Journal of Climate and Community Development
A Double-Blind, Peer-Reviewed, HEC recognized Y-category Research Journal
E-ISSN: 3006-7855 P-ISSN: 3006-7847

Regional Heterogeneity in Household Fuel Stacking and Energy Transitions: Microdata Insights from Pakistan

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Vol. *5,* ***Issue*** *1, 2026*

Article Information

Received:
2026-02-10

Revised:
2026-03-26

Accepted:
2026-05-23

ABSTRACT

This paper investigates regional disparities in energy transitions and fuel stacking behavior across households in Pakistan. For this purpose, Household Integrated Economic Survey (HIES) from 2004-05 to 2018-19 has been used. Results indicate that although electricity consumption has increased substantially over time, complete transition to cleaner fuels has not been achieved. Instead of moving up the energy ladder, households are stacking different traditional fuels, such as firewood, dung cake, and agricultural waste, along with the cleaner fuels. Regional analysis shows that the urban households are transitioning to cleaner fuels, while rural households are still relying on traditional fuels. Within provinces, urbanized and economically developed provinces like Punjab and Sindh are experiencing a transition to cleaner fuels, whereas households in KP and Balochistan are trapped in a dual energy paradigm by spending significant proportions on both types of fuels. Therefore, this study concludes that to bridge the gap created because of the divide across regions and provinces, policymakers must take steps beyond simply increasing access to electricity at the regional level to achieve sustainable transition to cleaner fuels.

Keywords: *Energy Transition, Fuel Stacking, Subnational Divergence, Household Energy, HIES, Pakistan.*

Citation: APA
Bashir, N & Mirza, F, M (2026). Regional heterogeneity in household fuel stacking and energy transitions: Microdata Insights from Pakistan, Journal of Climate and Community Development, 5(1), 80-94.

1. Introduction

Achieving equitable access to clean, reliable, and affordable household energy is a fundamental prerequisite for global sustainable development, directly impacting public health, economic opportunities, and climate change. However, empirical realities in emerging economies demonstrate that simply rising income and expanding infrastructure do not automatically guarantee energy transitions, opposing the energy ladder hypothesis. The energy ladder hypothesis is a theoretical framework explaining that with the increase in the income of households, consumers linearly move upward along the ladder towards cleaner and modern fuels (Leach, 1992). Furthermore, according to the study of Waleed and Mirza (2023), households move from biomass fuels such as firewood, dung cake, and crop residues to transitional fuels like kerosene, coal, and charcoal, and then eventually transition to cleaner fuels of electricity, natural gas, and LPG. However, empirical evidence on energy transition dynamics contradicts these findings, especially in developing countries. Instead of a linear transition, the literature of energy economics has identified the widespread phenomenon of fuel stacking (Ogwumike et al., 2014; Burke & Dundas, 2015). Energy transition is mostly observed through the lens of fuel stacking, where instead of fully abandoning traditional biomass fuels, households prefer to hold a mix of different energy fuels simultaneously because of the multiple structural realities, such as supply shocks, infrastructure deficiency, and price shocks (Imoisili & Mohlatlola, 2026).

Pakistan, being a developing country, lacks appropriate structure to support energy transition to comply with the Sustainable Development Goals and initiatives climate change. The data from past two decades indicates that energy transition is neither uniform nor complete in Pakistan's household sector (Awan et al., 2023). Therefore, after decades of infrastructural development and an increase in household income, traditional dirty fuels constitute a substantial proportion of household budget, creating a profound policy paradox for policymakers. Hence, empirical evidence for the case of Pakistan negates the theoretical standing of the energy ladder hypothesis and presents the realities that support the narrative of the energy stacking hypothesis (Awan et al., 2022; Awan et al., 2023; Moeen et al., 2016). Therefore, sluggish transition to cleaner fuels cannot be attributed to a single factor or indicator; rather, it is a multi-dimensional and complicated process involving a number of factors influencing household energy choices. High cost of cleaner fuels, supply shocks, infrastructural development, especially in rural and less developed areas, are some of the obstacles in the way of a complete energy transition.

Existing literature mostly discusses households at the aggregate national level and ignores the regional and provincial disparities, which could be the significant reasons behind the energy stacking behavior. Households living in Punjab experience a totally different energy infrastructure compared to Balochistan or the mountainous areas of KP. Similarly, households living in rural and dispersed areas have different energy supply chains compared to the urban areas. Consequently, a policy addressing national level findings fails to understand and address the regional realities that affecting energy consumption patterns in fuel stacking. Furthermore, irrespective of the fact that Pakistan is among the lowest energy consuming countries, its energy demand has been constantly increasing over the past three decades, signifying the need to pay more attention to energy transition efforts to establish a sustainable energy future (World Population Review, 2025; IEA, 2025).

This study attempts to address this research gap by investigating the regional and provincial analysis of fuel stacking across the household sector of Pakistan by analyzing consecutive Household Integrated Economic Surveys from 2004-05 to 2018-19. In doing so, this paper provides an empirical foundation for provincial and regional differentiated energy policies, demonstrating that a single policy fits all national strategies is structurally unsuited to address the localized realities of energy dynamics in Pakistan. We clearly demonstrate how Pakistan's household energy transition from 2004-05 to 2018-19 has diverged across places and remained nonlinear because of non-uniform energy infrastructure, poverty, education, gender, and

local contexts.

2. Literature on Pakistan Fuel Transitions

The earlier literature mostly focused on fuel choice through the energy ladder hypothesis (Reddy 1995; Rao and Reddy 2007; Song et al. 2018). The fundamental idea of the energy ladder hypothesis argues that with the rise in income, households start to shift from traditional lower level fuels to transition and then ultimately to modern fuels such as electricity (Mottaleb et al. 2022; Poddar et al. 2021). There are some other socio-demographic and economic variables that affect the choice of fuel consumption (Masera et al., 2000; Awan et al., 2023). Furthermore, it is also evidenced by the literature that even after switching to clean fuel, households keep on using traditional dirty fuels (Ngui et al. 2011). This concept in literature is attributed to the energy stacking hypothesis, which argues that as household income rises, households prefer to stack different traditional dirty and clean fuels rather than completely switching to one fuel (Van der Kroon et al. 2014). In literature, the idea of the ladder within a ladder is also put forward (Rahut et al. 2017a, b). Discovering a ladder within the ladder, Rahut et al. (2017), used the data from four African countries (Ethiopia, Malawi, Tanzania, and Uganda) and revealed that households don't necessarily shift to electricity for all their energy requirements.

In Pakistan, the literature directly supports the subnational divergence and fuel stacking hypothesis. Pakistan specific studies already utilized HIES data sets to track national trends, where some studies demonstrate that transitions are nonlinear, spatially uneven, and influenced by factors beyond income alone (Awan et al., 2022; Awan et al., 2023; Waleed & Mirza, 2023). Awan et al. (2023) analyzed seven rounds of HIES surveys from 2001 to 2019 in Pakistan to understand the patterns of energy consumption. They examined the determinants of using different fuel types by applying the Probit and Tobit models. They found that households led by female heads are more likely to consume more clean fuels. Wealth, education, and urban regions have a positive association with clean fuel adoption and consumption. Moreover, the study also found that age and household size have a non-linear impact on clean fuel consumption intensity.

Clean fuel adoption rose over time, but clean energy still accounts for a low share of total household energy use, which is consistent with persistent stacking rather than full replacement (Awan et al., 2023; Awan et al., 2022). India experienced even stronger phenomena of energy stacking, irrespective of the fact of increased consumption of LPG and transitions to cleaner and modern fuels among urban and wealthy households (Guta et al., 2024; Brahmanandam & Nagarajan, 2021). Similarly, empirical evidence from Pakistan also exposes the realities of regional deprivation and uneven energy transition across different regions where rural households still rely on traditional dirty fuels of firewood, dung cake, and crop residue (Waleed & Mirza, 2023; Wang et al., 2024; Mahmood et al., 2026). The provinces of Sindh, KP, and Balochistan contribute to multidimensional energy poverty and experience heterogeneity in determinants of energy transitions across provinces (Wang et al., 2024; Mahmood et al., 2026). Pakistan also witnesses variations in energy mix, where biomass fuels dominate households in Azad Kashmir and natural gas dominates the households in Punjab (Jiao et al., 2022).

Irrespective of household income, there are some other factors, such as household education, household size, household region, female bargaining power, and prices of fuels, which significantly impact Pakistan's household energy transition patterns (Waleed & Mirza, 2023). Household wealth, education, and locality significantly impacted household energy consumption decisions, where urban households, better educated households, wealthy households, and female headed household are inclined towards cleaner fuel consumption (Awan et al., 2023). Weak infrastructure, distance to refill LPG cylinders, credit constraints, demand side factors, and higher clean energy prices reduce the consumption of cleaner energy fuels, especially in developing countries, highlighting the importance of availability and affordability (Guta et al., 2024; Amrullah et al., 2026). Urbanization helps in the energy transition to cleaner fuels, but it does not eliminate stacking (Price et al., 2021). Factors related to community, social, and cultural aspects of households also influence the mixed

fuel consumption patterns (Goswami et al., 2023; Farah et al., 2023). Therefore, the existing literature portrays that household transitions are usually uneven, stacked, and region specific compared to uniform national shifts (Price et al., 2021; Vo et al., 2024; Waleed & Mirza, 2022).

3. Research Methodology and Data Sources

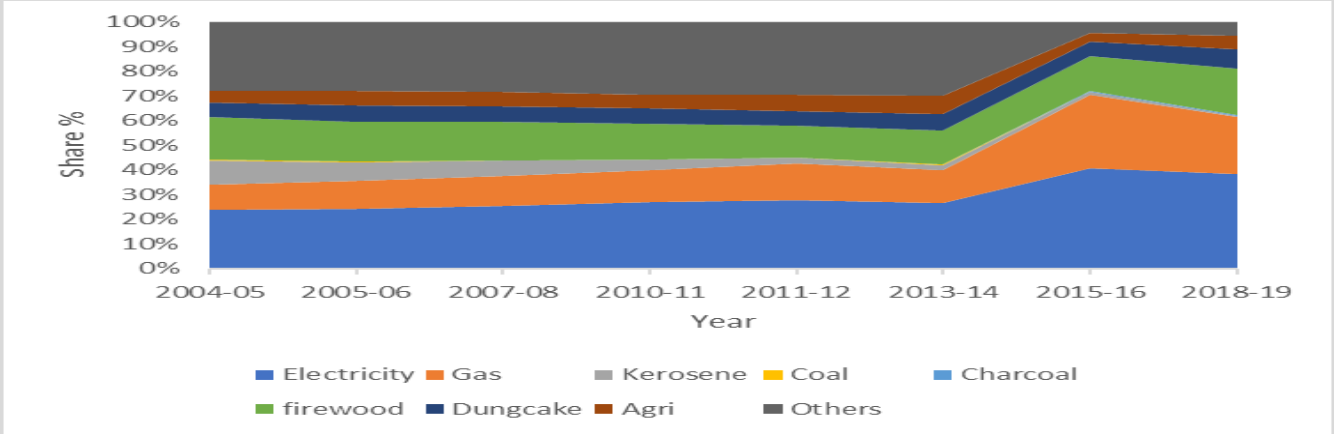
To investigate regional and provincial patterns of energy stacking across Pakistan's household sector, this study employs a descriptive and graphical analytical approach using nationally representative data from eight consecutive waves of the Household Integrated Economic Survey (HIES): 2004-05,2005-06, 2007-08, 2010-11, 2011-12, 2013-14, 2014-15, and 2018-19. HIES surveys are conducted by the Pakistan Bureau of Statistics (PBS) and provide socioeconomic characteristics of Pakistan's household sector, including fuel expenditures and household energy consumption. Graphical analysis through stacked area charts, trend plots, and line graphs has been employed to analyze the fuel expenditure patterns to explore energy transition dynamics and visualizations of energy stacking scenarios over time and across regions.

To investigate regional and provincial divergence, trends are compared across rural and urban regions of Pakistan and across provinces of Punjab, Sindh, KP, and Balochistan. Differences observed in the graphical analysis of the direction of energy consumption are interpreted as regional heterogeneity. Through this analysis, we can also identify the level of transition that occurred across each region and province. Therefore, this descriptive and graphical analysis approach provides a comprehensive overview of regional disparity and household energy transition behavior.

4. Household Energy Consumption Patterns and Transition to Cleaner Fuels

This section presents the graphical analysis of energy consumption patterns by disaggregating datasets by province and regions, revealing the region-specific variations of the country's energy dynamics. Figure 1 shows the proportions of household fuel consumption from 2004-05 to 2018-19. Data reveal a complex transition pattern, witnessing fuel stacking compared to the energy ladder hypothesis. Although there is a visible shift toward modern energy fuels, where electricity remains the dominant energy source throughout the period, traditional dirty fuels also show their consistent persistence in the household energy consumption basket. Natural gas also experienced an increased share in household energy consumption, but it shows a contraction after 2015 in the 2018-19 HIES survey, which could be because of supply constraints. Kerosene was among transitional fuels till 2013-14, but its share fell to almost a negligible level afterwards, and in 2018-19 it almost disappeared. Traditional fuels of firewood, dung cake, and agricultural waste still maintain their share in the overall energy consumption of households. Therefore, irrespective of the fact that households are consuming higher proportions of electricity and gas, they are still not abandoning the traditional fuels, hence supporting the energy stacking narrative.

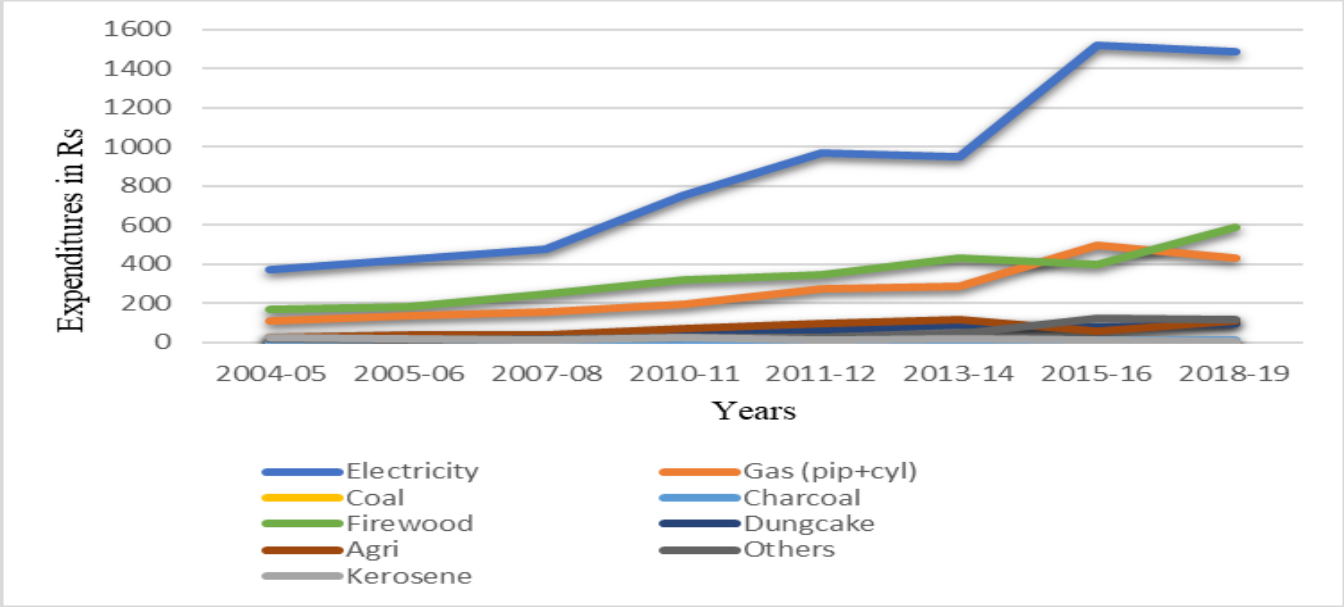
Figure 1: *Percentage of Households Using Each Fuel*



Source: *HIES 2004-19 (Author's calculation)*

Figure 2 displays household fuel expenditures in Rupees (Rs) from 2004-05 to 2018-19. This figure highlights that electricity is the largest energy expense for households, following firewood, and gas (piped and cylinder), which also experienced a gradual rise over the years. Furthermore, expenditure on firewood overtook gas in the period of 2018-19. Expenditures on dung cake, agricultural waste, coal, kerosene, and charcoal remained consistently low near the bottom of the scale throughout the entire period.

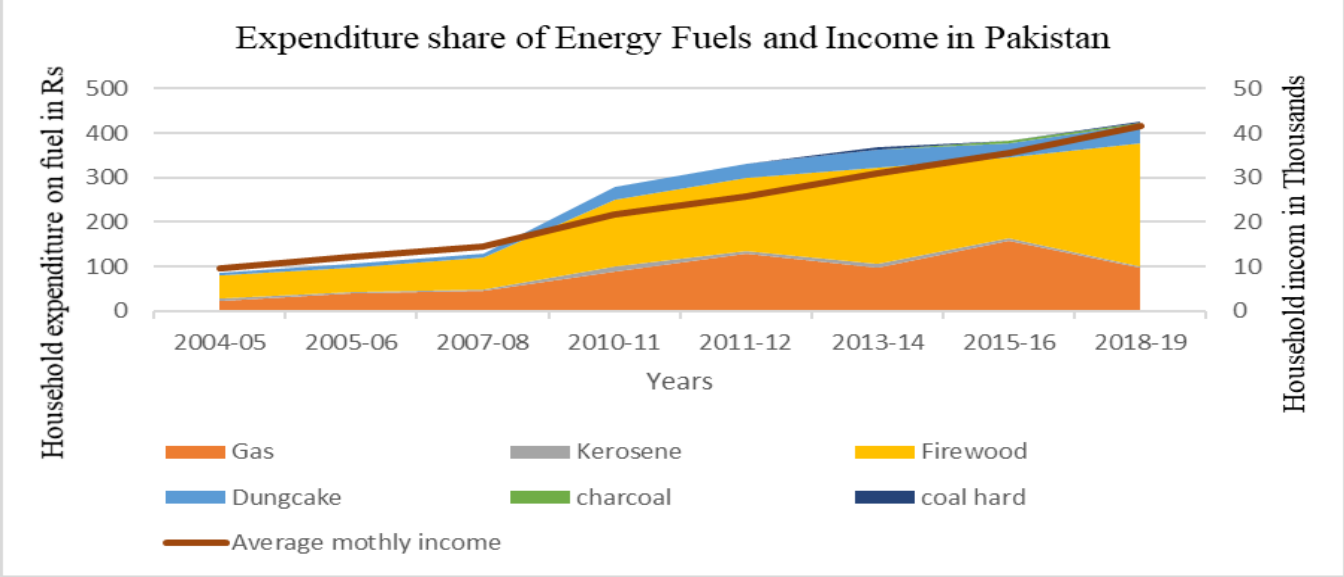
Figure 2: *Household Expenditure on Each Fuel*



Source: *HIES 2018-19 (Author's calculation and estimations)*

Figure 3 shows household fuel expenditures on primary heating and cooking fuels against rising average monthly incomes from 2004-05 to 2018-19. As household incomes increase, budget allocation to traditional fuels such as firewood and gas increases, but in the period of 2018-19, expenditure on firewood overtakes the expenditure on gas. Therefore, this graph witness's energy stacking of firewood, gas, and other fuels of dung cake and kerosene, and portrays that economic growth alone is not enough for energy transition.

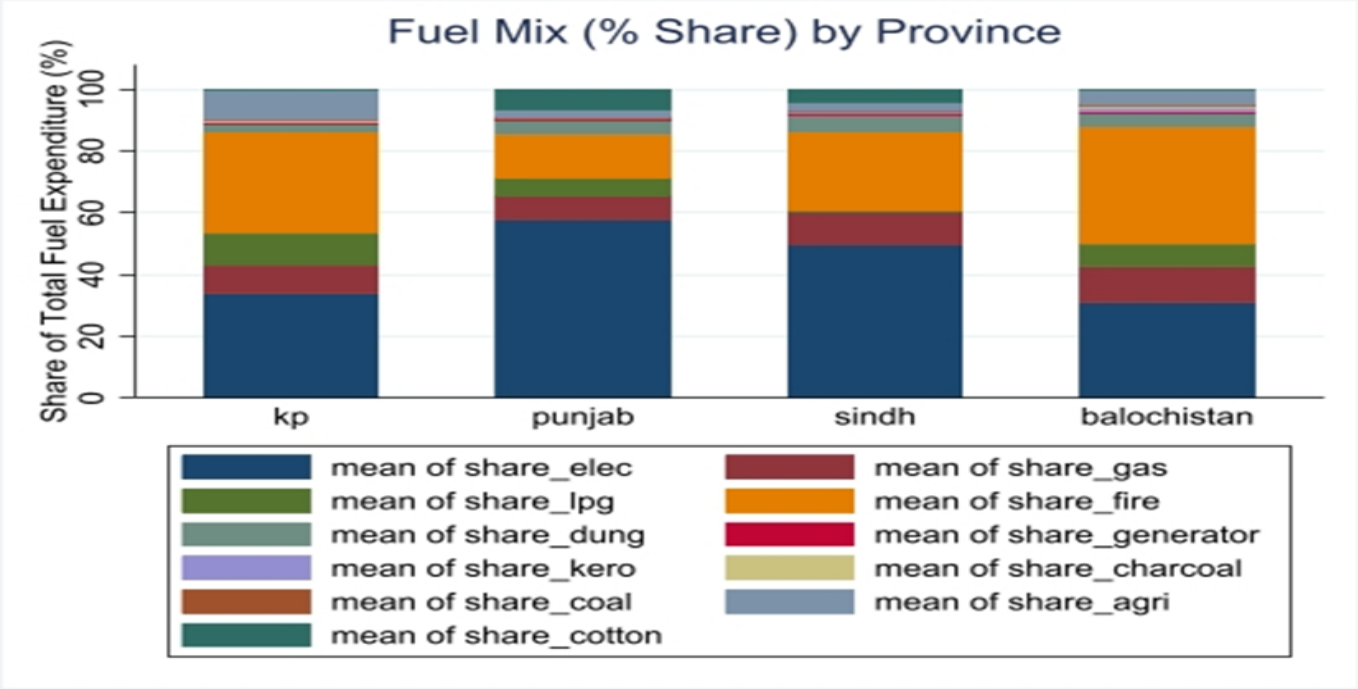
Figure 3: *Expenditure Share of Energy Fuels and Income in Pakistan*



Source: *HIES (2004-2019, Author's Own Calculation)*

Figure 4 depicts household fuel expenditure shares across provinces of Pakistan over 2018-19. Provinces of Punjab and Sindh exhibit more energy transition compared to the provinces of KP and Balochistan. Among these four provinces, Punjab shows the highest level of energy transition to cleaner fuels, while Balochistan shows the lowest level of energy transition. Among energy fuels, electricity dominates the other energy fuels, followed by firewood, gas, LPG, and other remaining fuels. In provinces of KP and Balochistan, firewood emerges and near dominant and dominant energy fuel competing with electricity in fuel expenditure, signifying the reliance of these provinces on traditional energy sources. Therefore, energy transition is uneven across regions because of less development, limited access to cleaner energy sources, and a lack of infrastructural development.

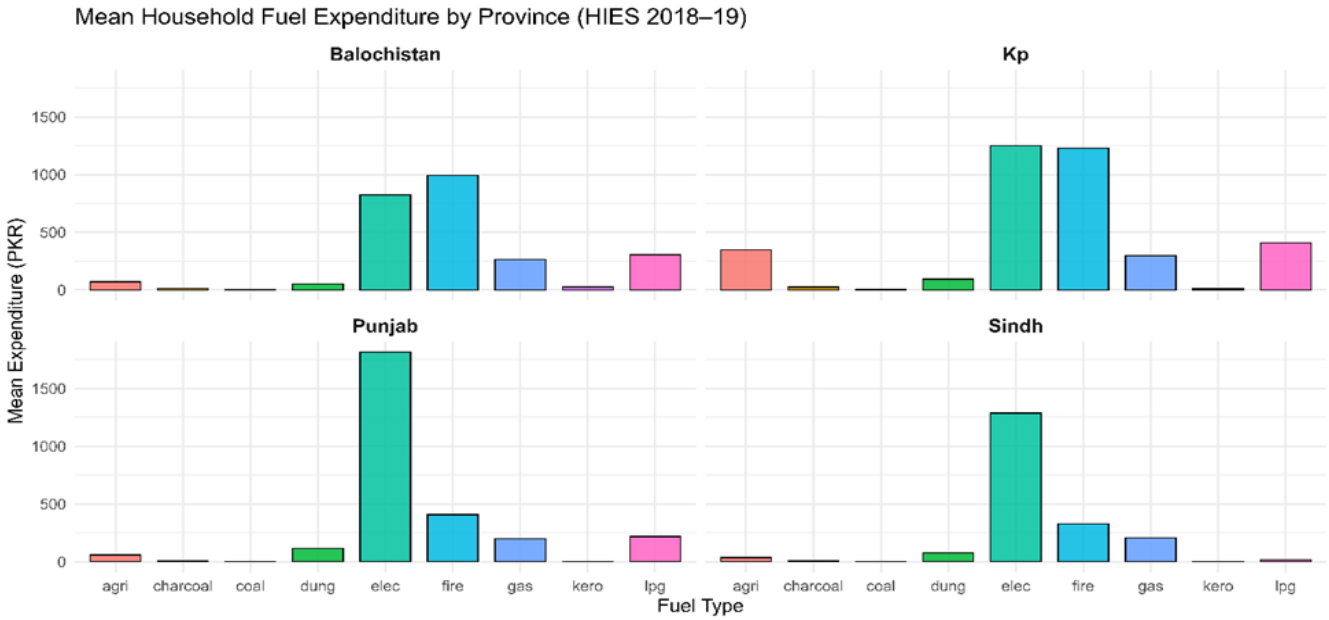
Figure 4: *Household's Fuel Mix (%Share) by Provinces 2018-19*



Source: *HIES, 2018-19 (Author's own calculations*

Figure 5 displays mean household fuel expenditures across Pakistan's four provinces during the 2018-19 period. In developed and populated provinces of Punjab and Sindh, household spends largest proportions on electricity. In Punjab, compared to electricity, all other fuels are in minor proportions, showing Punjab in a better position compared to other provinces. Conversely, in Balochistan and Khyber Pakhtunkhwa (KP), households prefer to expend more on firewood, where in Balochistan, households spend the largest proportion on firewood. This signifies provincial divide on energy mix, highlighting regional disparity and tracing the reasons behind the energy stacking behavior in Pakistan.

Figure 5: *Mean fuel expenditures by each province*

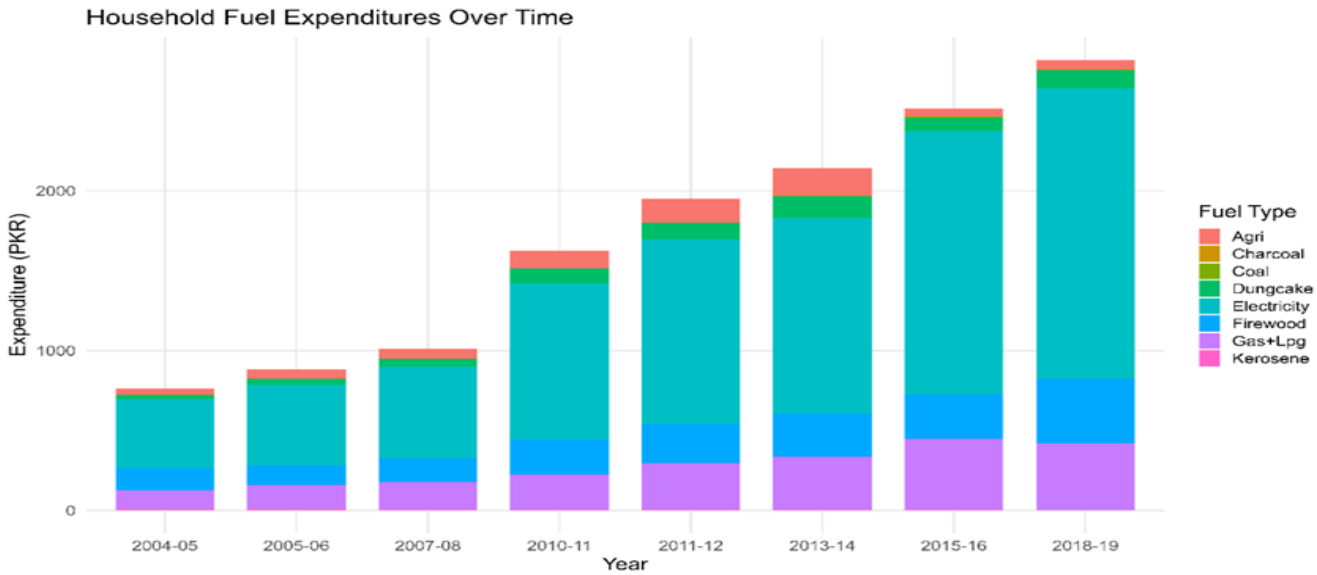


Source: *HIES, 2018-19 (Author's own calculations*

4.1. Energy Transition Across Provinces

After disaggregating the HIES data in four provinces of Pakistan, Figure 6 shows energy transition specifically within Punjab from 2004-05 to 2018-19. This graph highlights the increase in household fuel expenditures, which shows the persistent behavior of fuel stacking. This fuel stacking behavior is dominated by electricity throughout the time period, while expenditures on gas, LPG, and firewood have both steadily risen. Therefore, instead of climbing up the energy ladder, households in Punjab exhibit the consistent behavior of energy stacking, although the dominant fuel is electricity.

Figure 6: *Household Expenditure by Fuel Types (Punjab)*

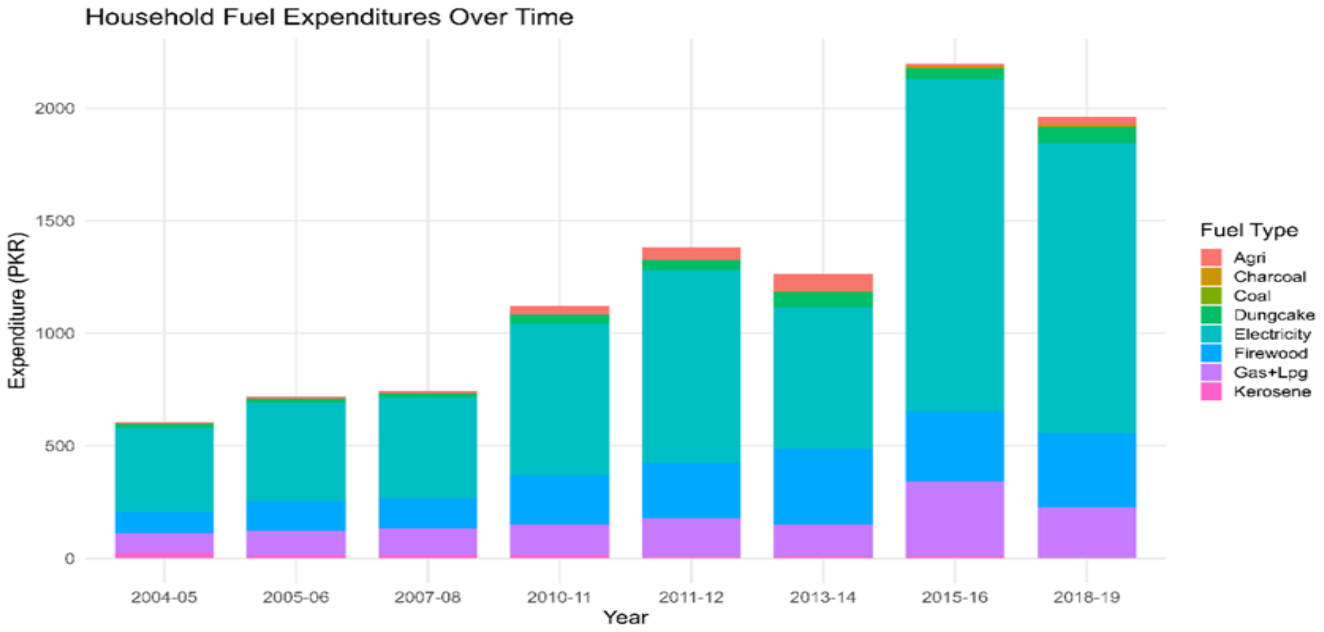


Source: *HIES, 2004-19 (Author's own calculations)*

Figure 7 shows shares of household fuel expenditures in Sindh from 2004-05 to 2018-19. This graph displays how Sindh experiences its own unique energy transition dynamics. Electricity remains the dominant energy source consumed by households. However, the transition level for Sindh also remains incomplete, as in Sindh, households persistently stack different modern fuels with traditional and transitional fuels. This illustrates that even within

a highly commercialized province like Sindh, pricing pressures and infrastructural deficits compel households to maintain a diversified stacking behavior by consuming both electricity and solid biomass.

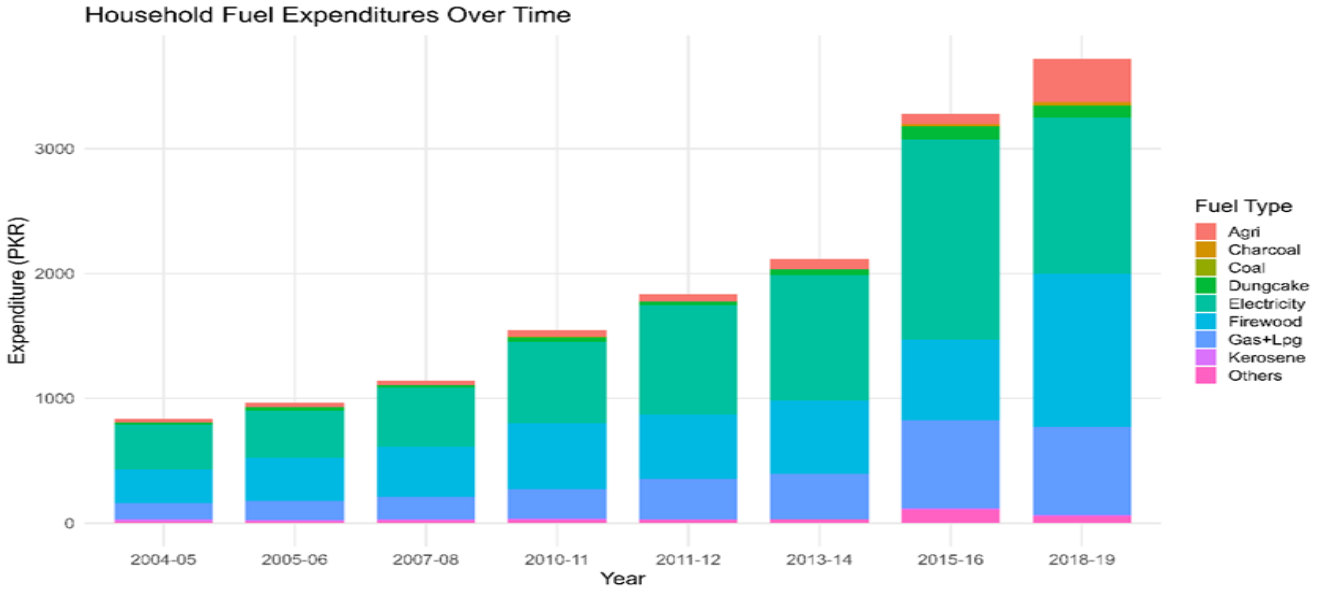
Figure 7: *Household Expenditure by Fuel Types (Sindh)*



Source: *HIES, 2004-19 (Author's own calculations)*

Figure 8 shows the proportions of household fuel expenditure trends in KP from 2004-05 to 2018-19. The province of KP presents intense fuel stacking behavior and is lagging in energy transition compared to Punjab and Sindh. Although expenditure on electricity is a major component of household energy spending, it did not displace other fuels. Instead, traditional biomass expenses grew over time, signifying a highly diversified fuel stacking behavior. Firewood and gas expenditures also experienced a rise, where firewood alone occupies a major segment of the household energy budget. This graph also highlights that households in KP face a compounding economic burden by coupling biomass fuels with modern fuels.

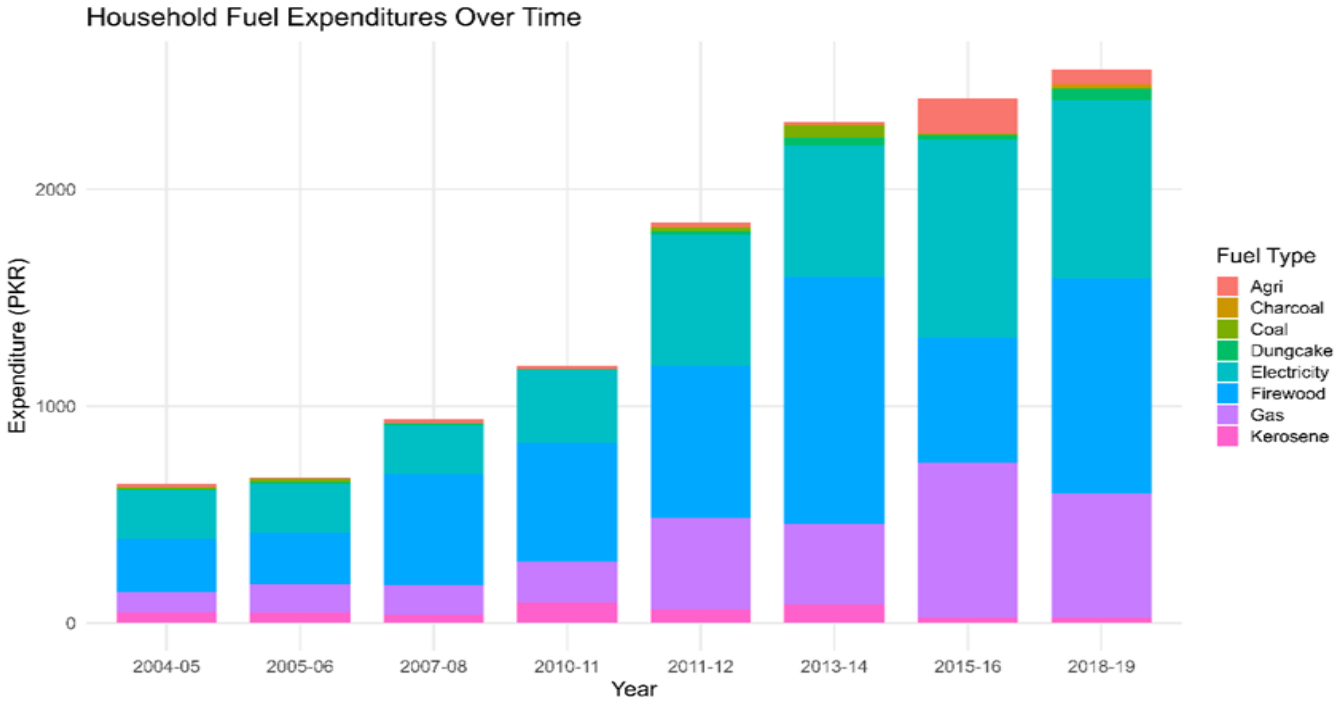
Figure 8: *Household Expenditure by Fuel Types (KP)*



Source: *HIES, 2004-19 (Author's own calculations)*

Figure 9 presents the proportions of household fuel expenditures in Balochistan from 2004-05 to 2018-19. This graph illustrates the most pronounced case of a delayed energy transition and high dependence on biomass compared to other provinces. In contrast to Punjab and Sindh, households in Balochistan are characterized by a heavy reliance on firewood and gas. The persistent stacking of electricity with firewood and gas demonstrates that infrastructural deficits and limited clean energy access have locked Balochistan's households into a highly traditional fuel dependent fuel-stacking pattern, where solid biomass remains an essential and costly survival necessity.

Figure 9: *Household Expenditure by Fuel Types (Balochistan)*

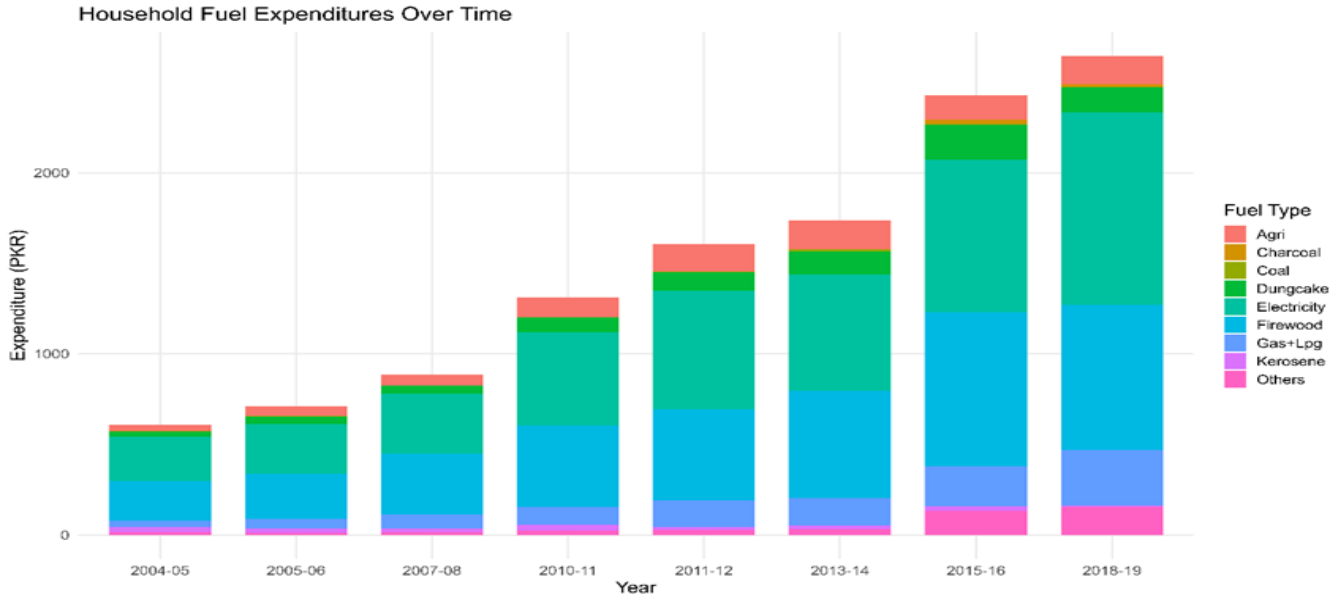


Source: *HIES, 2004-19 (Author's own calculation)*

4.2. Rural-Urban Trends in Energy Transition

Figure 10 shows the proportions of household fuel expenditures in rural Pakistan from 2004-05 to 2018-19. The graph displays that instead of substituting modern fuels for traditional old fuels, rural households rely on multi-fuel stacking throughout the time period. Expenditures on firewood also account for a major proportion of household energy expenditures, competing with the expenditures on electricity. Other fuels, such as dung cake and agricultural waste, are also persistent in the household energy consumption basket. Therefore, rural households also stack traditional and modern fuels and show intense energy stacking behavior similar to KP and Balochistan.

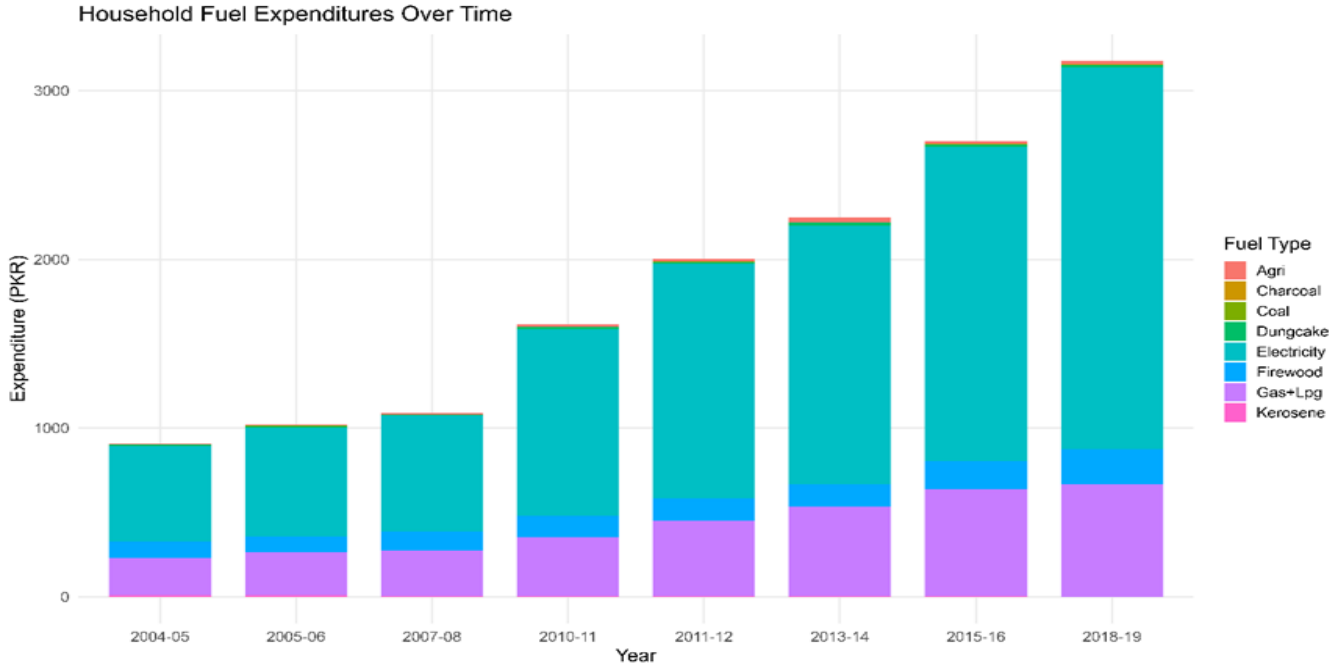
Figure 10: *Household Expenditure by Fuel Types (Rural Areas)*



Source: *HIES, 2004-19 (Author's own calculations)*

Figure 11 depicts the proportions of household fuel expenditures in urban Pakistan from 2004-05 to 2018-19. Urban households indicated a significantly more advanced level of energy transition compared to the rural households. Electricity overwhelming dominant the household energy expense. In contrast to rural areas, urban fuel stacking is characterized by a reliance on modern energy sources, primarily a combination of electricity and gas, and traditional fuels. This finding highlights a clear regional disparity, where higher levels of infrastructural development and urban commercialization have successfully shifted the household energy budget toward modern utilities, effectively marginalizing the role of traditional fuels.

Figure 11: *Household Expenditure by Fuel Types (Urban Areas)*

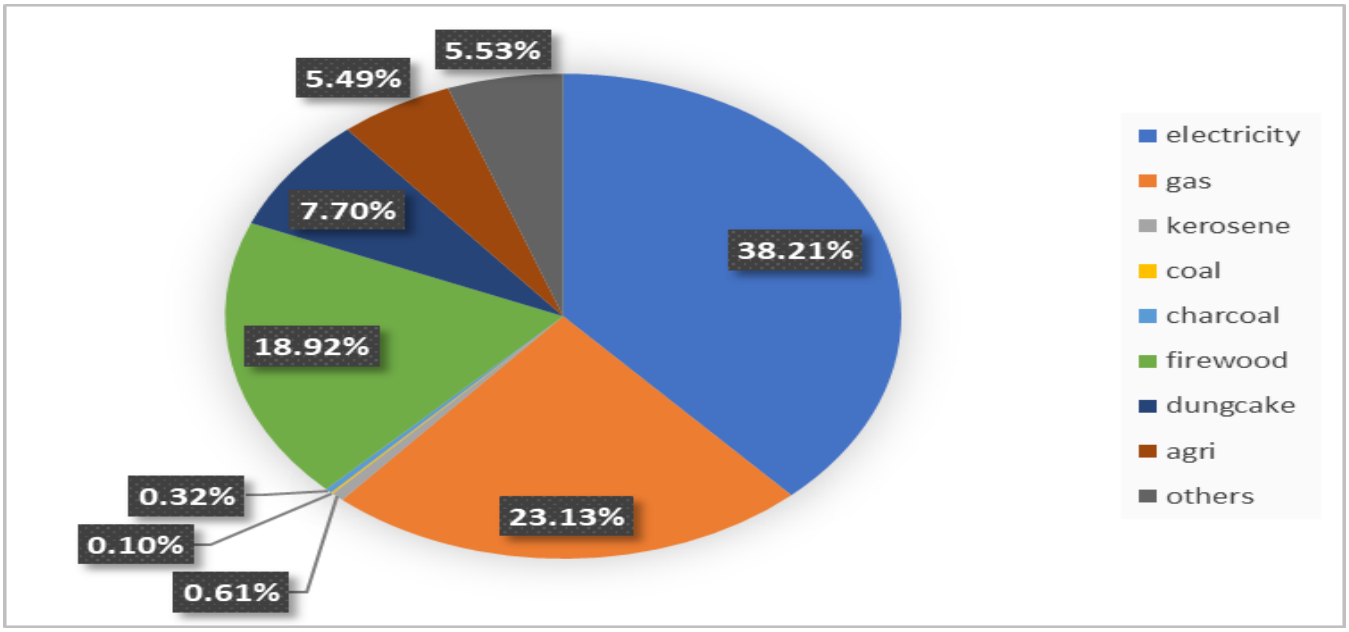


Source: *HIES, 2004-19 (Author's own calculations)*

Figure 12 shows the final percentage shares of household energy consumption in 2018-19 in Pakistan. Modern fuels such as electricity increased to about 38.21% share of total final energy consumption of households in 2018-19, while proportions of gas are the second highest

with its share of 23.13%. Among dirty fuels, firewood is the most consumed energy source, having 18.92% proportions in total energy consumption, which is the third highest after electricity and gas. Similarly, the share of dung cake is 7.70%, and agricultural waste is 5.49%. Therefore, from the following findings, energy stacking dynamics become clearer with the proportions of each fuel in the total final energy consumption. Ultimately, comparing these shares reveals that while infrastructure development has successfully brought modern electricity and gas into the majority of Pakistani households, it has not triggered a complete energy transition. Instead, it has institutionalized a resilient fuel stacking paradigm where nearly a third of households still rely on traditional solid fuels alongside modern utilities.

Figure 12: *Percentage Share of Each Fuel in Household (2018-19)*



Source: *HIES 2018-19 (Author's calculation and estimations)*

5. Conclusion

This study has employed descriptive and graphical analysis to investigate the regional and provincial heterogeneity in household energy transition. By using consecutive eight Household Integrated Economic Survey (HIES) from 2004-05 to 2018-19, energy stacking behavior across Pakistani households has been examined. To this end, we have disaggregated datasets at regional and provincial levels to investigate household energy choices across regions and provinces to investigate their energy choices. The findings suggest that although Pakistan has made significant improvements in energy transition, it still dominantly relies on traditional fuels. The traditional model of the energy ladder hypothesis fails to capture the multi fuel consumption patterns in households. Therefore, energy stacking behavior is found to be most consistent with variation in the degree of energy stacking across regions and provinces.

Electricity and gas experienced an increase in their consumption from 2004-05 to 2018-19, where electricity maintained its dominant position while gas experienced a slight decline in 2018-19. Transition fuels consumption reduced consistently across the time period and reached its lowest level in 2018-19. Dirty fuels still have maintained their share in total energy consumption of households, where firewood consumption leads dirty fuels, and in rural, KP, and Balochistan regions, it even competes with electricity consumption. Therefore, households prefer to stack different energy fuels rather than to consume a single fuel.

The core contribution of this research lies in exposing provincial and regional divergence that characterizes this transition. A stark regional divide separates the economically advanced provinces of Punjab and Sindh from the peripheral regions of Khyber Pakhtunkhwa (KP) and Balochistan. The provinces of Punjab and

Sindh experienced a relatively higher level of transition to cleaner fuels, where Punjab began as better performer among the provinces, but it still holds small fractions of traditional fuels. Households in KP and Balochistan are still relying on traditional dirty fuels, whereas in Balochistan, expenditures on firewood dominate even expenditures on electricity. Therefore, among provinces, Punjab leads the energy transition, while Balochistan is among the least transitioned provinces. Similarly, in regional analysis, urban households have higher rates of energy transition to cleaner fuels and have small shares of traditional fuels. In contrast to urban households, rural households still allocate a major share of their energy expenditures to traditional fuels. Therefore, urban households' energy stacking is led by modern fuels, while rural households are still facing both traditional and modern fuels as competing forces in their energy consumption basket.

Ultimately, these findings carry critical policy implications for Pakistan's sustainable development. This existence of regional and provincial disparities proves that a centralized energy policy cannot address divide in energy transition across regions. Energy transition can be improved by expanding regional LPG distribution networks in less developed areas and provinces and by subsidizing the adoption of clean energy. Further adoption of energy efficient appliances in rural areas foster energy transition in rural and less developed regions.

Conflict of Interest

The authors showed no conflict of interest.

Funding

The authors did not mention any funding for this research.

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