, show that the effect of income on wood use is statistically insignificant. Substituting wood for electricity, gas, and fuel oil for energy options is a potential argument for this negligible nexus between income and wood consumption. Soltani et al. (2019) found that the effect of income on kerosene is negative, supporting the argument that households tend to minimize expenditure on kerosene while increasing expenditure on LPG and electricity as income rises in the case of Iran. The results also show the negative impact of household size on LPG and obtain a positive impact on kerosene which implies that crowded household is likely to consume kerosene as an energy choice.

However, previous literature on household sector's energy consumption and associated carbon emissions is summarized in Table 1.

After reviewing above summarized literature, to the best of our knowledge, the literature on the household (non-

Table 1 Summary of the study's relevant literature

Author(s)	Country	Data and methodology	Findings
Rahut et al. (2019)	Pakistan	PSLM 2014-15, multinomial logit model	They found that education has positive impact on clean energy choices for cooking.
Baul et al. (2018)	Bangladesh	Questionnaire based survey 2013, spearman correlation	The per household carbon emission from use of firewood, electricity and liquefied petroleum gas in Bangladesh was 192 kg
Rahut et al. (2017a, b)	Bhutan	BLSM 2003, 07and 12, multinomial logit model	The key factors that induce household to consume electricity for cooking and lighting are household demographic characteristics, wealth, education, and access to infrastructure.
Li et al. (2016)	Northwest China	Questionnaire-based survey conducted in 2011-2012, spatial econometric model	Carbon intensity and per capita income are the key determinants for acceleration in household's carbon emissions. Higher carbon emissions from household sector are positively associated with intensity, income, weather, and urbanization level
Behera et al. (2015)	South Asia	51 villages of Bangladesh, India and Nepal, multivariate model	Households with higher income are likely to use electricity and liquefied petroleum gas, while lower income level households are likely to use fuel wood, dung and crop residue. In addition, female headed households have the tendency of adoption clean energy for domestic purposes.
X. Xu et al. (2015)	Yangtze River Delta, China	Questionnaire-based survey 2011, ANOVA	Carbon emissions from household level energy consumption are positively associated with income, house space, age, and household scale structure. The Per household carbon emissions is estimated 5.96 tons.
Rahut et al. (2014)	Bhutan	BLSM 2007–2008, multinomial logit model	Income and education are key determinants to use energy choices for cooking, heating, and lighting. Female headed households and those households live in urban areas are likely to use cleaner fuels.
Das and Paul (2014)	India	Between 1993–19994 and 2006–2007, input-output model	Increases in population lead to increases carbon emissions at household level.
Daioglou et al. (2012)	Developing countries	WDI 2007, bottom-up simulation model	There is slow tendency toward adoption of modern fuels for cooking, heating, and cooling in case of India, China, South East Asia, South Africa, and Brazil. The climate policy implementation has negative impact on residential energy emissions, i.e., reducing emissions. It also reduces traditional fuels choices of low-income households.

renewable and biomass) energy consumption and associated carbon emissions is very limited and few studies such as Rahut et al. (2019) have attempted to survey the issue in Pakistan. However, the previous studies failed to consider the magnitude of carbon emissions from non-renewable and biomass and income and clean energy as drivers of non-renewable and biomass energy choices in case of Pakistan. To fill this gap and contribute to the existing literature, this study tries to explore the household sector's non-renewables and biomass energy consumption magnitude and how much carbon is emitted from non-renewable and biomass in Pakistan by using the Pakistan Social and Living Standards Measurements (PSLM) 2018–2019 survey. Furthermore, using STIRPAT model, this study surveys the impact of income, household size, and clean energy on household sector's non-renewables and biomass energy choices and suggests policy options based on the study findings.

Material and method

Theoretical framework of STIRPAT model

Various models have been used in the literature for drivers of the household sector energy consumption; for example, Azam and Ahmed (2015), Baiyegunhi and Hassan (2014), Mensah and Adu (2015), and Rahut et al. (2019) used multinomial logit; Irfan et al. (2018) and Ngui et al. (2011) used linear approximate almost ideal demand system; Chen et al. (2006) and Damette et al. (2018) used energy demand of utility maximization; Han et al. (2018) used dynamic panel regression model; Heltberg (2005) used Engle curve; Huebner et al. (2016) used regression model; and Wang and Yang (2019) used the STIRPAT model. We use the STIRPAT model in this research, which has many advantages over other techniques, such as simple model modification, partitioning and inclusion of variables, and easy interpretation of findings (Dietz et al. 2007; Hayden and Shandra 2009; Zhou and Li 2020).

The stochastic impacts of regression on population, affluence, and technology (STIRPAT) are the extension of the IPAT model (Zhou and Li 2020). The IPAT model was proposed by Ehrlich and Holdren (1971), where the model consists of four variables, for example, influence (I), population (P), affluence (A), and technology (T). According to Zhou and Li (2020), the basic IPAT model can be expressed as follows:

$$I = PAT \tag{1}$$

Equation (1) for the impact of population, affluence, and technology on influence can be presented as follows:

$$I_{\mathrm{i}} = \gamma_o {P_{\mathrm{i}}}^{\beta_1} {A_{\mathrm{i}}}^{\beta_2} {T_{\mathrm{i}}}^{\beta_3} \tag{2}$$

The STRIPAT model is derived when to augment the stochastic variable in the IPAT model as follows:

$$I_{\mathrm{i}} = \gamma_o {P_{\mathrm{i}}}^{\beta_1} {A_{\mathrm{i}}}^{\beta_2} {T_{\mathrm{i}}}^{\beta_3}\, e^{\varepsilon_{\mathrm{i}}} \tag{3}$$

The logarithm of the STIRPAT model allows estimating the impact of drivers on the dependent variable (Dietz et al. 2007; Zhou and Li 2020):

$$lnI_{\mathrm{i}} = \beta_o + \beta_1 lnP_{\mathrm{i}} + \beta_2\, lnA_{\mathrm{i}} + \beta_3\, lnT_{\mathrm{i}} + \varepsilon_{\mathrm{i}} \tag{4}$$

where $\beta_0 = ln\,\gamma_0$ *and* $lne = 1$. Equation (4) is a re-specification of the initial model of STIRPAT, and this

Table 2 Description of variables (Descriptive statistics of variables are presented in Table 7 of Appendix A.)

Variables	Description	Unit
lnLPG	It consists of liquefied petroleum gas quantity consumed by household sector's and then performed logarithm according to STIRPAT modeling	kg
lnfirewood	It covers household sector's firewood consumed quantity and then performed logarithm according to STIRPAT modeling	kg
lnkerosene	It covers household sector's kerosene oil consumed quantity and then performed logarithm according to STIRPAT modeling	liter
lncoal	It covers household sector's charcoal, coal hard and soft consumed quantity and then performed logarithm according to STIRPAT modeling	kg
lndangcake	It covers household sector's dang cake consumed quantity and performed logarithm for STIRPAT modeling	kg
lnincome	Following Özcan et al. (2013), total income is incorporated for income effect upon energy consumption choices and performed logarithm for income elasticity and STIRPAT modeling	Rs.
lnhhsize	It uses for proxy of population effect on energy consumption choices and performed logarithm according to STIRPAT modeling	No.
Clean energy	Dummy: = 1 if household uses electricity or natural gas or solar energy for cooking and heating	0,1
	= 0 otherwise	

re-specification model is known as the elasticity model because the coefficients associated with drivers show elasticities.

In this study, we utilize the similar work of Wang and Yang (2019) by augmenting household sector non-renewable and biomass energy as dependent variables while augmenting income, household size, and clean energy as drivers. Thus, the modified STIRPAT models of household sector non-renewable and biomass energy consumption in a matrix form are as follows:

$$\begin{bmatrix} lnLPG_i \\ lnkerosene_i \\ lncoal_i \\ . \\ lnfirewood_i \\ lndangcake_i \end{bmatrix} = \begin{bmatrix} \beta_0 \\ \beta_0 \\ . \\ \vdots \\ \beta_0 \end{bmatrix} + \begin{bmatrix} lnincome_i & lnhhsize_i & energy_i \\ lnincome_i & lnhhsize_i & energy_i \\ lnincome_i & lnhhsize_i & energy_i \\ lnincome_i & lnhhsize_i & energy_i \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ \vdots \\ \varepsilon_5 \end{bmatrix} \quad (5)$$

In Eq. (5), dependent and independent variables are in logarithm, therefore, the coefficient β_1 shows income elasticity and β_2 shows the household size effect on non-renewables and biomass energy consumption; β_3 shows clean energy effect; β_0 shows constant term while $\varepsilon_1, \varepsilon_2, \varepsilon_3,$ *and* ε_4 show random terms for the selected models. The description of variables used in the study is given in Table 2.

Steps for carbon emissions calculation

To proceed the empirical investigation, the study follows Xu et al. (2017) to calculate carbon emission from household sector's energy consumption as[3]:

$$\text{carbon}_{\text{lpg}} = \text{lpg} \times \text{cef}_{\text{lpg}} \times \frac{44}{12} \quad (6)$$

$$\text{carbon}_{\text{kerosene oil}} = \text{kerosene oil} \times \text{cef}_{\text{oil}} \times \frac{44}{12} \quad (7)$$

$$\text{carbon}_{\text{coal}} = \text{coal} \times \text{cef}_{\text{coal}} \times \frac{44}{12} \quad (8)$$

$$\text{carbon}_{\text{firewood}} = \text{firewood} \times \text{cef}_{\text{firewood}} \times \frac{44}{12} \quad (9)$$

$$\text{carbon}_{\text{dangcake}} = \text{dangcake} \times \text{cef}_{\text{dangcake}} \times \frac{44}{12} \quad (10)$$

$$\text{total carbon emission} = \sum_{i=1}^{5} ec_i \times cef_i \times \frac{44}{12} \quad (11)$$

where *cef* refers to carbon emission factor and *eci* (i=1, 2,…,5) refer to five types of energy sources. The emission factors are reported in Table 3 for carbon emission calculation.

Data

The Pakistan Social and Living Standards Measurements (PSLM) survey 2018–2019 is utilized in this study. PSLM 2018–2019 is household's survey released by Pakistan Bureau of Statistics. The survey provides detailed information about consumption and expenditures on food and non-food items, education, health, demographic composition, occupations, and employment status of households.

The total 248,000 households were covered in survey; 65% rural and 35% urban households were the sub-population, respectively. The 3865 household for LPG, 340 for kerosene, 331 for coal, 10,636 for firewood, and 4328 for dang cake were selected based on positive consumed magnitude. Data on other variables, for example, income, household size, and total expenditure made on non-renewables and biomass, were also obtained from the survey. In addition, the clean energy variable was used as proxy for technology and was coded based on household with positive expenditure made either on natural gas or electricity or solar energy. The used values were 1 for positive expenditure and 0 otherwise.

Results and discussion

Users associated with non-renewables and biomass energy

The result in terms of non-renewable and biomass energy users is shown in Fig. 1. It confirms that 77% households were associated with biomass energy consumption while 23% households were associated with non-renewable energy choices for domestic purposes. The lion's share of households associated with use of biomass energy and it is consistent with finding of Baul et al. (2018) for Bangladesh, Behera et al. (2015) for South Asia, and Rahut et al. (2014) for Bhutan.

In case of disaggregate analysis and among the non-renewables, LPG (18% households), kerosene (3%), and coal (2%) were associated with these energy sources. The biomass information confirms that more than 50% households used firewood, while about more than 20% households consumed dang cake. The significant indication that derives from the

[3] Five energy choices were selected because quantity consumed of these in PSLM 2018–2019 was available.

Table 3 Carbon emission factor for non-renewables and biomass energy sources

Non-renewables	Emission factor (t CO_2/t fuel)	Biomass	Emission factor (t CO_2/t fuel)
Liquefied petroleum gas	0.401	Firewood	0.030
Kerosene	0.450	Dang cake	0.787
Coal	0.570		

Source: Zhang et al. (2014) and Baul et al. (2018)

Note: emission factor for dang cake is kg CO_2/kg from Baul et al. (2018)

finding is that majority of the households used biomass. The findings are consistent with Rahut et al. (2017a, b) for Timor-Leste, identified that households use sources of biomass, coal, and kerosene; Baiyegunhi and Hassan (2014) for Nigeria, that is, 63.3% households associated with usage of biomass and 23% with kerosene for domestic purposes; Mensah and Adu (2015) for Ghana which confirmed that more than 40% households were associated with biomass energy usage (Fig. 2).

Mean consumption of non-renewables and biomass

As the previous results confirm that households used different variety of non-renewables and biomass fuels for domestic purposes, the magnitude of non-renewable energy was 14.41 kg household^{-1} month^{-1}. The dominated energy category among non-renewable was coal with 22.85 kg household^{-1}, while kerosene only accounted for 4.08 L household^{-1} month^{-1}. The average magnitude of biomass consumption was 155.64 kg household^{-1} month^{-1}. Firewood was dominated with magnitude that was 142.06 kg household^{-1} month^{-1}, while dang cake magnitude was 92.92 kg household^{-1} month^{-1}. It derives that households used more than one variety of non-renewables and biomass choices. Firewood consumed magnitude was the highest, followed by dang cake, coal, LPG, and kerosene, respectively. The findings are consistent with Baul et al. (2018) who stated that in Bangladesh, firewood was consumed in highest magnitude, i.e., 160.14 kg household^{-1} month^{-1} (Table 4).

Total carbon emission (household^{-1} year^{-1} (tons)) and mean (household^{-1} year^{-1} (tons))

Concerning with non-renewable findings, the magnitude of carbon emission was 354.22 tons year^{-1} of 4350 households having positive quantity consumption. Coal was the highest contributor, and its carbon magnitude was 0.760 tons household^{-1} year^{-1}, while LPG was the lowest contributor with carbon magnitude that was 0.044 tons household^{-1} year^{-1} among non-renewables choices. Similarly, the 4342.04 tons year^{-1} carbon was emitted from use of biomass of 12,292 households, with the highest contribution from dang cake as accounted for 0.877 tons household^{-1} year^{-1} carbon emissions. In case of non-renewables and biomass, the highest emission contributor was dang cake, followed by coal, firewood, kerosene, and LPG, respectively. Since most households associated with biomass consumption, therefore, average carbon magnitude was 0.353 tons household^{-1} year^{-1}. The findings are similar with Baul et al. (2018) who reported in Bangladesh mean emission from burning of firewood was the highest, i.e., 192.03 kg household^{-1} month^{-1}, while electricity was the highest mean emission contributor among non-renewable sources. The 32.66 kg household^{-1} month^{-1} means that carbon was emitted from electricity consumption (Table 5).

Econometric analysis

The analysis reported in Table 6 describes the impact of income, household size, and clean energy on household sector's non-renewables and biomass energy choices. The econometric findings concerning with LPG show that logarithm income has positive and statistically significant association with LPG. The households consider LPG as necessity goods and if income increases by 1%, the LPG consumption increases by 0.661%. The effect of household members and clean energy on LPG consumption is negative and statistically significant. The findings show that additional member and adoption of clean energy choices lead to reduce LPG consumption. The findings of kerosene are like LPG but there are differences in magnitudes associated with logarithm income, household members, and statistically insignificant of clean energy. It is observed that if logarithm income increases by 1%, the kerosene consumption increases by 0.509% and falls in necessity category. The negative effect of household members illustrates that if household member increases by one unit, the kerosene consumption reduces by 0.238 units. In addition,

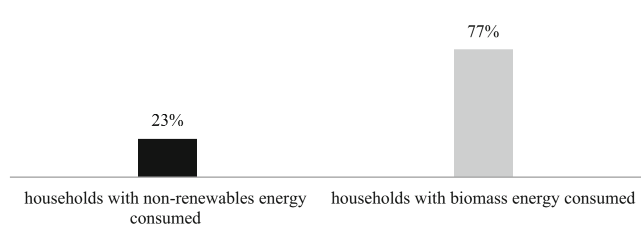

Fig. 1 Percentage of households associated with non-renewables and biomass in Pakistan

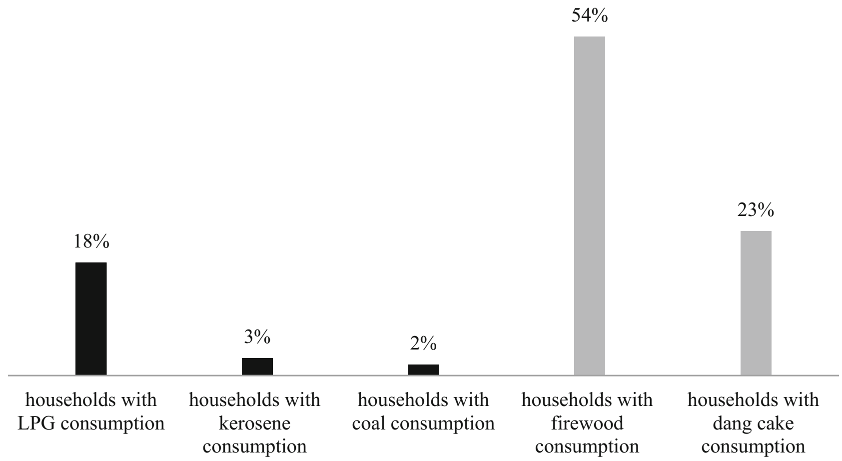

Fig. 2 Percentage of households associated with different sources of energy consumption in Pakistan

the findings of coal confirm that it is not a good choice to use for energy at household level because the coefficient associated with logarithm income is negative and statistically significant. Households are likely to consume lesser and lesser magnitude of coal as their income increases. Regarding biomass findings, the values associated to logarithm income and household size in case of firewood confirm that if income increases by 1% as well as increases in household members by one unit, the firewood consumption increases by 0.671% and 0.053%, respectively. The coefficient associated with logarithm also confirms that firewood is necessity commodity. This finding is in line with Baul et al. (2018) for Bangladesh who found that income is positively correlated with energy consumption at household; Rahut et al. (2014) found that income causes LPG, kerosene, firewood, and dang cake positively, while the dissimilarity found for coal. The study of Özcan et al. (2013) confirms the negative impact of income on firewood and kerosene which is consistent with our finding of income's positive impact on these energy choices. The study of Baiyegunhi and Hassan (2014) is parallel in results of kerosene as obtained positive impact on kerosene in case of Nigeria. In addition, Karimu (2015) findings are also consistent with our findings for income and household size impact on LPG. The findings of Mensah and Adu (2015) are parallel with our finding in case of household size effect on wood consumption for Ghana; Mottaleb et al. (2017) for households in Bangladesh found positive on biomass and kerosene.

The value associated with clean energy is negative and it confirms that adoption of clean energy choices reduces by 0.073% point's firewood consumption. Similarly, in case of dang cake, if income increases by 1%, it leads to increase 0.380% dang cake consumption and confirms that dang cake is necessity commodity. The coefficient associated with household size confirms that additional member increases 0.028% point dang cake consumption. Those households associated with dang cake may not consume clean energy because the coefficient associated with clean energy is statistically insignificant.

It is obvious from the findings that household sector of Pakistan uses more than one variety of energy, while biomass is dominated choice. Among energy choices, firewood is consumed in largest magnitude, followed dang cake, coal, LPG, and kerosene, respectively. Biomass is the highest contributor to emission than non-renewables in Pakistan. In case of biomass, the highest contributor is dang cake, while coal was the highest contributor to emission in non-renewables. The findings suggest that income, household size, and clean energy are key determinants for determining household sector's non-renewables and biomass energy consumption. From income effect, LPG, kerosene, firewood, and dang cake are necessities while coal is inferior energy choice at household level.

Table 4 Mean monthly consumption on non-renewables and biomass (kg household^{-1} month^{-1})

Non-renewables energy	Consumed quantity	Biomass	Consumed quantity
LPG (N = 3865)	09.21	Firewood (N =10,636)	142.06
Kerosene (N = 340)	04.08	Dang cake (N = 4328)	92.92
Coal (N = 332)	22.85	Total (N = 14,964)	155.64
Total (N = 4537)	14.41		

Source: Authors' calculation based on PSLM 2018–2019 dataset

Note: N denotes the numbers of households with positive non-renewables and biomass consumed quantity; LPG stands for liquefied petroleum gas; kerosene quantity was liter

Table 5 Total and mean emissions from non-renewables and biomass

Non-renewables	Emissions	Biomass	Emissions
LPG	0.044	Firewood	0.061
Kerosene	0.049	Dang cake	0.877
Coal	0.760		
Total (*N* = 4350)	354.22	Total (*N* = 12,292)	4342.04
Mean	0.081	Mean	0.353

Source: Authors estimation based on PSLM 2018–2019 dataset

Note: LPG stands for liquid petroleum gas; *N* stands for number of households with positive consumed quantity of non-renewable and biomass

Households prefer to spend on necessities, i.e., LPG, kerosene, firewood, and dang cake, while prefer to reduce spending on inferior foods, i.e., coal. The household size effect confirms that large household uses biomass and small one uses LPG and kerosene. As such, the clean energy coefficient confirms that households are likely to reduce non-renewable and biomass in response to clean energy increases.

Conclusion and policy implications

The objectives of this study are (i) to explore the magnitudes of household sector's non-renewable and biomass energy and associated carbon emissions and (ii) to estimate the impact of income, household size, and clean energy drivers on non-renewable and biomass. The study used the STIRPAT framework with the Pakistan Social and Living Standards Measurement (PSLM) 2018–2019 survey.

The findings of our study confirm that household sector uses biomass energy in largest magnitude, with the major fuels including firewood and dang cake. Among non-renewable and biomass energy choices, the magnitude of carbon emits from dang cake is the largest followed coal, whereas the lowest from LPG. The income effect confirms that household sector treats LPG, kerosene, firewood, and dang cake necessities while coal is an inferior commodity. The coefficient of household size confirms that large household uses firewood and dang cake while small one uses LPG and kerosene. As such, the consumption of non-renewable and biomass energy by the household sector decreases with response of increases in clean energy.

Finally, the study suggests that to reduce non-renewable and biomass energy consumption and follow clean energy provision at household level without compromising on environmental quality. Therefore, the transition from non-renewable and biomass energy consumption by the household sector to sustainable energy is crucial. These options could be renewable energy. In addition, the rise in household income and reducing household size could also be a valid policy option for reducing the non-renewable and biomass energy consumption.

Table 6 STIRPAT modeling for household sector's energy consumption

	Non-renewables			Biomass	
Variables	Model 1 ln LPG	Model 2 ln kerosene	Model 3 ln coal	Model 4 ln firewood	Model 5 ln dang cake
ln income	0.661*	0.509*	− 0.740*	0.671*	0.380*
	(− 0.02)	(− 0.059)	(− 0.086)	(− 0.017)	(− 0.019)
ln household size	− 0.196*	− 0.238*	0.027	0.053**	0.082**
	(− 0.024)	(− 0.108)	(− 0.132)	(− 0.01)	(− 0.026)
Clean energy dummy	− 0.277*	− 0.037	− 0.088	− 0.073**	− 0.072
	(− 0.05)	(− 0.409)	(− 0.294)	(− 0.034)	(− 0.104)
Constant	− 2.791**	− 0.313*	− 1.368**	0.312*	1.340**
	(− 0.146)	(− 0.045)	(− 0.584)	(− 0.045)	(− 0.128)
	Sensitivity results				
Adj.R^2	0.23	0.183	0.08	0.543	0.108
F-stat	372.182	26.02	31.71	4206.49	174.95
p-value	0	0	0	0	0
N	3865	340	332	10636	4328
Elasticity	0.661 (necessity)	0.509 (necessity)	− 0.74 (inferior)	0.671 (necessity)	0.38 (necessity)

Source: authors' estimation based on PSLM-2018–2019 dataset

Note: * and **The 1% and 5% significance level; the values in parenthesis show standard error; LPG stands for liquid petroleum gas; elasticity used to describe the nature of non-renewable and biomass energy sources at household level; expenditure made by households on clean energy choices like electricity, natural gas, and solar system assigned 1; otherwise, 0 as proxy for technology in regressions. The results based upon weighted least square to address heteroscedasticity

Appendix

Table 7 Descriptive statistics of dependent and independent variables

Variables	Min	Max	Mean	SD
lnLPG	− 1.39	5.19	1.92	0.80
lnfirewood	1.61	8.29	4.69	0.72
lnkerosene	− 1.39	3.91	0.85	0.97
lncoal	1.38	6.91	3.12	1.07
lndangcake	1.10	7.09	4.21	0.82
lnincome	4.61	9.93	7.31	0.77
lnhhsize	0.69	4.01	1.80	0.47
Clean energy	0.00	1.00	0.02	0.14

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Amdadullah Baloch: data curation and visualization.

Azka Amin: methodology and software.

Muhammad Akbar: review and editing

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Declarations

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Consent to participate NA.

Consent for publication NA.

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