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Contextualizing the Energy Models for Nepal: A Comprehensive Framework for Assessing Household Energy Choices and Clean Energy Transition

by
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ABSTRACT

Nepal's household energy landscape is in a gradual but uneven transition from traditional biomass to modern fuels. Despite distinct regional energy use patterns, region-specific policies remain limited. This study examines the energy consumption behavior of 586 households across Kathmandu (urban), Chitwan (semi-urban), and Ramechhap (rural). It critiques the traditional energy ladder model and underscores the relevance of the energy stacking model in Nepal's diverse socio-economic context. To quantify and compare clean energy adoption across regions, the study introduces a Household Energy Transition Index (HETI), built using the 6E framework: Ease of Access, Collection, Use, Economy, Efficiency, and Environmental Impact.

Findings reveal that urban households primarily use LPG and electricity, rural households depend heavily on firewood, and semi-urban households exhibit a transitional fuel mix. HETI effectively reflects these transitions. Socioeconomic variables—education, income, and occupation—emerged as key influencers in household energy decisions. Despite infrastructure development, Nepal's energy transition is hindered by affordability issues, inconsistent supply chains, and persistent traditional practices. The study recommends targeted, region-specific strategies including financial incentives, expanded rural electrification, and culturally adapted awareness programs to foster an equitable and sustainable energy transition across the country.

Keywords: *energy transition, energy stacking, household energy consumption, clean cooking, rural-urban energy divide*

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LIST OF ABBREVIATIONS

AEPC	Alternative Energy Promotion Centre
CES	Center for Energy Studies
CH_4	Methane
CO_2	Carbon Dioxide
COVID	Coronavirus Disease
DC	Direct Current
DFID	Department for International Development
DOI	Digital Object Identifier
EEDA	End-Use Energy Demand Assessment
EGDP	Energy Intensity of GDP
EKC	Environmental Kuznets Curve
ETI	Energy Transition Index
EU	European Union
EV	Electric Vehicle
FAO	Food and Agriculture Organization
FP	Fuel Portfolio
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Gigajoule
GTZ	German Technical Cooperation
HETI	Household Energy Transition Index
HH	Household Head
ICS	Improved Cook Stove
IEA	International Energy Agency
IHDS	India Human Development Survey
IOE	Institute of Engineering
LDC	Least Developed Countries
LPG	Liquefied Petroleum Gas
NLSS	Nepal Living Standard Survey
OLS	Ordinary Least Squares
PV	Photovoltaics
SS	Steering Stacking

LIST OF SYMBOLS

F_P	Fuel Portfolio: Total number of different fuels used by a household
SS	Steering Stacking: Ratio of clean fuels used to total fuels used
l_i	Gini–Simpson Index: Diversity index reflecting energy mixing behavior
L_i	Stacking Up the Ladder Index: Combines diversity and share of clean fuels
LR_i	Ladder Rank: Energy ranking of fuels based on the 6E framework
RP_i	Fuel Ranking Point: Normalized score of a fuel's ladder position
FW_j	Fuel Weightage: Share of each fuel weighted by its ladder rank
ETI_i	Energy Transition Index: Composite score from 1 (traditional) to 2 (modern)
β	Coefficient estimate in regression analysis
ϵ	Error term in OLS regression
Y_i	Dependent variable (e.g., energy consumption for a fuel type)
X_i	Independent variable (e.g., income, education, household size)

CHAPTER ONE: INTRODUCTION

1.1 Background

Access to modern, clean energy is a key component of sustainable development worldwide [1]. While substantial progress has been made globally, around 2.3 billion people primarily in the global South still rely on traditional biomass fuels such as fuelwood, agricultural residues, and animal dung to meet basic household energy needs [2], [3]. In rural and underprivileged regions, the transition to modern energy systems remains significantly hindered by inadequate infrastructure, income inequality, and failures within energy markets, as a result, dependence on traditional energy sources persists more severely in these areas [4], [5]. In such contexts, inefficient biomass combustion contributes to adverse health effects, deforestation, and socio-economic inequalities, disproportionately affecting women and children through indoor air pollution and drudgery linked with fuel collection [6]–[8].

Nepal exemplifies the multidimensional challenges of household energy transition faced by least developed countries (LDCs). Although electricity connectivity has reached approximately 99% of households, a significant proportion, especially in rural and semi-urban areas, continues to rely on biomass for cooking and heating [9], [10]. According to recent estimates, firewood remains the primary cooking fuel in over 79% of rural households, while urban areas show a higher adoption of LPG and electricity [9], [11], [12]. This rural-urban energy divide highlights broader structural inequities in energy access and reflects persistent barriers in affordability, infrastructure, and institutional support.

The energy ladder model has historically been used to explain home energy transitions [13]. It suggests a linear progression from traditional to modern fuels with increasing affluence and socioeconomic development [13]–[16]. However, this model has been increasingly critiqued for oversimplifying household fuel choices. In its place, the fuel stacking paradigm, where multiple fuels are used concurrently has emerged as a more realistic framework that accounts for factors such as reliability, cultural preferences, seasonal variability, and fuel availability [17], [18]. Studies from Nepal confirm that households frequently engage in fuel stacking, even after gaining access to modern energy sources mainly due to affordability concerns and unsatisfactory energy services [9], [12], [19].

Recent research highlights that energy behavior in Nepal is highly context dependent. Socioeconomic status, fuel prices, government subsidies, access to infrastructure, and deeply embedded cultural practices are some of the factors that jointly shape energy choices [9], [20]. Even among electrified households, electricity use for cooking remains minimal due to cost, load-shedding, or appliance limitations. While LPG usage has grown in urban regions, adoption remains limited in remote and economically disadvantaged areas due to high cylinder costs and unreliable supply chains [21]. Government programs such as those promoted by the AEPC, including biogas, ICS, and micro-hydro—have shown limited uptake and uneven geographic reach, constrained by technical, financial, and behavioural challenges [19], [20]. Despite Nepal's theoretical abundance of hydropower resources, the country continues to rely significantly on imported petroleum products, which strains the economy and reduces energy sovereignty [11]. Residential energy consumption alone accounts for over 60% of total national energy use, largely dominated by inefficient biomass combustion [11]. Furthermore, energy inequities persist; while some Terai region districts have relatively better access to LPG and electricity, hilly and mountainous regions remain underserved [9].

From a policy and planning perspective, Nepal's energy sector operates within a nexus of competing priorities like economic development, environmental sustainability, and social equity. The necessity of inclusive and equitable energy access is emphasized by international frameworks like the United Nations Sustainable Development Goals, especially SDG 7 on inexpensive and clean energy [22]–[24]. However, Nepal's progress has been limited by fragmented governance, weak institutional capacity, and lack of behavioral insights in energy planning [20], [25]. Some articles have noted, socio-economic heterogeneity and climate perceptions to significantly shape household energy behavior, suggesting the need for models that capture these dynamics within local contexts [26]. Likewise, Econometric modeling has emerged as a promising tool for understanding and forecasting energy consumption [27]. In this regards there are researches that proposed a suite of fuel-specific and sectoral econometric models based on macroeconomic indicators such as GDP, fuel prices, vehicle ownership, and demographic trends [28],[20] . These models provided medium-term forecasts and policy implications, laying groundwork for future research. However, they were limited in their ability to incorporate micro-level factors such as intra-household decision-making, energy preferences, and behavioral responses to policy instruments. More recent studies argue for multidimensional energy frameworks that incorporate energy (in)security, crisis adaptation, and perceptions of energy justice [29], [26], [30].

1.2 Problem Statement

Despite global and national efforts to facilitate household energy transitions, Nepal continues to experience slow progress in shifting from traditional biomass fuels to modern energy sources [31]. The residential sector remains the largest energy consumer, with firewood usage still dominant in rural areas, despite an increase in LPG and electricity adoption in urban settings. The transition towards clean energy remains slow and inconsistent, particularly in rural and semi-urban regions.

Existing energy transition models, such as the energy ladder and fuel-stacking framework, provide useful but limited insights into household energy dynamics in least developing nations [32]. Although the energy ladder model proposes a straight route from biomass to contemporary fuels, empirical data from Nepal supports the fuel-stacking model, in which households use several fuels at once depending on availability, price, and sociocultural considerations [17], [18], [31]. To quantify and interpret these energy transition patterns, more study is required as even fuel-stacking studies are still few in Nepal.

This thesis aims to assess and improve energy modeling in Nepal by integrating econometric techniques with socio-behavioral insights. It critically reviews previous modeling efforts and constructs household-level models using both primary and secondary data. This study analyzes household energy consumption patterns across urban, semi-urban, and rural regions to understand the dynamics of energy transition. It applies existing models such as the energy ladder and energy stacking approaches, and further investigates key socioeconomic and geographical factors. Based on these insights, a region-specific index tailored to the Nepalese context is formulated for more accurate representation of household energy transitions.

1.3 Research Questions

a. How do household energy consumption patterns and transition behaviors vary across rural, emerging city, and urban areas in Nepal, particularly in relation to energy ladder and energy stacking models?

b. How can a HETI be developed using the 6E Framework to systematically evaluate household energy transitions in Nepal?

c. What are the key socio-economic and geographical factors influencing household energy transitions in Nepal, and how can they inform data-driven sustainable energy policies?

1.4 Objectives of the Research

Main Objective:

To assess and model household energy transition in Nepal by integrating the Energy Ladder, Energy Stacking, and 6E Framework across rural, emerging city, and urban areas.

Specific Objectives:

a. To analyze household energy consumption patterns and transition behaviors across rural, emerging city, and urban areas in Nepal using the base of energy ladder and energy stacking models.

b. To develop a HETI using the 6E Framework ("Ease of Access, Ease of Collection, Ease of Use, Ease of Economy, Efficiency, and Environmental Friendliness").

c. To identify key socio-economic and geographical factors influencing household energy transitions and provide data-driven recommendations for sustainable energy policies.

1.5 Limitations

a. **Geographic Coverage:** While Kathmandu, Chitwan, and Ramechhap offer diverse urbanization patterns, the findings may not generalize to all ecological regions of Nepal, such as the high Himalayas or Terai lowlands.

b. **Temporal Limitation:** The use of cross-sectional data constrains the ability to track household energy transition dynamics over time or establish causal inferences.

c. **Index Calibration:** The HETI framework relies on weighted parameters, some of which—such as emission intensity and fuel convenience—depend on expert judgment due to limited standardized national benchmarks.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Numerous studies have been conducted on household energy use and its effects on the environment, including indoor and outdoor air pollution, forest degradation, and other issues. Additional studies have explored the dynamics of energy demand and supply, alongside macroeconomic analyses linking energy use to environmental outcomes, often framed within the EKC hypothesis.

The continued dependence on traditional biomass and polluting fuels has been strongly linked to negative health impacts, hindered human capital development, and the perpetuation of poverty, particularly in low-income settings [6]. In response, public policy measures have included fuel subsidies, the advancement of cleaner technologies, and the distribution of ICS to promote cleaner energy use at the household level [33], [34]. While the social, cultural, and economic viability of new stoves determines their continuous usage, the majority of interventions targeted at promoting clean cooking stoves solely address technical factors like their efficiency and the possible emissions reductions [35]. Recent findings suggest that in addition to household size, the number of families within a shared living arrangement serves as a stronger predictor of biomass consumption, due to economies of scale [12], [36]. This dynamic is especially relevant in the context of rapidly modernizing societies in developing and underdeveloped countries, where communal living and resource-sharing practices remain common [12], [31].

In the case of Nepal, the national consumption is dominated by the residential sector, which accounts for 60.59% of the total consumption or 387.78 PJ [11]. Fuelwood still dominates residential energy use in Nepal at 79.52%, though its share has dropped from 87% from previous years due to more efficient technologies, reflecting a gradual energy transition [11]. However, the sector remains vulnerable with rising reliance on imported LPG, which has more than doubled over the past decade [37]. The push for alternative energy sources like biogas and solar, along with increased electricity use, supports this shift toward cleaner energy. Despite a temporary setback in renewable energy growth during the pandemic, consumption trends resumed post-restrictions.

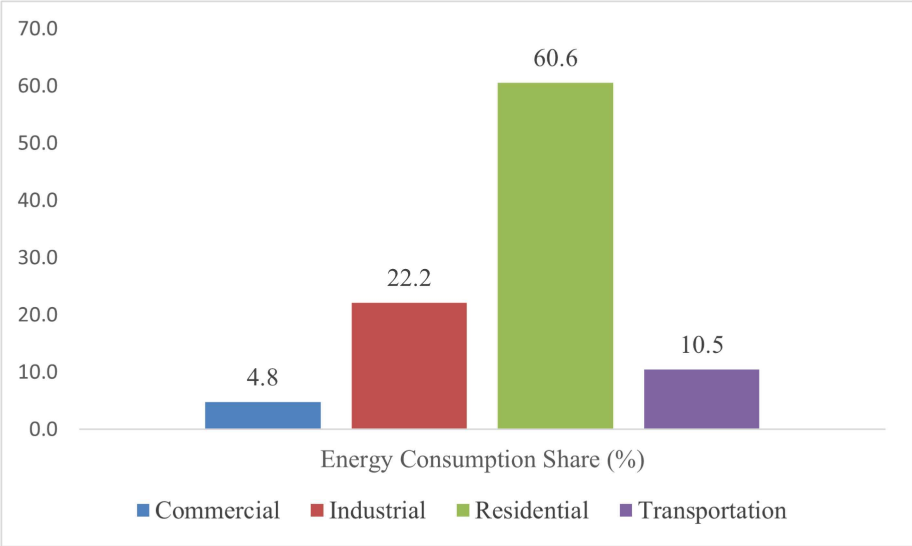

Figure 2.1: Sectoral Energy Consumption in Nepal [11]

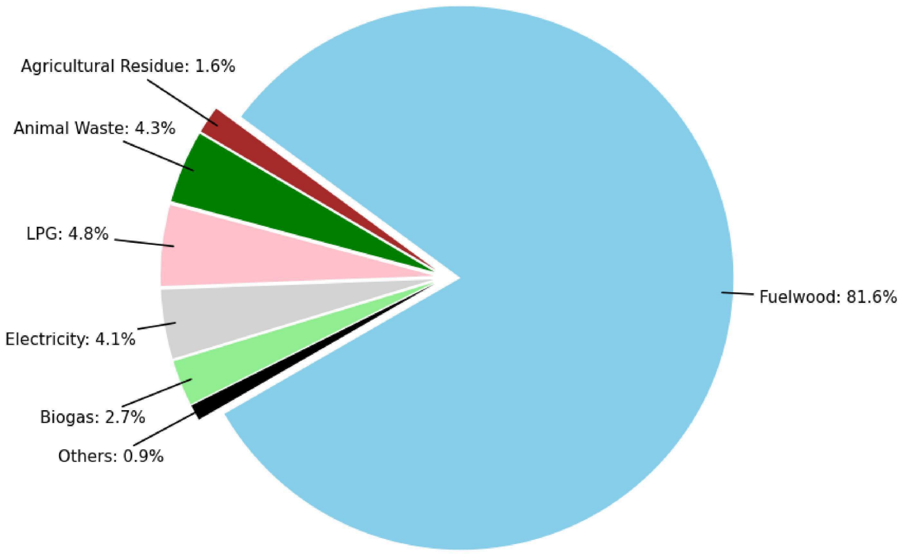

Figure 2.2: Residential Fuel Types [11]

2.2 Household Energy Transition

Households play an increasingly important role in the efforts to lower proportion of energy derived from fossils and other biomass [38]. The share of household energy consumption in total energy consumption is significant [39]. It is estimated that households consume nearly one-third of the world's energy supply. For example, household energy consumption accounts for almost 25% of total energy consumption in Germany [40], and the residential sector accounts for about 21.5% of total energy consumption in the U.S [41]. As such, household-oriented energy policies should not be taken lightly. Likewise, in Nepal, the majority of total energy consumption is residential [11]. The Figure 2.1 shows the breakdown of all the different energies used by Nepalese households.

Economic growth and development are associated with the transition in household energy use from traditional biomass to modern fuel sources [42]. This transition process can occur in three scenarios. First, modern energy types replace biomass energy sources. Second, the quantity of biomass energy remains the same, but the amount of non-biomass energy increases, leading to higher total household energy consumption. Third, the amount of biomass energy increases, but non-biomass energy increases even more [43].

Moreover, households use multiple types of fuels and energy-consuming appliances. Understanding the household energy transition process requires focusing on adopting and using modern fuels and reducing the use of traditional fossil fuels and firewood. In developing countries, people still depend on traditional energy sources such as biomass, firewood, and kerosene for daily use [44], [45]. The main reason for this choice is that traditional fuels such as firewood and biomass are readily available, especially in rural areas. Additionally, access to modern fuels in rural areas remains a challenge. Budget constraints also lead households to trade off between energy costs and fuel quality [46].

2.3 Household Energy Transition across South Asian Nations

A complex interaction of economic, social, cultural, and infrastructure elements shapes household energy changes in South Asia, especially in India and Nepal [8], [47]. In India, studies using IHDS data have shown a gradual shift from traditional biomass to cleaner fuels like LPG, although the pace varies across socio-economic groups, with barriers such as affordability and accessibility slowing adoption [48]. Comparative studies indicate that China has progressed faster than India in residential energy transition due to stronger policy frameworks and urbanization [49]. Broader analysis across 45 Asian economies confirms that income growth facilitates cleaner energy use but is insufficient without complementary infrastructure and policy support. In India, cultural preferences, infrastructure disparities, and awareness gaps significantly affect LPG adoption [50], while spatial inequalities in urban energy access persist [51].

In Nepal, the energy transition has been slow and uneven. Although residential energy use slightly increased in 2020–2021, the ETI shows stagnation [3]. Nepal lags behind other South Asian countries in electricity consumption, with rural areas still heavily reliant on biomass due to income and access barriers [9], [20]. While research has explored renewable adoption and socio-economic determinants of fuel choice [12], [52], there remains a gap in understanding energy ladder and stacking dynamics across rural, semi-urban, and urban settings. Nepal's declining Energy Transition Index—from 50.1 in 2019 [53] to 49.6 in 2024 [54], underscores the inadequacy of current policies and the need for more nuanced, region-specific strategies to foster equitable, sustainable household energy transitions.

2.4 Energy Choices, Energy Security, Environmental Sustainability and Socio-economic Development

The Table 2.1 highlights relationship between the 3E's with socio-economic development.

Table 2.1: 3E Benefits from Net-Zero Emission Strategy in Nepal [55]

Dimension	Key Findings	Indicators & Implications
Energy Security	Nepal's WAM (With Additional Measures) scenario enhances energy security by reducing import dependency and improving domestic energy supply.	• Net Energy Import Ratio (NEIR) reduced significantly • Share of Renewable Energy (SRE) increases • Energy Intensity of GDP (EGDP) drops from 46.7 GJ/1000 USD (2019) to 15.8 GJ/1000 USD (2050) • Indicates improved availability, accessibility, and efficiency in energy supply, reducing economic vulnerability
Environmental Sustainability	Transition to renewable energy significantly reduces GHG and air pollutants, supporting climate and environmental health.	• CO_2 emissions reach net negative by 2050 • BC reduced by 85.6%, OC by 69.9% • Overall GHG reduced by 78% under WAM compared to REF • Mitigates climate change, reduces indoor/ambient air pollution, and slows glacier melt
Socio-Economic Development	Improved energy access supports equity and development outcomes like productivity, health, and income growth.	• Electricity consumption per capita increases from 276 kWh (2019) to 3396 kWh (2050) • Meets global average of electricity use • Promotes energy equity, supports SDG-7, enhances quality of life, and reduces energy poverty

2.5 Theoretical Framework

2.5.1 Overview of Energy Ladder Hypothesis:

The concept of energy ladder gained attention in the 1970s and 1980s, primarily due to the growing concerns of fuel-wood crisis [14], [15]. This period saw significant burgeon of interest among energy experts and researchers in understanding the household fuel choices and their economic situation. The energy ladder postulates hierarchical transition from traditional biomass fuels, such as fuel-wood, to more modern and efficient energy sources as the household income rises, according to a paper from 1987 [16]. This is credited as the first academic work to contextualize the relationship between rising economic status and household use of fuel type. This idea elaborates on the consumer economic theory relating it to energy, assuming that households make choices about energy options based on the goal of maximizing their utility [16], [17], [56]. The transition from less efficient to cleaner alternatives like energy is viewed as rational decision-making maximizing the overall household well being, considering cost, convenience, and health impact.

The energy ladder model was initially structured as a five-rung hierarchy, with electricity at the top, followed by kerosene, purchased firewood, and gathered firewood at the base [16], [56], [57]. It was observed that Zimbabwean households moved up this ladder as their income increased [56]. In 1995, the model was expanded to include a six-step ladder, adding animal dung, charcoal, and LPG [58]. A later refinement classified fuels into primitive, transitional, and modern categories, highlighting gaps in understanding energy transitions [56]. Further categorizations were made based on specific activities like cooking and lighting [59]. The association between household income and fuel preference is highlighted by these studies taken together, along with the overall trend of switching from traditional to a contemporary fuels [57], [60].

2.5.2 Criticism of Energy Ladder Hypothesis and Overview of Energy Stacking:

There are of course later criticisms and modifications to the energy ladder hypothesis, called the energy-stacking model. While the energy ladder suggests a linear progression from traditional to modern fuels with rising income, the energy stacking model suggests that households do not completely abandon inferior fuels but use multiple fuel types simultaneously, sequentially increasing the reliance on superior fuels as income rises. For example, a study in three Mexican states observed that only a small percentage of households completely abandoned biomass [17], while another found that less than 10% of rural households in Hubei, China fully stopped using biomass [18]. Similarly, despite widespread ownership of LPG stoves in Guatemala, 77% of migrant households still primarily used fuelwood [15].

The main justification for this is that the energy stacking approach provides households with greater energy security, allowing them to switch between fuels based on availability, cost, and income fluctuations. This flexibility offers important context when there are fuel supply and price volatility [17]. Additionally, critics argue that the energy ladder fails to account for cultural and habitual factors influencing fuel choices, such as education, household composition, and tradition [14].

A survey across eight developing countries found a positive and significant effect of household head education on the choice of modern fuels, especially for developing nations [6]. Recognizing these limitations, the study proposed the "energy profile cube," which incorporates the quality of fuel, the efficiency of conversion technology, and the demand for energy as dimensions for understanding household energy use.

2.5.3 Choice Between the Models and Modifications:

The debate between proponents of the energy ladder and fuel stacking models continues, partly due to varying definitions and applications of these concepts. For example, one study found that while the share of biomass declined with rising income in northern Thailand, the decline was gradual rather than abrupt, supporting both models depending on data interpretation [61].

One of the significant challenges in applying the energy stacking model lies in the difficulty of ranking fuels. The model inherently involves a more intricate set of variables than the energy ladder, making it harder to create a standardized or universally applicable measure of energy use. This complexity is exacerbated by the varying definitions and conceptual frameworks used in research, leading to inconsistencies in how energy stacking is quantified and interpreted.

Some studies attempted to address these challenges by developing a measure that combines aspects of both the energy ladder and energy stacking models [62]. This approach aimed to provide a more comprehensive estimate of energy stacking by considering the simultaneous use of multiple fuels. However, this measure has its limitations. For instance, it assigns a higher value to households that use a combination of fuels rather than those that rely entirely on modern fuels. This scoring system may inadvertently favor the practice of fuel stacking even when it may not reflect a household's optimal energy situation.

Furthermore, the exclusion of transitional fuels such as coal and kerosene in the methodology introduced a potential bias. These fuels often serve as intermediates between traditional and modern energy sources, and their omission could skew results and lead to an incomplete understanding of household energy transitions [62]. Furthermore, despite the fact that the literature has created a thorough measure that combines the ladder and stacking frameworks to quantify the phenomena of energy stacking, this measure has drawbacks [57]. It assigns higher weight to households using multiple fuels, for instance, a household with 100% modern fuel consumption may score lower than one that consumes 90% electricity and 10% firewood [57], [62]. Moreover, by ignoring transitional fuels such as coal and kerosene, a form of bias is introduced. A more contemporary method could involve developing a new framework for ranking various fuels and creating a "Household Energy Transition Index" that integrates the 6E factors. This approach, as validated in the context of Pakistan, may better elucidate the transition process from traditional to modern fuels in Nepal [61].

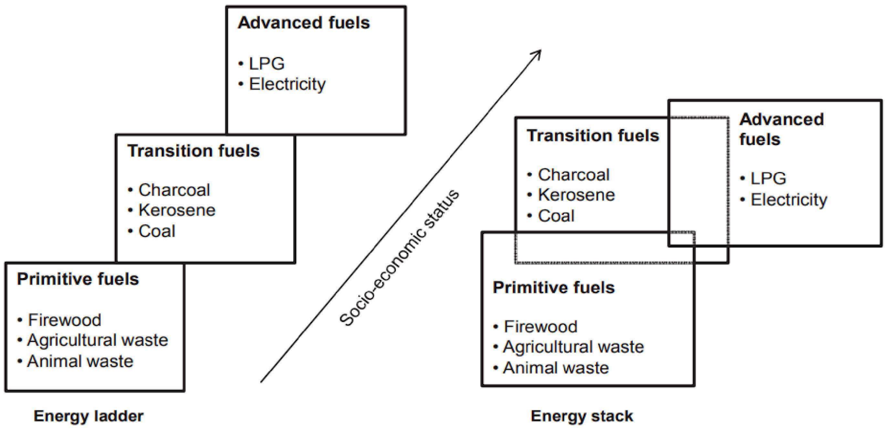

Figure 2.3: Energy Ladder and Energy Stacking [56]

2.6 6E Framework for Fuel Choice

To better understand household energy choices, the 6E Framework provides a structured approach by evaluating fuel options based on six key factors [57]:

a. **Ease of Access:** Fuels are ranked based on their availability and distribution. Traditional biomass fuels like firewood are readily accessible in rural areas, whereas LPG and electricity are more prevalent in urban settings [14], [17].

b. **Ease of Collection:** The effort required to obtain fuels influences household choices. Firewood collection demands significant labor, while modern fuels such as LPG and electricity require minimal effort [14], [17].

c. **Ease of Use:** The complexity of using a fuel impacts its adoption. Firewood and biomass require manual handling, whereas LPG and electricity offer convenience and efficiency [17], [56].

d. **Ease of Economy:** Economic feasibility plays a major role. Firewood is often freely available but has high opportunity costs, while LPG and electricity involve recurring expenses but provide higher efficiency [14], [17].

e. **Efficiency:** Fuel efficiency determines energy output. Traditional biomass sources have low combustion efficiency (as low as 15%), whereas LPG and electricity offer significantly higher efficiency levels [14], [17], [57].

f. **Environmental Friendliness:** The environmental impact of fuel choices varies. Firewood and biomass produce high emissions of CO_2 and methane, while LPG and electricity provide cleaner alternatives [14], [56].

The 6E Framework provides a comprehensive tool to assess household energy transitions and supports the formulation of sustainable energy policies for Nepal.It provides a significant advancement over traditional models like the Energy Ladder and Energy Stacking by integrating both household centered factors (ease of access, collection, use, and economy) and policy relevant dimensions (efficiency and environmental friendliness) into a unified, quantifiable structure. Unlike the energy ladder, which assumes linear fuel progression, or energy stacking, which often lacks clear transition thresholds. HETI and the 6E provides a continuous index between 1 and 2 that allows for precise measurement of household transition stages based on the various fuels used. This approach resolves empirical biases inherent in previous models and enables statistical robustness in analyzing energy behavior [57]. For a geographically and socioeconomically diverse country like Nepal, where households often rely on multiple fuels and exhibit non-linear transitions, the 6E-based HETI offers a flexible, context-sensitive, and policy-aligned tool for effectively assessing and guiding household energy transition pathways.

2.7 Major Factors Affecting Fuel Choice in Nepal

The trajectory of household energy transition in Nepal reveals a multifaceted interaction of socioeconomic, infrastructural, behavioral, and regional determinants. A recurring empirical concern is the disconnect between improved access to modern fuels—such as electricity and liquefied petroleum gas (LPG) and the continued dependence on traditional biomass [11]. This phenomenon challenges conventional linear models of energy transition, such as the Energy Ladder Hypothesis, prompting scholars to explore more nuanced explanations of household fuel choices.

The Energy Ladder Hypothesis suggests that rising household income leads to a gradual shift from traditional biomass fuels to transitional fuels (like kerosene and LPG), and eventually to modern fuels (such as electricity). However, empirical findings from Nepal complicate this narrative. Despite income improvements, many households continue practicing fuel stacking using multiple fuels for different purposes. Analyses of NLSS data report that income is a necessary but insufficient factor for clean fuel adoption [20], [63]. This divergence from the linear transition model has become a focal point in recent energy research.

2.7.1 Socioeconomic Determinants

Household energy decisions are significantly influenced by important socioeconomic factors, including occupation, household size, income, and education. For example, the usage of clean fuels like LPG and electricity is favorably connected with both better educational attainment and employment in non-agricultural occupations [9], [17], [18], [20]. It is also shown that while wealthier households are more likely to adopt modern fuels, they often retain traditional fuels due to cultural familiarity and cooking preferences [8], [63].

2.7.2 Infrastructure and Supply-Side Constraints

Energy infrastructure significantly shapes household fuel choices. The reliability, accessibility, and affordability of fuels act as critical determinants. Studies highlight how Nepal's load-shedding era discouraged electricity based cooking, even among grid-connected households [64]. Additional evidence using the End-Use Energy Demand Assessment (EEDA) framework emphasizes that lack of sustained access to clean fuels and modern appliances slows down the transition process [65]. High upfront costs for LPG cylinders and improved stoves further restrict adoption [19].

2.7.3 Behavioral and Cultural Factors

Energy choices are deeply embedded in behavioral and cultural contexts. They are influenced not just by cost and access, but also by cooking habits, taste preferences, and social perceptions. Factors such as perceived fuel efficiency, ease of use, and peer influence serve as strong behavioral drivers [26]. Long-standing habits, especially firewood use in rural households, contribute to resistance against switching, reinforcing the Fuel Stacking Hypothesis [9].

2.7.4 Gender, Time Use, and Labor Dynamics

Gender dynamics and labor roles critically affect household energy decisions. Traditional biomass collection—typically done by women and children—carries high opportunity costs not captured in standard economic models. During crisis events like the Indian blockade, households reverted to firewood and agricultural waste, intensifying the labor burden on women [30]. This highlights the embeddedness of fuel choice within gendered labor structures.

2.7.5 Regional and Climatic Variation

Fuel use patterns in Nepal also vary with geography and climate. Households in high hill and mountain regions continue to rely on firewood due to logistical constraints and limited LPG availability [20], [55]. Furthermore, responses to policy incentives and climate perceptions differ across provinces, underlining the need for localized energy strategies instead of generalized national models [26].

2.8 Household Energy Use Patterns in Nepal

2.8.1 Theoretical and Empirical Puzzle

A central puzzle in the literature on household energy use in Nepal lies in the persistence of traditional biomass fuel use, even amidst rising income levels and increased access to modern fuels. The energy ladder hypothesis suggests that with improved socioeconomic conditions, households should transition from traditional to cleaner fuels such as electricity and LPG. However, empirical evidence from Nepal contradicts this trajectory. For example, one study found that despite the availability of clean energy options, a significant portion of households continues to rely on firewood due to cost, cultural preferences, and habit [19]. Another study observed that energy use behavior varies across rural, semi-urban, and urban settings, further challenging a uniform application of the energy ladder model [9].

2.9 Substantive Case: Household Energy in Nepal

Nepal presents a valuable case for studying energy transition due to its diversity in geography, socioeconomic conditions, and energy infrastructure. A household energy survey revealed that only 8% of respondents used exclusively clean cooking fuels, while 67% used a mix of traditional and modern fuels [19]. The study, conducted across three different climatic zones (Solukhumbu, Panchthar, and Jhapa), and demonstrates that even where electricity or LPG is available, usage patterns remain complex due to reliability concerns and entrenched fuel stacking behavior highlighting great correlation of location. A broader modeling approach projected a steep rise in household electricity demand by 2030 under clean energy scenarios, emphasizing the need for behavioral change and infrastructure expansion [65]. Another investigation emphasized the role of non-economic factors such as education, gender roles, and cultural practices in shaping fuel choices, suggesting that affordability alone does not determine energy behavior [30].

2.10 Literature for Theoretical Contribution

This research builds upon two widely discussed concepts in household energy studies: the energy ladder model and the fuel stacking model. Several Nepal based studies support these ideas, showing that household energy decisions are shaped not just by income but also by social norms, local culture, and geographic location [9], [19], [30]. For example, even in urban or semi-urban areas, many households continue to use firewood and other traditional fuels. One reason for this is the lack of clear policies, limited public awareness, and difficulties in distributing clean fuels like LPG or electricity to all areas [66].

Furthermore, the bounded rationality framework explains that people do not always make decisions that are perfectly logical or optimal. Even when households are aware of the health and convenience benefits of modern fuels, they may still not switch [30]. This could be because they are used to traditional fuels, or maybe believe food tastes better when cooked with firewood, or are uncertain or skeptical about using new energy technologies . These social and psychological factors create resistance to changing fuel use, even when cleaner options are available.

2.11 Identifying the Research Gap

Existing studies on household energy use in Nepal often treat energy access and behavioral dynamics as separate areas of inquiry, lacking an integrated framework that reflects how households actually navigate energy choices. The widely used energy ladder model assumes a linear shift from traditional to modern fuels, which fails to capture the common practice of energy stacking in Nepal. Moreover, comparative research across urban, semi-urban, and rural settings remains limited, with insufficient attention to how urbanization and socio-economic differences influence energy transitions. Global models further reduce applicability by including fuels such as charcoal, kerosene, or natural gas, which are largely irrelevant in the Nepali context. Existing models overlook Nepal's specific energy context, where hydropower dominates and fuel usage differs across regions, highlighting the need for a tailored, weighted index that incorporates socio-economic factors to more accurately assess household energy transitions and guide regionally appropriate policy development.

CHAPTER THREE: METHODOLOGY

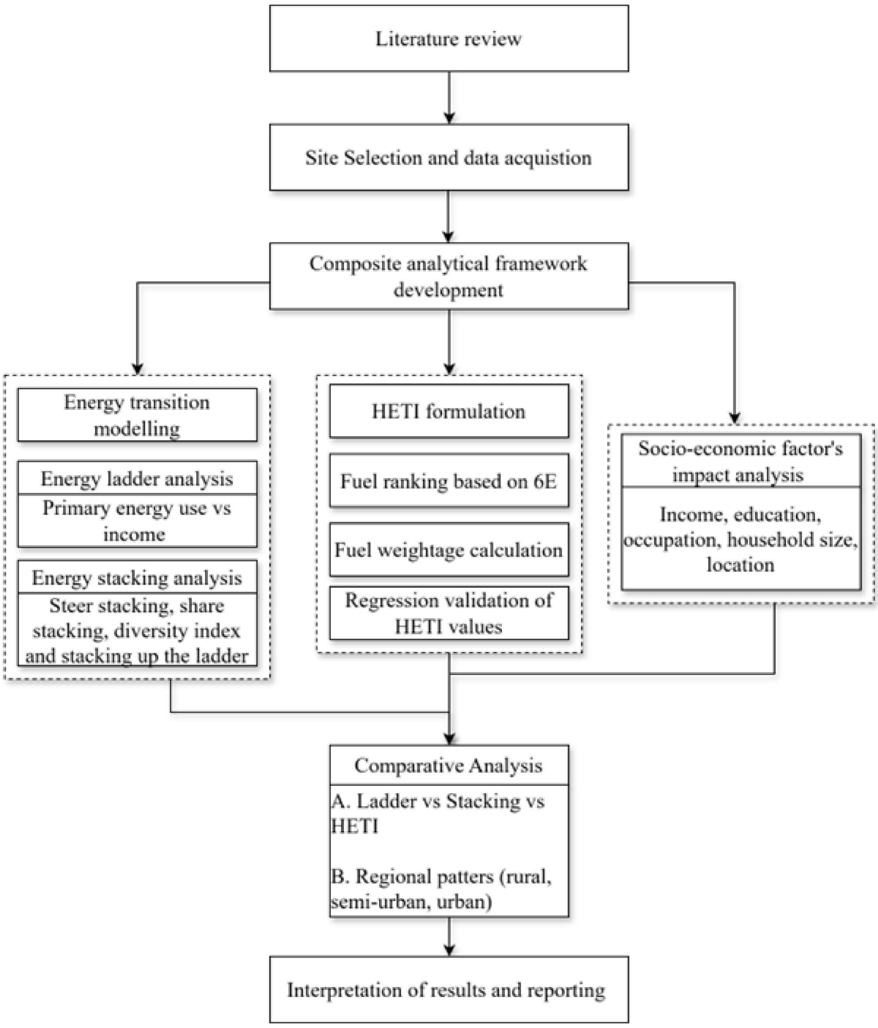

Figure 3.1: Flowchart for Methodology

3.1 Site Selection

Selecting appropriate locations representing diversified nature of urbanization is crucial, capturing multiple perspectives for household energy consumption behaviors in the context of Nepal. During this research, the data was taken from three different places, Urban, Emerging City and Rural area of Nepal. The locations have been chosen as: Kathmandu, Chitwan and Rammechhap districts accordingly as shown in Figure 3.2. Even though these locations fall within the same province, their stark contrasts in terms of energy access, economic development, geography, and population density highlight the significant energy disparity in Nepal.

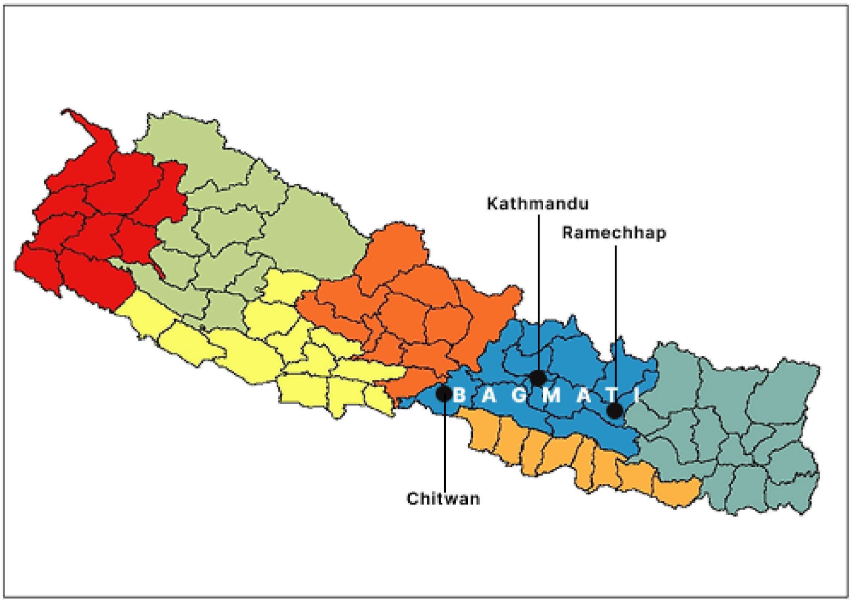

Figure 3.2: Survey Locations

3.2 Data Collection and Quantification

Primary Data

This study adopts a mixed-methods design that combines quantitative survey data with qualitative insights to assess household energy consumption across distinct geographic settings. A structured questionnaire was developed to capture detailed information on energy usage by category—including cooking, water heating, space heating, space cooling, lighting, appliances, electric vehicles, and farming/food related activities, as well as key demographic variables (e.g., household size, income, and location type). The questionnaire can be found in the APPENDIX.

The questionnaire was pre-tested with a pilot group to ensure clarity and reliability before full deployment. Data collection was executed using both online platforms and in-person interviews for Kathmandu, and in other places field survey was used ensuring a diverse and representative sample across rural, semi-urban, and urban areas.

Sampling Strategy and Justification

The sample size was determined using Cochran's formula to ensure statistical rigor at a 95% confidence level with a 10% margin of error [67].

Sample Size Calculation

The sample size was calculated using the formula [67]:

$$n_0 = \frac{Z^2 \cdot p \cdot 1 - p}{E^2} \tag{3.1}$$

where:

$$\begin{aligned} Z &= 1.96 \quad \text{(Standard normal value for 95\% confidence)} \\ p &= 0.5 \quad \text{(Assumed maximum variability)} \\ E &= 0.10 \quad \text{(Margin of error, 10\%)} \end{aligned}$$

Substituting the values:

$$n_0 = \frac{1.96^2 \times 0.5 \times 1 - 0.5}{0.10^2} \tag{3.2}$$

$$n_0 = \frac{0.9604}{0.01} = 96.04 \tag{3.3}$$

Thus, the initial sample size before applying the population correction is ”96’.

Finite Population Correction

Since the total population (N) of the three regions are finite for example: ($N = 2,996,341$) for Kathmandu, we apply the "finite population correction" using the formula:

$$n = \frac{n_0 \cdot N}{N \;\; n_0 - 1} \tag{3.4}$$

Substituting the values:

$$n = \frac{96.04 \times 2,996,341}{2,996,341 \;\; 96.04 - 1} \tag{3.5}$$

$$n \approx 96 \quad (3.6)$$

Thus, the final corrected sample size remains '96'.

Thus, the sample size (n=96), calculated using Cochran's formula [67], shall validate for finite populations, to ensure statistical rigor comparable to engineering tolerance analysis.

However, to enhance the precision of our estimates, account for potential non-responses, and allow for detailed subgroup analyses critical for understanding the nuances between rural, semi-urban, and urban settings, intentionally over 196 data had been collected per region. This oversampling strategy is supported by literature on survey methods, which suggests that larger sample sizes reduce standard error and improve reliability [68], [69]

- **Urban Area:** 194 households from Kathmandu Metropolitan
- **Emerging Cities (Semi-urban):** 196 households from Chitwan Municipalities
- **Rural Areas:** 196 households from Ramechhap Rural Municipality

Thus, collecting more than twice the minimum required data per region not only decreases the margin of error but also provides a robust dataset that captures the inherent heterogeneity of household energy consumption [70]. Such an approach is particularly important given the diverse socioeconomic and infrastructural characteristics across rural, urban, and semi-urban areas. A higher sample size facilitates the detection of subtle differences in energy use, especially in dominant categories like cooking and supports comprehensive analysis that can inform targeted policy interventions. As noted in [70], [71], oversampling is a well established practice to mitigate non-response bias and ensure the study's findings are statistically sound and generalizable. This rigorous data collection strategy strengthens our analysis and ensures that our conclusions about energy consumption patterns are both reliable and actionable.

Secondary Data

Existing literature on the energy ladder hypothesis, energy stacking, energy security and the 6E framework were reviewed. Data from previous studies on household energy transitions in similar developing countries were used for comparative analysis. Likewise, the data from national surveys and reports (e.g., NLSS, Energy Progress Reports, and WECS etc.) were utilized to assess the current state of energy access and usage in Nepal.

3.3 Data Processing and Analysis

After the completion of the survey, the collected data underwent a rigorous data cleaning and reprocessing phase to ensure consistency, accuracy, and completeness. The steps involved in this process included:

- **Checking for inconsistencies**: Household responses were verified for unrealistic energy consumption values or missing demographic data.
- **Handling missing values**: Mean imputation was used for numerical variables, while categorical variables were imputed using mode.
- **Standardization of categorical variables**: Energy sources (firewood, LPG, electricity) and socio-economic indicators (household income, education levels) were categorized for consistency.
- **Categorization of energy usage patterns**: Energy consumption was segmented into different purposes such as cooking, water heating, space heating, space cooling, lighting, appliances, and electric vehicles for each region.

This structured approach ensured that the dataset was well-prepared for statistical analysis and regression modeling, making the findings statistically robust and interpretable.

3.4 Descriptive Analysis

A comprehensive descriptive analysis was performed to provide an overview of household energy consumption patterns and their variations across different regions. The descriptive analysis included:

- **Summary statistics**: Mean, median, standard deviation, and quartiles for energy consumption in kWh, household income, and household size.
- **Frequency distributions**: Breakdown of energy sources used (firewood, LPG, electricity) and socio-economic indicators such as education levels.
- **Graphical visualizations**: Bar charts and pie charts to illustrate the proportion of households using different energy sources. Histograms displaying the distribution of energy consumption levels. Stacked area and heat maps to show regional energy usage differences.

- **Comparison across geographic locations**: Trends in household energy use across urban, semi-urban, and rural areas.

3.5 Energy Transition Analysis and HETI Development

The traditional energy ladder model cannot alone explain the transition in a dynamic energy landscape like Nepal, thus this study adopts a multi-dimensional framework incorporating both fuel stacking metrics and a HETI. Drawing from the work in [57], [62], several indicators were used to capture the extent, diversity, and direction of fuel use across households.

Firstly, basic energy ladder has been analyzed which merely looks into how income affects the likelihood of choosing a cleaner energy primarily specially for cooking. Then the stacking characters of the households are calculated. Simple stacking measures such as the Fuel Portfolio (FP) and Steering Stacking (SS) quantify the number and proportion of clean fuels in use. More advanced formulations like the Gini-Simpson Diversity Index and Stacking Up the Ladder Index considering the share of different fuels used as show in Table 3.1.

HETI was developed by improving upon the energy stacking by weighing the fuels used. It numerically represents each household's position on the energy transition dimension. It incorporates fuel ranking, weighted fuel shares, and a composite scoring system that ranges from 1 (traditional fuel dependency) to 2 (exclusive modern fuel use) as shown in Table 3.1. This approach allows for a more reliable and context-specific assessment of energy transition in Nepal, accommodating both the progressive shift toward modern energy and the persistent reliance on traditional fuels within household energy portfolios and also considers the quality and sustainability of fuels.

Table 3.1: Energy Stacking Analysis and Formulation of HETI

Name	Specification	Description	Literature
A. Simple stacking measures			
Fuel portfolio	$FP_i = 1, 2, 3, 4, 5, \ldots, n$	FP_i represents the total number of fuels in use in the households	[62]
Steering stacking	$SS_i = \frac{CF_i}{FP_i}$	CF_i refers to the number of cleaner fuels used in the household.	
B. Formulation of *Stacking up the Ladder* measure			
Share stacking	$SS_i = \frac{\text{Share of Cleaner Fuels}}{\text{Total Fuel Share}}$	It shows the ratio of cleaner fuels in total fuel share for the households	[62]
Gini–Simpson diversity index	$l_i = 1 - {}^{n}_{k} w_j^2$	w_j represents the share of each fuel used by the households	[62]
Stacking up the ladder	$L_i = l_i SS_i \ 1$	l_i and SS_i are explained above	[62]

Name	Specification	Description	Literature
C. Formulation of HETI			
Energy ladder ranking	$LR_i = 0, 1, 2, 3, 4, 5, \ldots, n$	The ranking have been done specifically for Nepal's context based on the survey and is subject to ranking standards based on the 6E's outlined in the literature.	[57]
Fuel ranking points	$RP_i = \frac{LR_i}{n-1}$ (e.g., for firewood: 08, if total number of fuels = 9)	Fuel ranking points have been assigned by dividing energy ladder points by $n - 1$, where n is the total number of fuels used in the study	[57]
Fuel share weightage	$FW_j = W_j \times RP_i$, Where $j = 1, 2, 3, \ldots, n$	FW_{ij} refers to the weightage of each fuel based on ranking (LR_i) of respective fuels. This can be calculated by multiplying share of each fuel with its RP_i. For example, if a household consumes firewood for total of 50% of the total use then: $0.50 \times 0.25 = 0.125$. RP_i is explained above	[57]

Household energy transition index	$ETI_i = 1 \ {}_k^n FW_j$	To add the stacking dimension to above-mentioned fuel weightage measure, the index sums up all the fuel weightage a household. Its value remains between 1 and 2. 1 reflects 100 percent primitive fuel-powered household, while 2 represents 100 percent modern fuels. For example, if a household energy end use share is 25, 40 and 35 percent of fuel budget on electricity, charcoal, and dung cake respectively, then HH's score on energy transition index would be: $= 1 \ \ 1 \times 0.25 \ \ 0.5 \times 0.4 \ \ 0 \times 0.35$ $= 1 \ \ 0.25 \ \ 0.2 \ \ 0$ $= 1 \ \ 0.45$ $= 1.45$	[57]

This study evaluates household fuel stacking behavior across three diverse regions in Nepal, in this research-Kathmandu, Chitwan, and Ramechhap by using the five key indices: Fuels Stacked, Steer Stack, Share Stack, Gini-Simpson Index, and Ladder Index. To assess regional differences in these indices, the non-parametric Kruskal-Wallis H-test was employed, as the data did not meet normality assumptions. Then, the developed HETI was analyzed in relation to household income to assess the extent of its influence and to evaluate whether the index aligns with actual household energy transition patterns in Nepal, as observed in past studies and available literature.

3.6 Regression Analysis (OLS)

To quantify the impact of socio-economic factors on household energy choices, the study employed OLS regression models. OLS is widely used in econometric studies to establish relationships between dependent and independent variables.

OLS Regression Equation

OLS regression assumes that the dependent variable is a linear function of independent variables:

$$Y_i = \beta_0 \ \beta_1 X_{1i} \ \beta_2 X_{2i} \ \cdots \ \beta_n X_{ni} \ \epsilon_i \tag{3.7}$$

where:

- Y_i = Dependent variable (firewood, LPG, or electricity consumption in kWh per household).
- $X_{1i}, X_{2i}, \ldots, X_{ni}$ = Independent variables (household income, household size, education level, region, etc.).
- β_0 = Intercept (constant term).
- $\beta_1, \beta_2, \ldots, \beta_n$ = Coefficients representing the impact of each independent variable.
- ϵ_i = Error term capturing unobserved factors.

Application of OLS in the Study

Separate OLS regression models were run for firewood, LPG, and electricity consumption:

$$\text{Firewood Use} = \beta_0 \ \beta_1\text{Income} \ \beta_2\text{Household Size} \ \beta_3\text{Education Level} \ \beta_4\text{Region} \ \epsilon \quad (3.8)$$

$$\text{LPG Use} = \beta_0 \ \beta_1\text{Income} \ \beta_2\text{Household Size} \ \beta_3\text{Education Level} \ \beta_4\text{Region} \ \epsilon \quad (3.9)$$

$$\text{Electricity Use} = \beta_0 \ \beta_1\text{Income} \ \beta_2\text{Household Size} \ \beta_3\text{Education Level} \ \beta_4\text{Region} \ \epsilon \quad (3.10)$$

Each model was tested for:

- P-values to determine statistical significance of variables.
- R-squared values to assess goodness of fit.
- F-tests to evaluate overall model validity.
- Heteroskedasticity and multicollinearity diagnostics to ensure robustness.

3.7 Comparative Analysis of Energy Transition Models

To interpret regression results, findings were compared with two key theoretical models of household energy transition:

Energy Ladder Hypothesis

- Suggests a linear transition from traditional biomass (firewood) to modern fuels (LPG, electricity) as household income rises.
- Tested whether income was a strong determinant in fuel switching.

Energy Stacking Model

- Instead of abandoning firewood entirely, many households continue to use multiple fuels simultaneously.

- The study analyzed whether households engage in fuel stacking by maintaining traditional energy sources while integrating modern fuels.

These models helped determine which framework best explains household energy behavior in Nepal.

Geospatial and Regional Comparison

A regional comparison was conducted to highlight urban-rural disparities in energy consumption. Regression results were analyzed considering separately for urban, semi-urban, and rural areas as variables.

3.8 Justification for Methodological Approach

The methodology was designed to accurately capture real-world household energy behaviors in Nepal:

a. **Mixed-Methods Approach:** Combines quantitative surveys with qualitative insights to bridge statistical findings and contextual realities.

b. **OLS Regression:** Provides quantifiable relationships between household characteristics and fuel choices.

c. **Comparative Energy Transition Analysis Using Various Energy Transition Models:** Assesses whether Nepalese households follow the energy ladder or engage in fuel stacking and to what extent

d. **Regional Comparisons:** Highlights policy-relevant disparities in energy access.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Detailed Total Energy Consumption (in GJ)

Table 4.1 shows the overall breakdown of the total energy consumption in GJ for all types of energy and the per capita energy consumption for the respective number of households in Ramechhap, Chitwan, and Kathmandu obtained from the survey. It includes data for 196 households each from Ramechhap and Chitwan, and 194 from Kathmandu. It is clear from Table 4.1 that Kathmandu, being highly urbanized, has the most electric cooking and other appliances for use, showcasing prosperity, access, and reliability of electricity.

Table 4.1: Total Energy Consumption by Energy Type and Use

Purpose/Source	Cooking	Water Heating	Space Heating	Space Cooling	Lighting	Appliances	EV	Others	Total Per Year	Per Household	Per Capita
Ramechhap (196 Households)											
Firewood	5571.99	268.18	80.45	-	-	-	-	2333.19	8253.82	42.11	12.31
LPG	560.29	-	-	-	-	-	-	-	560.29	2.86	0.84
Electricity	-	1.94	-	3.48	15.36	34.57	0.26	-	55.61	0.28	0.08
Biogas	-	-	-	-	-	-	-	-	0.00	0.00	0.00
Solar PV	-	-	-	-	3.24	-	-	-	3.24	0.02	0.00
Solar Thermal	-	-	-	-	-	-	-	-	0.00	0.00	0.00
Total	6132.28	270.13	80.45	3.48	18.60	34.57	0	2333.19	8872.96	45.27	13.23
Chitwan (196 Households)											
Firewood	1026.53	-	80.42	-	-	-	-	1255.59	2362.53	12.05	2.93
LPG	975.17	-	-	-	-	-	-	-	975.17	4.98	1.21
Electricity	198.49	19.40	78.80	139.43	5.13	59.31	20.62	3.10	524.28	2.67	0.65
Biogas	28.55	-	-	-	-	-	-	-	28.55	0.15	0.04
Solar PV	-	-	-	-	3.17	7.19	-	-	10.36	0.05	0.01
Solar Thermal	-	31.08	-	-	-	-	-	-	31.08	0.16	0.04
Total	2228.75	50.48	159.22	139.43	8.30	66.50	20.60	1258.69	3931.98	20.06	4.88
Kathmandu (194 Households)											
Firewood	40.58	-	11.77	-	-	-	-	-	52.34	0.27	0.06
LPG	1390.46	35.91	-	-	-	-	-	-	1426.38	7.28	1.70
Electricity	989.35	29.15	78.80	40.58	12.79	69.00	107.48	92.46	1409.93	7.23	1.70
Biogas	-	-	-	-	-	-	-	-	0.00	0.00	0.00
Solar PV	-	-	-	-	13.99	55.94	-	-	69.93	0.36	0.08
Solar Thermal	-	135.97	-	-	-	-	-	-	135.97	0.69	0.16
Total	2420.39	201.04	90.56	40.58	26.78	125.00	107.60	92.46	3094.54	15.79	3.69

Note: All values are derived from the author's own calculation
The per capita electricity consumption was found to be: Ramechhap: 22 kWh, Chitwan: 181 kWh, and Kathmandu: 467 kWh.

4.1.1 Energy Consumption by End Use

The results for the energy consumption from the heat map in Figure 4.1, clearly reveal that cooking dominates the use of household energy in all locations, accounting for 78% in Kathmandu, 69% in Ramechhap and 56% in Chitwan, significantly more than any other category. This overwhelming value suggests that any major reduction in the overall use of traditional home energy is dependent on improving cooking methods, technology, and perceptions, making it vital to continue researching this sector for improvements in efficiency and alternative sustainable fuels.

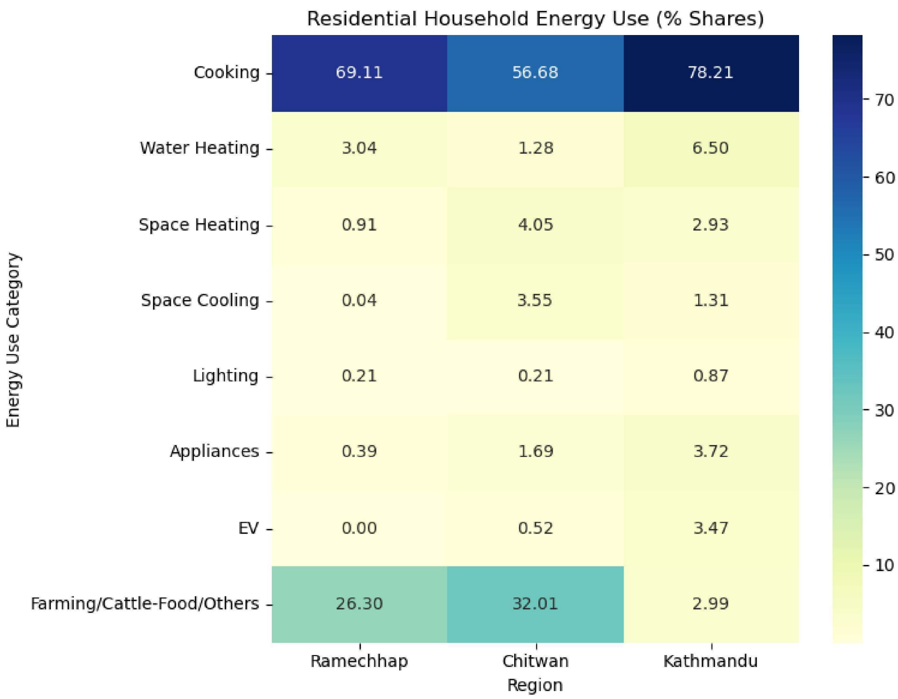

Figure 4.1: Energy Consumption by Share for various Activities over all three Regions

4.1.2 Overall Energy Use

The Figure 4.2 presents a comparative analysis of per capita energy consumption in three locations in Nepal: Ramechhap (rural), Chitwan (semi-urban), and Kathmandu (urban). The energy sources included in the analysis are firewood, LPG, electricity, biogas, solar PV, and solar thermal, providing insight into the energy transition patterns in these regions.

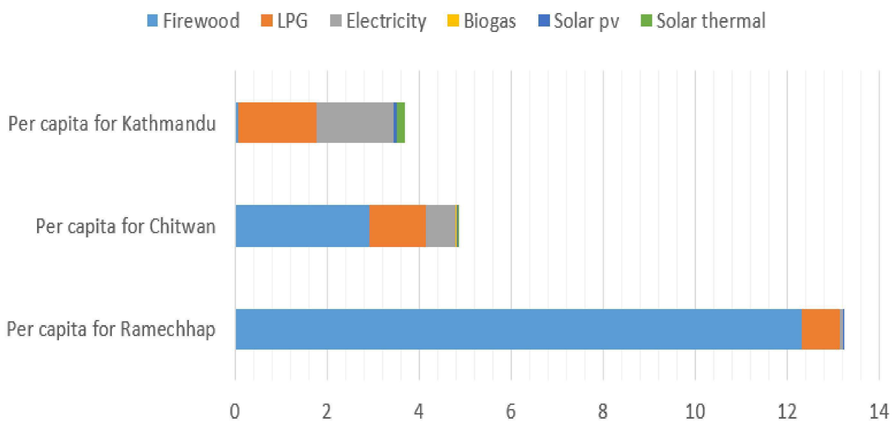

Figure 4.2: Per Capita Energy Consumption IN GJ for all Locations

a. **High Dependence on Firewood:** Ramechhap, a rural district, shows a great dependence on firewood, which accounts for most of the total energy consumption. LPG and electricity contribute only a small fraction, highlighting the limited access to modern energy services. The total per capita energy consumption in Ramechhap exceeds 13 GJ per year, making it the highest among the three locations. This high consumption is largely due to the inefficiency of biomass combustion.

   This large dominance of firewood further shows the energy poverty in the region. The continued dependence on biomass has led to deforestation and indoor air pollution, which negatively impacts health, particularly for women and children who spend significant time in smoke-filled kitchens.

   Some previous attempts have been made to promote better cookstoves (ICS) and LPGs. Despite this households still resorted to traditional modes of cooking. It was clear from the qualitative interview that the lockdown due to the COVID-19 pandemic and impracticality of LPG and ICS for certain tasks like animal feed preparation were main contributors to preference for traditional firewood cooking.

b. **A Transitioning Energy Mix:** Chitwan, being a semi-urban location, has a diversified energy composition, with firewood, LPG, and electricity being of significance. Compared to Ramechhap. There is a higher proportion of LPG and electricity use, indicating improved access to modern energy. The uses of biogas, solar PV, and solar thermal, which are small but very prominent, indicating some form of take up of renewable energy sources other than the grid. The per capita energy consumption in Chitwan is around 4.78 GJ per year which is significantly lower than in Ramechhap. However, it is higher than in Kathmandu, due to prevalence of some inefficient fuels such as firewood in the mix more often.

The trend of energy use in Chitwan reflects a sustained process of change, where households are moving increasingly away from firewood towards modern forms of energy. However, the fact that firewood continues to be used, reflects the need for more incentives to aid this transition.

Even though, expanding biogas programs as a renewable alternative to firewood; the survey found evidence to argue otherwise. Based on the interview most biogas users in Chitwan faced some issues such as charring and greasing in their kitchens and nearby parts of the house. This led to many of them to stop using. They simply consider it to be poorer in quality. Likewise, when it comes to firewood usage for cooking, even with good access to LPG or electricity, most of them used firewood for cooking (at lease for one meal, usually in the evening), simply because they preferred the taste of the food with smoky taste. Furthermore, females (especially housewives) gather the firewood in their leisure during the days or evenings, such that they do not feel the need to buy LPG for cooking purpose. This led them to perceive firewood as an economically viable option compared to LPG or electricity. likewise, When it comes to electric cooking, most people found the learning curve to use such devices a bit too much.

c. **Modern Energy Dominance:** Kathmandu, Nepal's urban center, exhibits the most modernized energy consumption pattern, with LPG and electricity as the dominant energy sources. Firewood use is minimal only used during occasional gatherings and parties which is due to the preference for firewood cooked foods. Solar PV and solar thermal make small but increasing contributions, reflecting a growing interest in renewable energy solutions.

   Even with such preferences, the total per capita energy consumption in Kathmandu is the low (0.288 GJ/month). Clean energy consumption is a good indicator of prosperity and socio-economic growth, and the findings suggest Kathmandu has a long way to go in this regards.

The shift from firewood to LPG and electricity in Kathmandu represents a successful energy transition. However, reliance on LPG remains a concern, as it is a fossil fuel with significant import dependency. To ensure long-term energy security and sustainability, policies should focus on promoting electric cooking solutions, such as induction stoves and electric pressure cookers, to reduce LPG dependency. Additionally, expanding rooftop solar PV installations can help decentralize power generation and lessen the stress on the national grid. Urban households could also benefit from waste-to-energy initiatives, which can contribute to both energy production and waste management in Kathmandu.

4.2 Comparative Insights on Nepal's Energy Transition

The data from Figure 4.2 clearly illustrates that urbanization plays a significant role in shaping household energy transitions in Nepal. Rural areas like Ramechhap remain heavily reliant on traditional biomass fuels, while semi-urban regions such as Chitwan show a mixed energy usage pattern, indicating a transitional phase characterized by both traditional and modern energy use. In contrast, urban areas like Kathmandu have largely shifted to modern energy sources, particularly electricity and LPG.

These patterns generally support the energy ladder hypothesis, where energy use evolves from traditional to modern forms as income and infrastructure improve. However, the prevalence of energy stacking—where multiple fuel types are used simultaneously—is especially noticeable in semi-urban and rural areas due to various economic and infrastructural barriers. Even in urban settings like Kathmandu, energy stacking is evident, particularly for cooking, where households commonly use both LPG and electricity. This reflects a broader transitional phase, with LPG acting as an intermediate fuel before full electrification.

Nepal's energy transition exhibits a unique trajectory. While energy stacking remains common across all regions, the composition of fuels varies significantly. Interestingly, transitional fuels like kerosene, coal, and charcoal are rarely used. Instead, the transition is moving directly towards cleaner alternatives such as electricity, solar energy, and biogas. This suggests that Nepal is bypassing some conventional transitional fuels in favor of a more direct path toward electrification and renewable solutions, with energy stacking serving as a key feature of the ongoing shift.

Fig 4.3, represents the probable energy transition process undergoing on in Nepal, based on the findings of the research. Even more than a linear shift from traditional to advanced/modern fuels, the energy transition in Nepal hinges between traditional fuels, LPG and electricity with some share of other renewables in the mix.

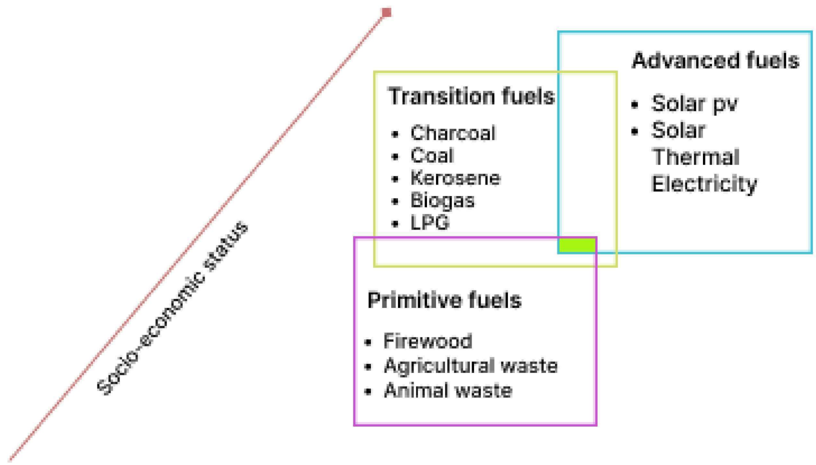

Figure 4.3: Energy Transition Model Based on Survey for Rural, Periurban & Urban Regions

4.3 Energy Ladder Analysis

The pattern of the energy ladder of primary cooking fuel consumption in Nepal indicates a strong linkage between energy choice and household income like the literatures. Thus, With increased incomes, the consumption of clean fuels like electricity, LPG, and biogas grows, and consumption of traditional fuels like dung and firewood diminishes substantially.

Bar graphs of Kathmandu, Chitwan, and Ramechhap data collectively suggest that poor households consume predominantly traditional fuels, but the middle-income groups present signs of fuel stacking—both traditional and clean fuels being consumed. The high-income groups display a near-universal consumption of clean energy, moving unequivocally up the rungs of the energy ladder.

The trend therefore confirms the classical energy ladder model, which asserts that households will shift from traditional to modern fuels as a function of their level of socioeconomic development. The transition to clean energy in Nepal is clearly occurring, particularly for semi-urban and urban residents. The persistence of traditional fuels among the poorer groups still implies the necessity of targeted interventions. Policies that encourage access, affordability, and awareness of clean energy alternatives are most important to assisting all Nepali households in climbing the energy ladder equitably.

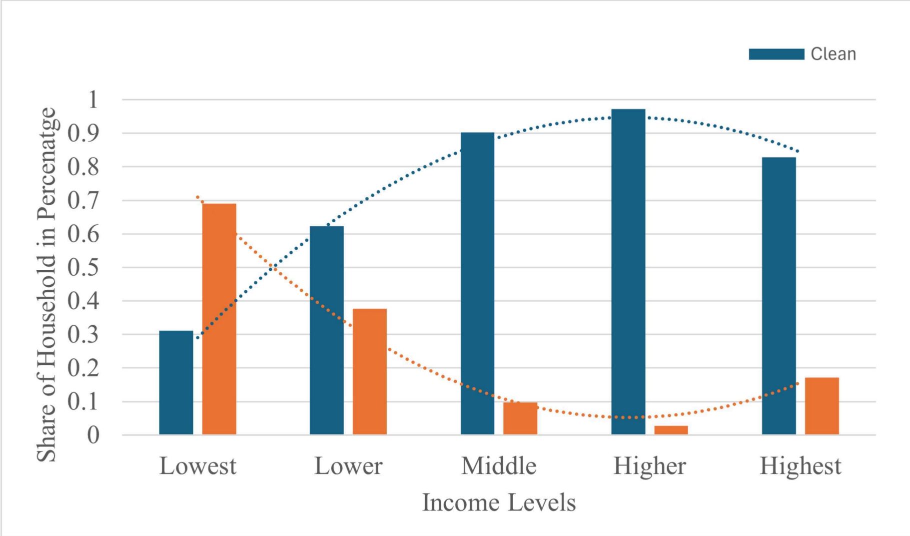

Figure 4.4: Share of Clean and Unclean Energy Use VS Income

4.4 Energy Stacking Analysis

This section presents a comprehensive quantitative analysis of traditional household fuel stacking behavior across three regions: Kathmandu, Chitwan, and Ramechhap. The study employs five key indices to assess fuel stacking behavior: Fuels Stacked, Steer Stack, Share Stack, Gini-Simpson Index, and Ladder Index.

Thus this stacking analysis provides a much more versatile and non-linear character of fuel consumption in Nepal, in contrast to the conventional energy ladder model. It demonstrates that households frequently stack various fuels based on access, d by employing indices such as steer stack, share stack, and Gini-Simpson. This provides a more realistic perspective of Nepal's energy transition by better reflecting regional inequalities and demonstrating that even wealthy or urban households may continue to stack fuels, but with higher ratio of cleaner fuels in the mix as suggested by the scores for the regions from Tables 4.2 and 4.3.

4.4.1 Regional Summary Statistics

Table 4.2 shows the mean and standard deviation for each fuel stacking index by region. Chitwan and Kathmandu exhibit higher stacking behavior and cleaner energy use than Ramechhap.

The regional analysis of the fuel stacking behavior reveals stark contrasts in energy transitions across Nepal. Kathmandu exhibits the most advanced transition, with high reliance on clean fuels (steer stack = 0.91, share stack = 1.00) and minimal fuel diversity, indicating near-complete adoption of modern energy. Chitwan shows moderate stacking behavior (fuels stacked = 3.09) and substantial use of clean fuels (share stack = 0.84), reflecting an ongoing transition with reliance on multiple sources. In contrast, Ramechhap remains heavily biomass-dependent, with low fuel diversity (Gini-Simpson = 0.05) and limited clean energy usage (ladder index = 0.08), highlighting severe access and affordability barriers. These patterns suggest urban areas are consolidating around clean energy, semi-urban regions are in transition, and rural areas are still energy-poor and locked into traditional fuels.

Table 4.2: Regional Summary of Fuel Stacking Indices

Region	Fuels Stacked	Steer Stack	Share Stack	Gini-Simpson	Ladder Index
Chitwan	3.09 (0.52)	0.71 (0.10)	0.84 (0.16)	0.56 (0.09)	1.03 (0.16)
Kathmandu	2.94 (0.87)	0.91 (0.13)	1.00 (0.01)	0.50 (0.10)	1.01 (0.20)
Ramechhap	2.06 (0.29)	0.65 (0.22)	0.29 (0.44)	0.05 (0.11)	0.08 (0.15)

- ***Simple Stacking (1–n)****: Higher values mean more fuels used (greater stacking), lower values indicate clearer fuel reliance.*

- ***Directional Stacking (0–1)****: Higher values reflect stronger preference for modern fuels, lower values indicate dominance of traditional fuels.*

- ***Share Stacking (0–1)****: Higher values show greater share of useful energy from modern fuels, lower values imply reliance on traditional sources.*

- ***Gini-Simpson Index (0–1)****: Higher values indicate greater fuel diversity, lower values reflect reliance on fewer (possibly cleaner) fuels.*

- ***Ladder Index (0–2)****: Higher values represent greater modern fuel use combined with stacking diversity, lower values suggest traditional fuel dominance.*

4.4.2 Kruskal-Wallis Test Results

To determine whether regional differences are statistically significant, the Kruskal-Wallis test was conducted for each index. All five indices exhibited highly significant p-values (<0.001), confirming substantial regional variation.

4.4.3 Visualization of Regional Comparisons

The Figure 4.5 presents the regional comparison for the Ladder Index, demonstrating that Ramechhap significantly lags behind in clean energy transition.

Table 4.3: Kruskal-Wallis Test Results for Fuel Stacking Indices

Variable	H-statistic	p-value
Fuels Stacked	259.62	4.21×10^{-57}
Steer Stack	218.70	3.23×10^{-48}
Share Stack	247.33	1.96×10^{-54}
Gini-Simpson	385.86	1.62×10^{-84}
Ladder Index	380.82	2.02×10^{-83}

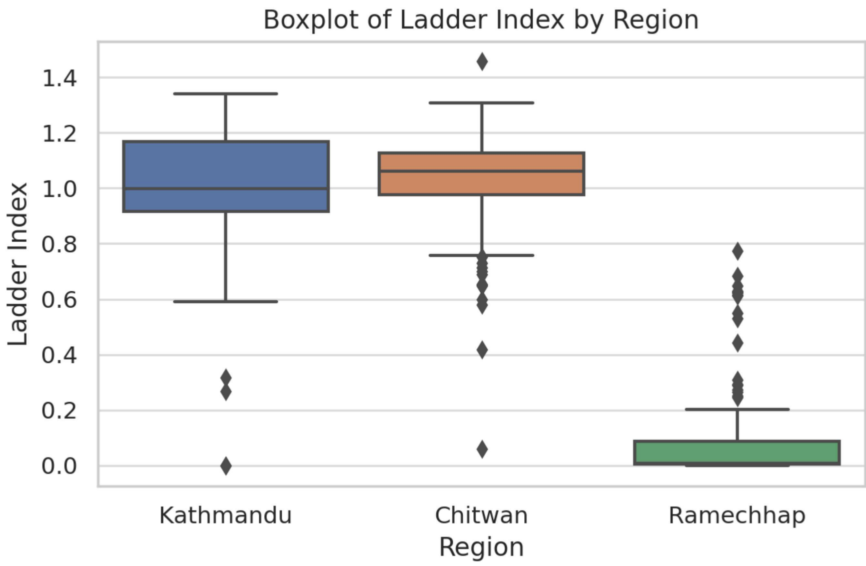

Figure 4.5: Boxplot of Ladder Index by Region

4.4.4 Correlation Analysis

The correlation heatmap in Figure 4.6 also, reveals strong relationships between several indices. Notably, Share Stack and Steer Stack are highly correlated (nearly 0.96), and the Ladder Index also shows strong positive correlations with both (nearly 0.89 to 0.92). This indicates that higher clean energy use directly contributes to climbing the energy ladder, even more so than fuel diversity.

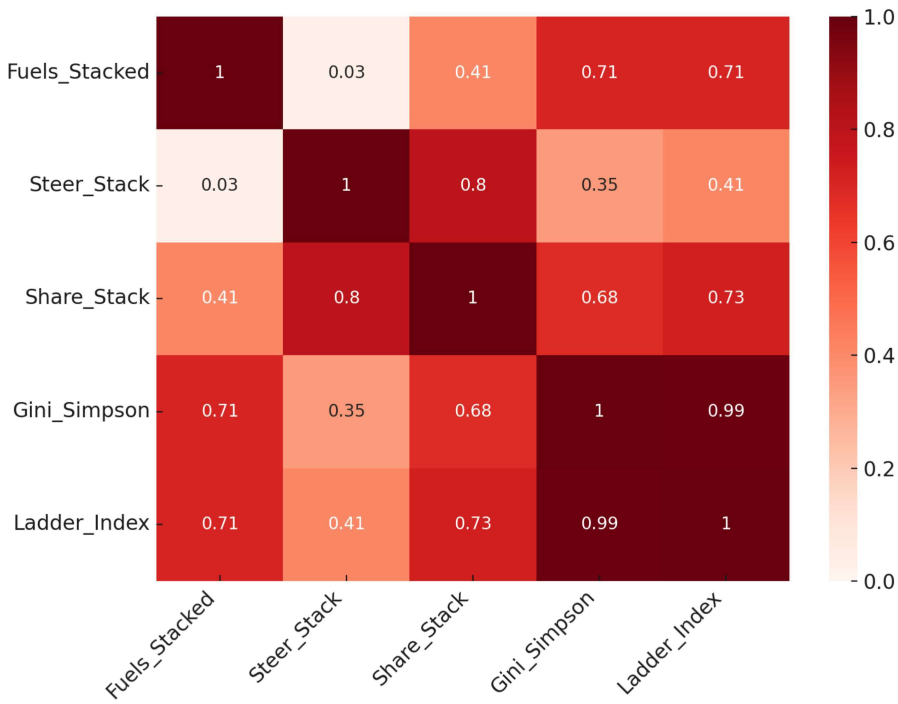

Figure 4.6: Correlation Heatmap of Fuel Stacking Indices

Descriptive statistics indicated that Kathmandu and Chitwan incorporated significantly more clean energy technologies than Ramechhap. In particular, Kathmandu had the highest rates of Steer Stack and Share Stack, indicating widespread use and spending on clean fuels. Chitwan had the highest fuel diversity, as indicated in Gini-Simpson Index, and was slightly ahead of Kathmandu in Ladder Index, which integrates diversity with the use of clean energy.

On the other hand, Ramechhap had poor access to or adoption of numerous and clean fuels, and therefore rated lowest across all indices as only a little progress in the energy transition was shown by Ramechhap's extremely low Ladder Index.

These regional differences are statistically significant for all five indices, according to the Kruskal-Wallis test form Table 4.3. This is compelling evidence that households' energy choices are influenced by contextual and regional factors. Increased use and spending on cleaner fuels are at the heart of moving up the energy ladder, as revealed by the correlation analysis, which showed a very strong positive connection between the Share Stack and Steer Stack (nearly 0.96) and between the Ladder Index and the two stacks (nearly 0.89–0.92).

4.5 Energy Ladder & Stacking based on Quantitative Data

The energy ladder and stacking analysis based on the surveyed data are given below in Figures 4.7 and 4.8. The stacking transitioning as we move from lower income to higher income is clearly visible in the figures.

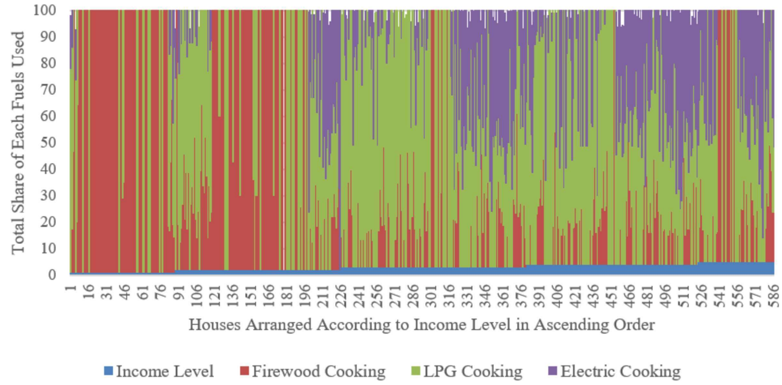

Figure 4.7: Energy Stacking Trend Based on the Survey Findings

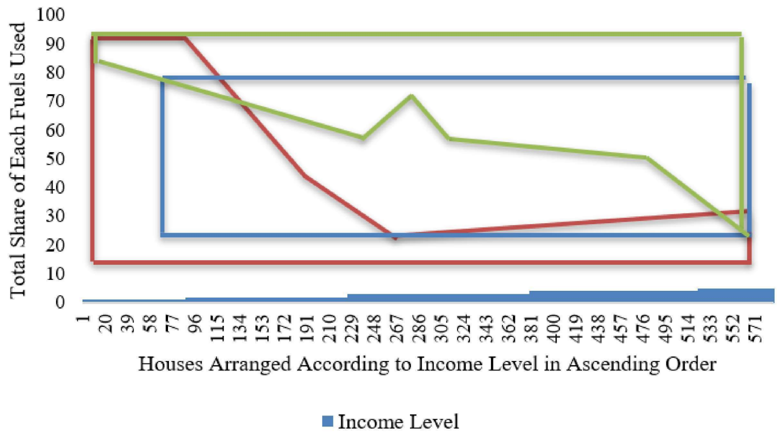

Figure 4.8: Energy Usage Stacking Overview based on the Findings

4.6 Formulation of HETI

This section develops an a HETI to assess household progress toward clean energy use in Nepal, and uses it to compare the three regions. It improves upon the traditional energy stacking models by integrating a 6E framework ie Ease of Access, Ease of Collection, Ease of Use, Ease of Economy, Efficiency, and Emissions to evaluate and rank each household fuel as like in literature [57]. Each fuel is assigned a score under these criteria, balancing household convenience with technical and environmental sustainability. The scores have been provided based on available literature and research findings.

In this formulation, the scores are summed to create a total energy ladder score, which is then used to rank fuels from least to most sustainable. It differs from the original energy ladder models, including those used by past literature like [57] and [62] among few, which employed eight fuel types and eight ranks. This study extends the model to reflect Nepal's ground realities. Specifically, it includes ten fuel types (e.g., electricity, LPG, solar thermal, solar PV, biogas, kerosene, charcoal, firewood, agri-waste, and dung cake), creating a nine-rank ladder. This adaptation better captures Nepal's diverse energy landscape, where solar and biogas play a more pronounced role than in other South Asian contexts, and fuels like piped natural gas are largely absent. Likewise, instead of fuel expenditure which are very unreliable and not accurate representation of energies used in household, we employ the share of energy end use consumption instead of share of expenditure.

Each ranked fuel is assigned a normalized weight (0 to 1) based on its position on the revised ladder, with electricity as the cleanest (weight = 1.0) and dung as the dirtiest (weight = 0.0). These weights are multiplied by the actual fuel share in a household's energy use to compute the HETI score, which ranges from 1 (traditional) to 2 (fully modern). This allows HETI to reflect real-world fuel stacking behavior and differentiate households using partially clean mixes.

By addressing fuel types specific to Nepal and adapting the energy ladder accordingly, this methodology ensures contextual accuracy. It also advances previous models by recognizing that not all "clean" fuels are equal to electricity. Thus, this offers a more realistic, nuanced, and policy-relevant tool for analyzing clean energy transitions in Nepal.

The Table 4.4 represents the rankings and points assigned to the values and the justifications are provided in the Table 4.5.

Table 4.4: Energy Ladder Ranking for Nepal Based on Fuel Type, Region, Convenience, Efficiency, and Emissions

Fuel Type / Region	**Dung Cake**			**Agri Waste**			**Firewood**			**Charcoal**			**Kerosene**			**LPG**			**Biogas**			**Solar Thermal**			**Solar PV**			**Electricity**		
Region	R	SU	U	R	SU	U	R	SU	U	R	SU	U	R	SU	U	R	SU	U	R	SU	U	R	SU	U	R	SU	U	R	SU	U
Ease of Access	2	2	1	3	2	1	3	2	1	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	2	3	1	2	3	1
Ease of Collection	2	2	1	3	2	1	3	2	1	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	2	3	3	2	3	3
Ease of Use	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	2	3	2	2	2	1	2	3	1	2	3	1	2	3
Ease of Economy	3	2	1	3	2	1	3	2	1	1	2	3	1	2	2	1	2	3	1	2	2	1	2	3	1	2	3	1	2	3
Convenience Score	8	7	4	10	7	4	10	7	4	5	8	11	5	8	10	4	8	12	5	8	10	4	8	12	6	10	10	6	10	10
Efficiency Points	1			1			2			2			3			3			3			4			3			5		
Emission Points	2			1			1			2			3			4			4			5			5			5		
Total Score	22			23			24			28			29			31			30			33			34			36		
Energy Ladder Rank	0			1			2			3			4			6			5			7			8			9		

Where R, SU and U represent the Rural, Semi-urban and Urban areas

4.6.1 4E Justifications with Literature for Energy Sources in Nepal

The convenience points have been assigned values form 1 through 3 where 1 means least and 3 meaning most or best, the Table4.5 shows the justifications for the values taken.

Table 4.5: Justification for the Convenience Point Assigned to Each Regions

Category	**Justification**	**Literature**
	Electricity	
Ease of Access	Over 90% rural access, but low quality (Tier 1–2); semi-urban areas fare better; urban areas enjoy stable supply.	[72], [73], [74]
Ease to Collect	Off-grid users maintain systems; grid access in towns is stable; effortless in cities.	[75]
Ease to Use	Appliance usage limited in rural (weak systems); improves in semi-urban; widespread use in urban.	[72], [75]
Ease of Economy	Maintenance and tariff burdens in rural; moderate cost in towns; affordable in cities.	[76], [73]
	Firewood	
Ease of Access	Freely available in rural forests; limited by deforestation in towns; rare in cities.	[77], [78]
Ease to Collect	Regularly collected in rural; needs purchase in towns; rarely used in cities.	[79], [78]
Ease to Use	Smoke, health issues, low efficiency; discouraged where cleaner fuels exist.	[78], [80]
Ease of Economy	Free in villages; sold in towns; costly and scarce in urban areas.	[77], [80]
	LPG	
Ease of Access	Weak cylinder distribution in rural; moderate in towns; reliable in urban areas.	[81], [82]
Ease to Collect	Carried from far-off depots in rural; available through vendors in cities.	[83], [84]
Ease to Use	Common in urban kitchens; rural users may lack awareness/confidence.	[85], [82]
Ease of Economy	Costly for rural poor; manageable in towns; affordable in cities.	[86], [84]
	Dung Cake	

Ease of Access	Abundant in livestock-rich villages; less in towns; nearly absent in cities.	[10], [87], [88]
Ease to Collect	Collected regularly in rural homes; occasional in towns; unavailable in urban areas.	[89], [90]
Ease to Use	Smoky, low efficiency, time-consuming; generally avoided where options exist.	[91], [82]
Ease of Economy	Free in villages; small cost in towns; rare and expensive in urban.	[92], [93]
Agricultural Waste		
Ease of Access	Abundant post-harvest in rural; less available in towns; very rare in cities.	[87], [94]
Ease to Collect	Manually collected from fields in rural areas; difficult or impossible in cities.	[89], [95]
Ease to Use	Poor combustion efficiency, high smoke across all regions.	[96], [97]
Ease of Economy	Free in rural; costs arise in transport/storage in towns and cities.	[98], [10]
Coal		
Ease of Access	Scarce in rural; some availability in towns and cities through trade networks.	[99], [100]
Ease to Collect	Always purchased—not self-collected; retail access better in urban areas.	[10], [87]
Ease to Use	Burns steadily; ventilation needed; utility consistent across regions.	[101], [95]
Ease of Economy	Pricey, especially in urban areas; not commonly used as a primary fuel.	[82], [3]
Charcoal		
Ease of Access	Limited production in rural areas; available in urban markets.	[102], [10]
Ease to Collect	Purchased in all cases; urban areas have better access.	[93], [89]
Ease to Use	More stable and cleaner than firewood; used consistently where available.	[103],[98]
Ease of Economy	High unit cost limits use, especially in urban areas.	[90], [10]
Kerosene		

Ease of Access	Distributed through ration in rural/semi-urban; widely sold in cities.	[104], [105]
Ease to Collect	Available via local shops; most organized in urban settings.	[88], [99]
Ease to Use	Easy ignition, mostly used as lighting/cooking backup; familiarity high.	[106]
Ease of Economy	Moderate post-subsidy price; rarely a primary household fuel.	[10], [91]
	Biogas	
Ease of Access	Mostly found in rural livestock-rich households; promoted in semi-urban areas; rare in dense urban settings.	[107], [89], [108]
Ease to Collect	On-site generation in rural areas; semi-urban areas with community digesters; not applicable in urban.	[109], [89]
Ease to Use	Easy to operate if maintained; used mainly for cooking in rural homes; lack of awareness in urban areas.	[107], [110]
Ease of Economy	High upfront cost but low running cost in rural; subsidies improve adoption; unsuitable in city homes.	[108], [92]

4.6.2 Efficiency and Emission Scoring in the 6Es Framework

The last two components of the 6Es framework Efficiency and Environmental Friendliness are assessed using technical parameters:

- Efficiency is evaluated based on the calorific value (MJ/kg) of each fuel.
- Environmental Friendliness is measured by CO_2, CH_4, and CO emissions per unit of energy (g/MJ).

4.6.3 Efficiency Scoring (1–5 Scale)

Fuels are assigned a score from 1 to 5 based on their calorific value, where higher values reflect greater combustion efficiency.[96], [111],[112], [113]

Table 4.6: Efficiency Ranking Range

Calorific Value (MJ/kg)	**Efficiency Score**
Below 15	1
15–19.9	2
20–25	3
25–34	4
Above 34	5

Example: Firewood has a calorific value of 15-20 MJ/kg, hence receives an efficiency score of 2.

Emission Scoring (1–5 Scale)

Emission scores are based on the intensity of CO_2, CH_4, and CO emissions per MJ of energy. Cleaner fuels score higher. The upper and lower bounds, along with CO and CH emission values for various household fuels, were taken from the literature, and so were the values for each based on [114],[74],[115],[116],[117].

Table 4.7: Emission Scoring for Fuels Used in Household

Emission Intensity (g/MJ CO_2eq)	**Emission Score**
Above 150	1
100–150	2
50–99	3
10–49	4
Below 10	5

Example: LPG emits 63 g/MJ CO_2eq (Score 3); electricity emits nearly 10% less CO_2 (Score 4)

Scoring Method Summary

Each fuel is evaluated using three criteria:

- Convenience Score: Sum of rural and urban 4E scores
- Efficiency Score: Based on calorific value

- Emission Score: Based on pollutant emission intensity

Total Score = Convenience Score + Efficiency Score + Emission Score

4.6.4 Fuel Weightages

From the rankings of Table4.8, the fuels' weightages are calcualted as in this index not all fuels are equal. Especilly in the case of Nepal, even though LPG and electricity are both considered clean, they cannot be equal as there are severe other disadvantages to using LPG over electricity. The table below employs a similar rank wise weigh calculation like [57].

Table 4.8: Fuel-wise Energy Ladder Ranking and Weights

Fuel Type	**Fuel**	**Energy Ladder Rank**	**Ranking Points**	**Weight**	**Notation**
Modern Fuels	Electricity	9	9/9	1.00	W1
	Solar PV	8	8/9	0.89	W2
	Solar Thermal	7	7/9	0.78	W3
Transitional Fuels	LPG	6	6/9	0.67	W4
	Biogas	5	5/9	0.56	W5
	Kerosene	4	4/9	0.44	W6
	Charcoal	3	3/9	0.33	W7
Primitive Fuels	Firewood	2	2/9	0.22	W8
	Agri. Waste	1	1/9	0.11	W9
	Dung Cake	0	0/9	0.00	W10

Table 4.9: Average of the Main Fuel Shares by Region

Fuel Type	**Rural Share**	**Semi-urban Share**	**Urban Share**
Electricity	0.03	0.29	0.52
Solar PV	0.00	0.00	0.01
Solar Thermal	0.00	0.02	0.05
LPG	0.21	0.42	0.41
Biogas	0.00	0.01	0.00
Kerosene	0.00	0.00	0.00
Charcoal	0.00	0.00	0.00
Firewood	0.76	0.25	0.00
Agri. Waste	0.00	0.00	0.00
Dung Cake	0.00	0.00	0.00
Total	1.00	1.00	1.00

The average of the main energies consumed for all the activities in the research areas were, firewood LPG and electricity and the end use energy ratio's are given in Table 4.9. The fuels are assigned weights based on the energy ladder ranked from the 6E Framework as depicted by the Table 4.8. Now these values for the fuels will be used alongside the total share of each type of fuel to formulate a household energy transition index using the following formula:

$$\left[\frac{\begin{matrix} n{-}1w_1\ n{-}2w_2\ n{-}3w_3\ n{-}4w_4\ n{-}5w_5 \\ n{-}6w_6\ n{-}7w_7\ n{-}8w_8\ n{-}9w_9\ n{-}10w_{10}\end{matrix}}{n-1}\right] 1 \tag{4.1}$$

This equation is adapted from [57].

Where, w_i represents the product of share of respective fuel in the mix and the weightage W_i. Using this the HETI have been calculated for all the households, the statistical analysis based on the regions are calculated as in Table4.10, the detailed HETI calculations for each household have been attached in the Appendix.

Table 4.10: Statistical Summary of Household Energy Transition Index (HETI) by Region

Statistic	Kathmandu	Chitwan	Ramechhap
Mean HETI	1.847	1.759	1.362
Standard Deviation	0.050	0.121	0.212
Minimum	1.70	1.25	1.22
25th Percentile	1.82	1.70	1.22
Median	1.85	1.78	1.23
75th Percentile	1.88	1.85	1.67
Maximum	2.00	1.93	2.00

The comparative analysis of the Household Energy Transition Index (HETI) across Kathmandu, Chitwan, and Ramechhap reveals further trends just like the energy stacking and climbing up the ladder as shown in Table 4.10. Kathmandu exhibits the highest mean HETI (1.847) with a narrow standard deviation (0.050), indicating an uniform and advanced stage of transition toward clean household energy sources. This is likey due to the widespread adoption of modern fuels such as LPG and electricity and low access to firewood. In contrast, Chitwan shows a moderate mean HETI (1.759) and a higher standard deviation (0.121), suggesting greater variations in household energy behavior. This pattern indicates a transitional phase, where households are increasingly adopting cleaner fuels but continue to rely on traditional sources, possibly due to economic or cultural factors. Likewise, Ramechhap, records the lowest mean HETI (1.362) and the highest variability (standard deviation of 0.212). The scores are tightly clustered around the lower end, reflecting continued dependence on biomass fuels such as firewood, dung, and agricultural waste, though the presence of high outliers suggests that clean energy adoption has begun in some households.

These give further assessment of the energy transition readiness, direction, and the intra-regional disparities , such that it underscore the value of the HETI framework over traditional ladder models by capturing energy stacking behaviors and . The results highlight the need for region-specific interventions: while Kathmandu may benefit from policies that enhance efficiency and sustainability of clean energy use, Chitwan requires strategies that reduce transitional reliance on solid fuels, and Ramechhap demands foundational support in energy access, affordability, and awareness to catalyze the clean transition.

Table 4.11: Linear Regression Output: Income as Predictor of HETI or Energy Transition

Variable	Coefficient	Std. Error	t-Stat	P-value
Intercept	1.313	0.023	57.97	2.01×10^{-244}
Income Score	0.117	0.007	16.39	5.99×10^{-50}
Model Summary Statistics				
R (Correlation)		0.561		
R-squared		0.315		
Adjusted R-squared		0.314		
Standard Error		0.212		
Observations		586		
F-statistic		268.64		
Significance F		5.99×10^{-50}		

4.6.5 Regression Against Income for Validity

The regression shows statistically significant and strong relationship between household income and the Household Energy Transition Index (HETI). With an R^2 of 0.315, income alone explains approximately 31.5% of the variation in HETI, supporting the theoretical expectation that higher-income households are more likely to adopt cleaner and modern energy sources and also the fact that higher income households are usually in urban settings. This is further supported by the p-value ($p < 0.001$), and the positive coefficient of 0.117 that shows families' share of cleaner or advanced fuels rises as their income levels rise. These results support the HETI framework's ability to accurately rank regions and provide greater explanatory power than other transition theories, such as the Energy Ladder and Energy Stacking models. They also show that the framework is viable for capturing real-world energy transition dynamics.

4.7 Comparison of the Energy Transition Frameworks

All the three frameworks of energy transition offers distinct insights. The Energy Ladder model assumes a linear shift and holds partially in the data. The model fails to explain fuel mixing behaviors observed in the regions for example in Chitwan, where households stack LPG, electricity, and biomass—highlighting its limitation in dynamic energy settings.

The Energy Stacking model reflects this complexity more accurately. It captures fuel diversity (e.g., Chitwan Gini-Simpson = 0.56) and simultaneous use across types. Share Stack and Steer Stack extend this framework to show transition direction, but it still lacks a unified measure of sustainability or transition quality. However, stacking metrics still treat all fuels equally unless adjusted, and they do not integrate technical or sustainability attributes.

HETI addresses these gaps of both the ladder and stacking by combining fuel-use patterns with sustainability attributes through the 6E framework. It differentiates between modern, transitional, and traditional fuels while accounting for emissions, efficiency, and convenience. HETI scores align well with observed trends—Kathmandu (1.847), Chitwan (1.759), Ramechhap (1.362)—and correlate strongly with directional stacking indices (r = 0.89–0.92). Unlike other frameworks, HETI enables robust regional comparisons and supports targeted policy analysis.

The Table 4.12, shows the comparative analysis for the various energy transition analysis.

Table 4.12: Comparative Features of Energy Transition Frameworks

Feature	Energy Ladder	Energy Stacking	HETI
Assumes linear shift	Yes	No	No
Captures fuel mixing	No	Yes	Yes
Captures direction of transition	No	Partially	Yes
Reflects quality of fuels	No	Partially	Yes
Incorporates efficiency and emissions	No	No	Yes
Offers a composite score	No	No	Yes
Regionally/contextually adaptable	Limited	Moderate	High
Differentiates transitional fuels	No	Partially	Yes
Supports policy targeting	Limited	Medium	High
Requires detailed household-level data	Low	Medium	High
Easy to interpret	High	Medium	Medium
Captures variability within income groups	Low	High	High
Appropriate for dynamic/mixed fuel settings	No	Yes	Yes

4.8 Socio-economic Impacts

4.8.1 Impact of Income on Fuel Type Usage in Cooking

The series of graphs in Figure 4.9 illustrate the relationship between income levels (low, middle, and high) and energy usage across three primary sources: firewood, LPG, and electricity for cooking purpose. As, cooking accounts for the most significant amount of energy for a household in Nepal, this is highly important to take heed of.

There is a clear trend where firewood consumption decreases as income levels rise in rural and semi-urban areas, while LPG and especially electricity usage increase with higher income groups across regions. This pattern aligns well with the energy transition theories, where wealthier households shift away from traditional biomass towards cleaner and more efficient energy sources. But the average consumption per income level is not quite low and the household simply do not abandon the traditional fuels at higher income levels but only decreases it's shares slightly, making use of more cleaner fuels. Thus, in low-income households, firewood remains the dominant energy source, reflecting economic constraints and limited access to modern fuels in the rural only. However, as income increases, there is a notable increase in LPG and electricity consumption, indicating a transition towards cleaner energy solutions. In high-income groups, firewood usage is minimal, while LPG and electricity dominate, highlighting affordability and infrastructure availability.

This data underscores the need for policies that facilitate energy access in lower-income regions, such as subsidizing LPG, expanding rural electrification, awareness and promoting ICS to enable a smoother and more sustainable energy transition.

However, this is different in the case for Kathmandu as most all households have clean cooking energy, but we can clearly see that in higher income household's energy and electricity consumption increases. The electrical cooking growth rate is higher compared to even LPG. There is also a limited share of use of firewood usage across all income levels in urban area (Kathmandu), this has stemmed from tendency to use firewood cooking during gatherings, and special occasions.

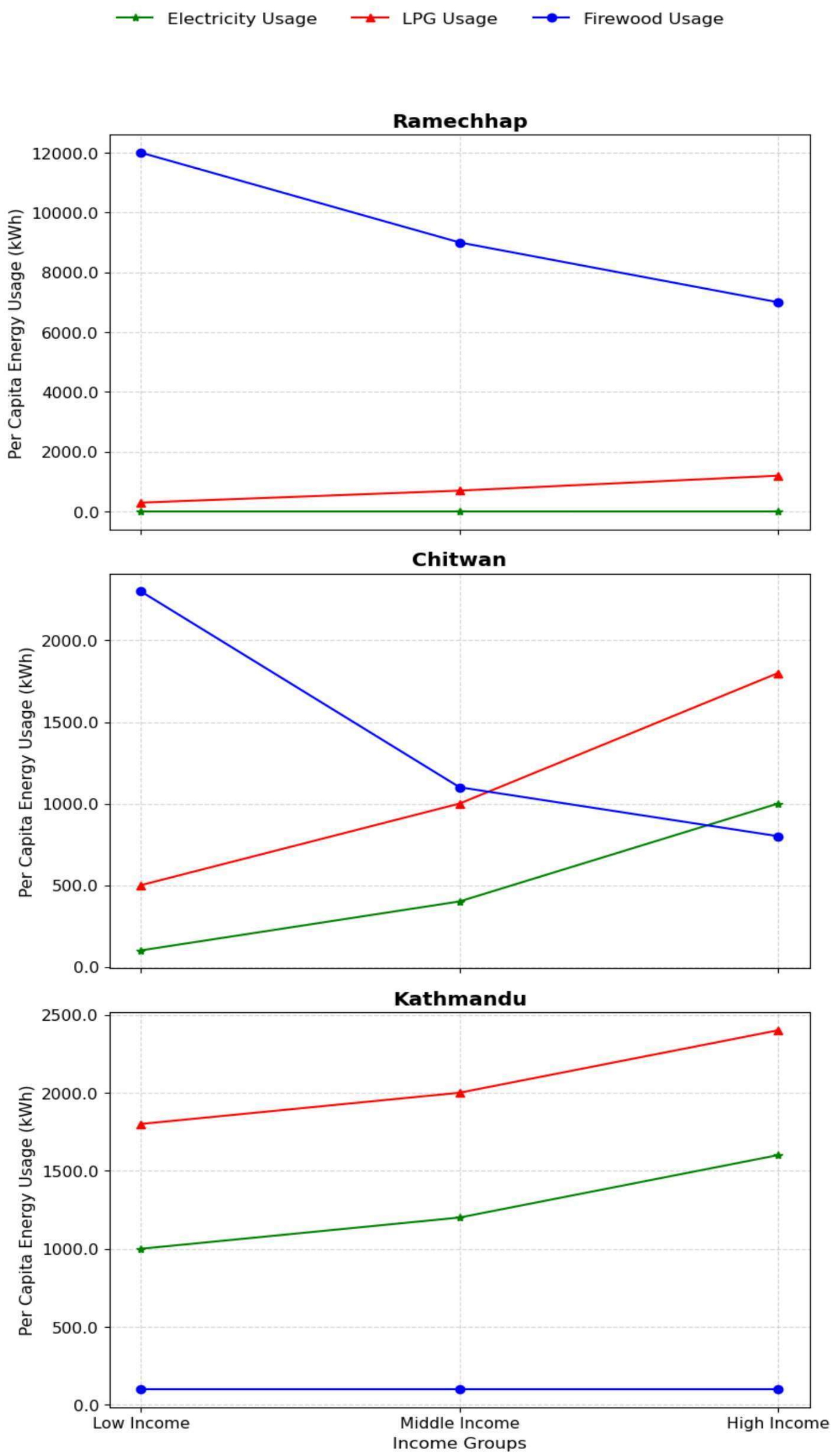

Figure 4.9: Energy Usage by Income Level in the Three Regions

4.8.2 Impact of Education on Different Fuel Types

The education level is seen to vary vastly by region and thus, influences decisions regarding energy consumption. The accounts indicate that in rural areas like Ramechhap, have mostly household head with minimal or no education. Contrary to that, a pattern in Chitwan's data suggests that a considerable portion of its population having done achieved a higher secondary schooling. While the most urbanized district, Kathmandu, has the greatest proportion of individuals with higher education. These differences mirror stark contrast in educational access most likely due to geographical, economic, and infrastructure constraints. Thus, it is an indicator to explain the energy usage across the three regions.

The relationship between educational level and behavior regarding energy use is evident in the reserach, mainly in in rural (Ramechhap), as this regions hasn't transitioned much to clean energy . Here poorer educated households make extensive use of firewood. As education increases for general cooking applications the consumption of firewood reduced and in place LPG took over. This trend suggests that education plays a central role in facilitating energy transitions, likely due to increased health and environmental risk awareness, as well as economic opportunities. Moreover, the strong correlation between education and modern energy use suggests that energy poverty is a consequence of low educational levels as much as affordability and availability

This was also verified through qualitative interviews with participants, who perceived LPG as costly, risky, and inconvenient for daily use. Alot of the respondents mentioned fear of insecure supply of LPG kept them away from completely adopting modern. This was stemed from their experince of prolonged disruptions experienced during the COVID-19 pandemic. The remaining, retained the LPG stoves but employed them not on a regular basis, perhaps again because of affordability, skepticism about the dependability of the fuel, or reliance and ease of access of traditional biomass. These results highlight the need for education and building public confidence in new energy sources and technology particularly in rural areas.

4.8.3 Imapct of Occupation of household head in Energy usage in Rural Ramechhap

In Ramechhap, farming households consumed up to 1.75 times more firewood than non-farming households. This is primarily due to easier access to forests, traditional cooking practices, and higher energy needs for large families (household primarily engaged in farming were larger families) and agricultural tasks. Thus, firewood remains essential for activities like animal feed preparation, where LPG and electricity are impractical due to cost and heat control limitations.

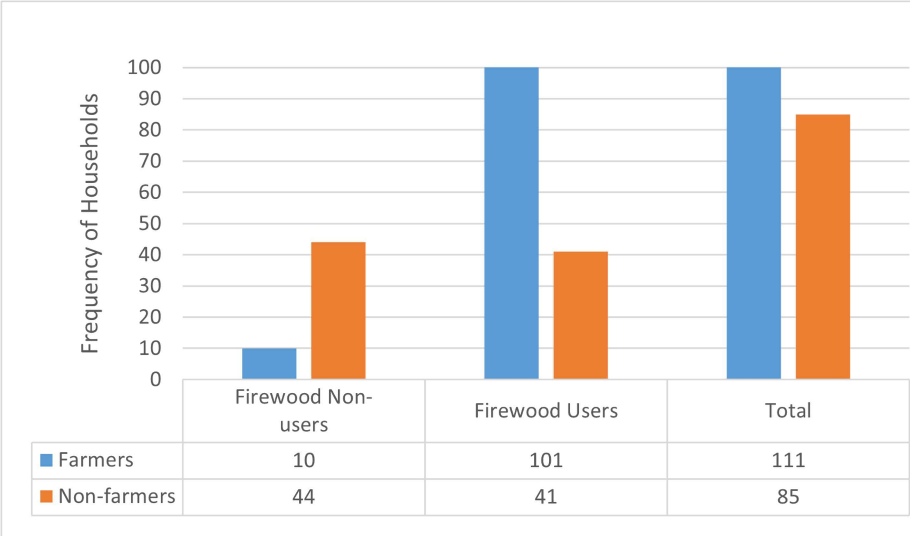

Figure 4.10: Farming and Non-farming Household Frequency Distribution Based on Firewood Usage

From the survey, it was clear that many farmers find LPG and ICS unsuitable for large scale cooking needs. ICS, in particular, struggled to accommodate large pots , as such even the small-scale livestock owners preferred traditional stoves for their flexibility for both household cooking and livestock needs. Also, contrary to popular belief, ICS adoption actually often led to increased indoor air pollution due to poor design, lack of maintenance, and installation issues. The clogged chimneys and mishandling negated the expected health benefits. These challenges highlight the need for better ICS designs, proper user training, and culturally adapted solutions if it is to be made viable. They even cited that after the first few rounds of ICS distribution and installation, there were lack of experts for this technology that assisted in the process later on.

Farming households prioritized, ease of access, need and economy when choosing their fuel. In contrast, non-farming households, such as traders and service workers, tend to use LPG and electricity more due to better accessibility and time savings. However, nearly 57%, as shown in Figure4.10 of the households in the survey were involved in farming and the significant firewood use among farmers raises concerns over deforestation, indoor air pollution, and health risks.

4.9 Determinant of Household Energy Preferences

The residents were requested to pick the key drivers that influenced their fuel choice. The main drivers studied in this research and the survey based rankings on a scale of 1-5 for the most influential factors are in Table4.13:

Table 4.13: Ranking of Key Determinants for Household Energy Choice

Rank	Factor	Percentage of Respondents
1	Affordability	80%
2	Policy & Government Support	75%
3	Reliability of Supply	70%
4	Health Impact	65%
5	Usability & Appliance Compatibility	62%
6	Efficiency	60%
7	Ease of Use	55%
8	Ease of Access	53%
9	Environmental Friendliness	48%
10	Ease of Gathering/Procurement	45%
11	Community Norms & Traditional Practices	30%

As seen in the table,affordability (80%), policy support (75%), and reliability (70%) emerged as the top drivers for energy selection. In contrast, cultural norms and traditions played a relatively minor role in decision-making. This suggests that economic and infrastructural factors dominate household energy choices over sociocultural influences. The findings highlight people's direct preferences, and a clear need for targeted subsidy programs, improved fuel supply chains, and enhanced energy infrastructure to promote a sustainable transition to clean energy in Nepal.

4.10 People's Perception on Firewood Cooking

Throughout the survey process across all places from rural, semi-urban and urban people commonly highlighted they liked the food cooked in firewood over LPG. Thus, after surveying 200 people randomly from all the regions. The findings supported the fact that many people preferred traditional cooking to modern alternatives. Refer to Figure 4.11

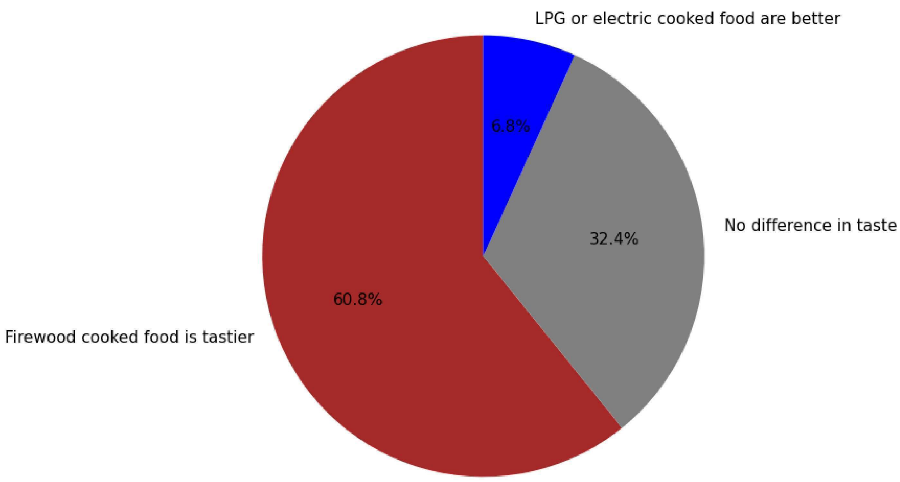

Figure 4.11: Taste Survey Results for Firewood Cooking vs LPG and Electricity

The survey revealed that 60.8% of respondents preferred the taste of food cooked with firewood, reflecting strong cultural attachment and traditional beliefs. Only 6.8% favored food cooked with LPG or electricity, while 32.4% noticed no taste difference. These results suggest that taste perception is a key factor in fuel preference, and clean energy adoption must consider not just cost and access, but also culinary habits and flavor preferences.

4.11 Challenges to Clean Cooking in Rural Households

Despite efforts to promote LPG use, adoption is still low. From the research people had negative qualms about LPG technology, mainly reliability in supply and sustainable pricing alongside safety. This was further exacerbated by the COVID-19 lockdown as access to LPG became unaffordable or out of stock for months. Furthermore, families with lower awareness and education had safety concerns that discouraged adoption. Some households find firewood safer than LPG, and their main concerns are explosions, all the while with no awareness of LPG's indoor air pollution and health advantages.

Similar to LPG stoves, the residents of rural Ramechhap deemed ICS unsuitable to meet their daily needs. Many found ICS impractical for preparing large quantities of animal feed, as they could not accommodate large utensils effectively. In contrast, traditional open-fire stoves, despite their inefficiencies, offered greater flexibility for handling large pots and prolonged heating. Even the households who are not primarily involved in farming often kept livestock in smaller frequencies, they as well preferred traditional cooking methods. Another major concern was the ineffectiveness of ICS in reducing indoor air pollution over time. Households reported increased smoke accumulation due to poor design, inadequate maintenance, or improper installation. In several instances, clogged or faulty chimneys led to smoke being trapped indoors, undermining the key health benefit of ICS adoption.

The survey results shown in Figure4.12 validates this issues with ICS adoption. We can see that among households that had installed ICS, 69% had either abandoned or did not use them, while only 23% used them regularly. This high abandonment rate underscores the severity of the mismatch between ICS design and rural cooking needs. These challenges indicate that though ICS can improve energy efficiency and reduce firewood use, their success is hindered by design flaws, limited adaptability to local cooking practices, low awareness, and poor implementation strategies. Addressing these issues requires improved stove designs, user training, and context-specific modifications to better align with the cultural and practical needs of rural households.

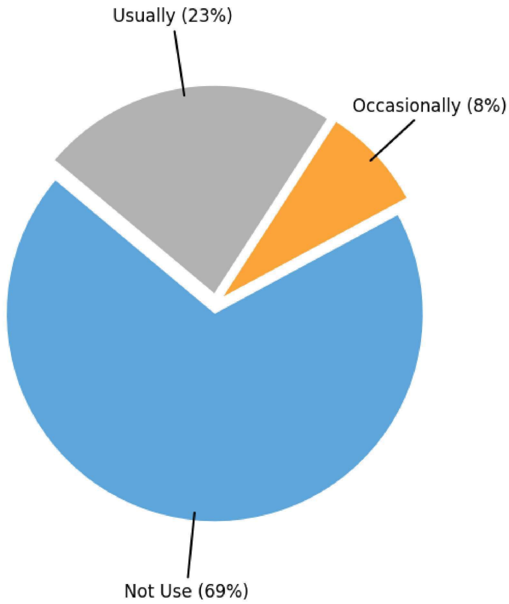

Figure 4.12: Usage of ICS based on Frequency of Use for Households Owning ICS

4.12 Regression Analysis

Multiple Linear OLS Regression for Total Energy Consumption

The regression results from Tables 4.14 and 4.15 reveal key socio-economic and locational determinants of household energy consumption in Nepal. Mainly the electricity consumption is positively and significantly influenced by household income and urbanization, indicating greater consumption of modern appliances in urban and more affluent households. The model's high explanatory power (R^2 = 0.710) suggests that income, location, and socio-economic factors are strong predictors of electricity consumption.

On the other hand, firewood consumption is inversely related to income and urbanization, but larger families and farming families have higher reliance on traditional fuels. These findings validate the energy ladder hypothesis, where rising income and urbanization results in a shift to a cleaner fuel, while the share of the inefficient and traditional fuels decrease. The firewood model also fits well (R^2 = 0.659), validating the role of socio-economic determinants in fuel consumption.

Education has a positive yet context-contingent impact, influencing clean energy adoption and interacting with cultural behavior and access challenges. Overall, while linear regression is informative, it may not be adequate to capture household energy choices that are adaptive and multidimensional.

These results also point to energy stacking use, where households use more than a single fuel simultaneously rather than switching fully. This behavior exhibits non-linear dynamics that obscure the predictions of standard regression methods. In particular, LPG is typically augmented with firewood, especially for middle-income and rural households that face affordability and supply constraints, thus this linear regression analysis did not yield a good fit or had much explanatory power.

Table 4.14: Electricity Usage Regression Model

Variable	Coefficient (β)	P-value	Interpretation
Intercept	45.2	–	Baseline electricity usage
Income	12.8	0.014	Higher income increases electricity consumption
Semi-Urban	87.4	0.000	Semi-Urban households use more electricity than rural
Urban	114.6	0.000	Urban households use the most electricity
R-squared	**0.710**	–	

Multiple Linear OLS Regression for HETI

The results from the multiple linear OLS regression for HETI is also run accordingly. Table 4.16 and Table 4.17 demonstrates a clear and statistically significant relationship between the Household Energy Transition Index (HETI) and key socio-economic predictors. Notably, income level exhibits a strong positive gradient (like previously done one to one in Table 4.11, with HETI values increasing from Income B through E, indicating

Table 4.15: Firewood Usage Regression Model

Variable	Coefficient (β)	P-value	Interpretation
Intercept	750.3	–	Baseline firewood usage
Income	-25.89	0.013	Higher income reduces firewood consumption
Household Size	21.67	0.002	Larger households use more firewood
Farming	79.2	0.0023	Farming households use more firewood
Semi-Urban	-522.2	0.000	Semi-Urban use significantly less firewood than rural
Urban	-670.2	0.000	Urban households use the least firewood
R-squared	**0.659**	–	

that wealthier households tend to transition more toward cleaner and modern energy sources. Similarly, higher educational attainment significantly increases HETI, while being uneducated is associated with a lower index.

In this regression framework, all categorical variables are treated as dummy variables compared against a designated base category. For income level, the base case is Income A, representing the lowest income group. All coefficient estimates for Income B to E thus reflect the change in HETI relative to Income A. Similarly, for education level, the base case is Basic Education—hence, the positive coefficient for Higher Education and the negative coefficient for Uneducated are interpreted in comparison to this middle tier. Lastly, Female is used as the base gender category, against which the Male dummy is evaluated. These reference categories provide the benchmark for interpreting the relative influence of different socio-economic strata on the Household Energy Transition Index.

Despite the insignificance of gender, the overall model fit statistics (Table 4.17) support the robustness of the regression: an R-squared of 0.445 and an F-statistic of 57.86 with a p-value < 0.001 confirm that the model explains a substantial portion of the variation in HETI. The Figure 4.13, shows the effect of the factors on the HETI as well.

Furthermore, this analysis confirms the validity and robustness of HETI as a metric for assessing household energy transitions. Compared to traditional methods such as the energy ladder or stacking frameworks, HETI offers a more nuanced and data-driven representation of household energy behavior. This reinforces its value in informing policy and tracking energy transition progress at the micro (household) level.

Table 4.16: OLS Regression Results for Predictors of HETI (Excluding Farming)

Predictor	Coefficient	Std. Error	P-Value	95% Lower	95% Upper
Intercept	1.2975	0.0345	0.0000	1.2297	1.3653
Income B	0.1446	0.0264	0.0000	0.0928	0.1964
Income C	0.3652	0.0267	0.0000	0.3128	0.4176
Income D	0.4015	0.0277	0.0000	0.3472	0.4558
Income E	0.3319	0.0327	0.0000	0.2676	0.3961
Higher Education	0.0806	0.0216	0.0002	0.0383	0.1229
Uneducated	-0.0500	0.0220	0.0236	-0.0933	-0.0067
Gender Male	-0.0007	0.0183	0.9710	-0.0366	0.0352
Average Age	0.0020	0.0007	0.0034	0.0007	0.0033

Table 4.17: Model Fit Statistics

Metric	Value
R-squared	0.445
Adj. R-squared	0.437
F-statistic	57.86
p (F-statistic)	5.73e-69

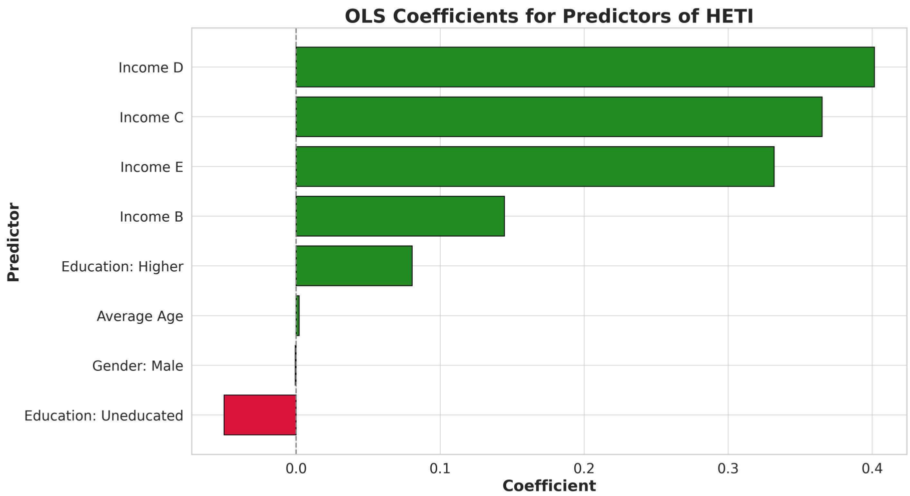

Figure 4.13: HETI Regression Analysis Coefficients Compared to Base Case

4.13 Nepal's Energy Transition Framework: Reconciling the Energy Ladder and Energy Stacking

This study illustrates the region specific results in Nepal's internal energy transition demonstrates aspects of both the Energy Ladder and Energy Stacking paradigms, a more emphasized on the later. While the Energy Ladder hypothesizes linear advancement towards new fuels in relation to rising incomes and urbanization, experiences illustrate that this is an adaptive process and by no means always linear, but what is linear is preference or frequency of households making use of cleaner primary cooking fuel with rise in income.

Regression analysis further confirms the role of higher income, education and urbanization as prominent indicators that are strongly associated with more electricity usage and less firewood reliance. As such, from the reserarch it can be safely said that, the urban areas like Kathmandu have shifted to cleaner fuels to a large degree while rural Ramechhap continues to rely on biomass. The severity or the intesity of the energy use/stacking can be noted from the forumated Household Energy Transition Index. Not only that but the share of households employing cleaner primary fuel also increased significantly with income level. The trends above support the ladder assumption that wealth and infrastructure are driving cleaner energy adoption.

Despite upward transitions, energy stacking even in urban, high-income households, firewood is retained for cultural uses (e.g., festival cooking). In Chitwan, households mix LPG, biogas, firewood, and electricity based on task, availability, and policy incentives. In rural areas, fuel use varies with season, income flow, and biomass access, undermining the idea of full fuel substitution.

Thus, while aspects of the Energy Ladder remain valid, Nepal's transition is best understood through a stacking framework, emphasizing flexibility over linear progression. The intensity and effects of varied fuel usages can be quantified with the Household Energy Transition Index.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Conclusion

a. Fuel stacking is the dominant energy use behavior across all regions. In Kathmandu, over 85% of households use LPG and electricity, though some still use firewood culturally. Chitwan shows a transitional pattern, with about 48% relying on clean fuels. In Ramechhap, more than 70% of households depend on firewood due to affordability, access limitations, and cultural cooking practices.

b. The HETI developed using the 6E framework effectively captures both fuel diversity and transition quality. Kathmandu recorded the highest average score (1.85), followed by Chitwan (1.76), and Ramechhap (1.36). HETI outperforms traditional models by integrating behavioral and technical dimensions of household energy use.

c. Income, education, and occupation significantly influence energy transitions. Higher income households are 3.5 times more likely to use LPG or electricity. Education positively correlates with HETI scores, and agricultural households remain dependent on firewood due to long cooking needs. ICS adoption dropped sharply, with 69% abandonment due to impracticality and safety concerns.

Recommendations

a. Clean fuel subsidies and improved distribution systems are recommended to reduce reliance on biomass in low-income and rural households.

b. Redesign of Improved Cookstoves (ICS) considering local cooking practices is suggested to enhance the adoption and sustained use.

c. The Household Energy Transition Index (HETI) is proposed as a tool to monitor regional progress and guide energy transition planning.

d. Awareness and information programs are recommended to enhance clean fuel adoption, particularly in regions where education levels influence energy choices.

e. The promotion of electric cooking is to be prioritized in Kathmandu and Chitwan to accelerate the transition to modern energy solutions.

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APPENDIX A: SURVEY QUESTIONNAIRE

Contextualizing the Energy Models for Nepal
Final Questionnaire

Respondent's Information

- Full Name:____________________
- Age:____________________
- Gender: [M] [F]
- Contact Number:____________________
- Email:____________________

Location

- Province:____________________
- District:____________________
- Municipality:____________________
- Ward No.:____________________
- Name of settlement or tole:____________________

Geographic Information

1. Distance to nearest paved road:

   a) 0–2 km
   b) 2–10 km
   c) Greater than 10 km

2. Distance to market, health service, school:

   a) 0–3 km
   b) 3–15 km
   c) Greater than 15 km

Household Characteristics

3. Gender of Household Head:

   a) Male
   b) Female
   c) Other

4. Age of household head:

   a) 16–25
   b) 26–50
   c) 50–70
   d) 70+

5. Education level:

a) No education
b) No formal education
c) Primary
d) Secondary
e) High School
f) Vocational/Technical
g) Bachelor's Degree
h) Master's Degree
i) Doctoral Degree

6. Total Household Members:

a) 2
b) 3
c) 4
d) 5
e) 6
f) 7
g) 8
h) More

Employment Status

7. Employment Status of Household Head:

a) Self-employed
b) Salaried job
c) Casual Labor
d) Student
e) Farmer
f) Unemployed
g) Retired
h) Abroad for work
i) Business
j) Government job
k) NGO/INGO or social organization
l) Seasonal worker
m) Technical field
n) Medicine
o) Others: ________________________

8. Employment Status of other household members:

a) Self-employed
b) Salaried job
c) Casual Labor
d) Student
e) Farmer
f) Unemployed
g) Retired
h) Abroad for work
a) Business
j) Government job
k) NGO/INGO or social organization
l) Seasonal worker
m) Technical field
n) Medicine
o) Others: ________________________

House Type

9. Walls of the house are made of:

a) Mud
b) Brick
c) Wood
d) Stone
e) Other

10. Roof is made of:

a) Thatch
b) Tin
c) Cement
d) Wood
e) Other

11. Number of rooms: ____

a) 1–2 rooms
b) 3–4 rooms
c) 5–6 rooms
d) 6–7 rooms
e) 8–10 rooms
f) More

Electricity Sources

12. Sources of electricity (Select all that apply):

a) Grid connection (NEA)
b) Solar PV
c) Diesel Generators
d) Wind energy
e) Micro hydro
f) Others
g) Not connected to electricity

13. Electricity connection (Ampere):

a) 5 Ampere
b) 15 Ampere
c) 30 Ampere
d) Others: ______________________________

Socio-economic Information

14. Monthly Household Income (NPR):

a) Less than 15000
b) 15000 – 30000
c) 30000 – 60000
d) 60000 – 120000
e) Greater than 120000

Energy Information

15. What do you use energy for? (Select all that apply)

a) Cooking
b) Lighting
c) Heating and cooling
d) Water heating
e) Entertainment and other utility
f) EV charging
g) Others: ______________________________

Cooking Information

16. Cooking Schedules (Select all that apply):

a) Breakfast
b) Lunch
c) Dinner
d) Meal/Snacks
e) Other

17. Rank energy source usage for cooking (1 = least, 5 = most):

– LPG: ______________________________
– Firewood: ______________________________
– Electricity: ______________________________

18. Time spent cooking on average:

- a) 1–2 hrs
- b) 2–3 hrs
- c) 3–4 hrs
- d) 5–6 hrs
- e) More than 6 hrs

19. Peak cooking hours (Select all that apply):

- a) Mornings (6 to 11am)
- b) Day (12 to 5pm)
- c) Evenings (6 to 11pm)
- d) Nights (12 to 5am)

20. Select/Write the appropriate energy sources used for the following:

- Lunch: ______
- Meal: ______
- Breakfast: ______
- Others: ______

21. What cooking appliances are used? (Select all that apply)

- a) LPG stoves
- b) Electric Rice Cookers
- c) Induction and infrared stoves
- d) Microwave oven
- e) Improved cooking stoves (ICS)
- f) Traditional stoves (Mud/Teen Dhunga)
- g) Gas ovens
- h) Solar cookers
- i) Kerosene stoves
- j) Biogas stoves
- k) Others: ______

22. Rate the importance (1 = least, 5 = most) of the following for cooking:

- a) Affordability ______
- b) Traditional practices, Community norms & Social Status ______
- c) Appliance availability/usability ______
- d) Health Impact (Cleanliness, Indoor Pollution, Safety) ______
- e) Reliability (Uninterrupted supply) ______
- f) Policy, Govt. support ______
- g) Environmental Friendliness ______
- h) Efficiency ______
- i) Ease of Use ______
- j) Ease of Access (fuel/appliances) ______
- k) Ease of Gathering Fuels ______

Lighting Information

23. Lighting appliances used (Select all that apply):

- a) LED bulbs
- b) CFL bulbs
- c) Tube lights
- d) Table lamps
- e) Solar/battery LED
- f) Kerosene lamps
- g) Oil lamps
- h) Decorative/Smart lights
- i) Firewood
- j) Others: ______

24. Average daily lighting hours:

a) 1–2 hrs
b) 2–3 hrs
c) 3–4 hrs
d) 5–6 hrs
e) 6–7 hrs
f) More

25. Peak lighting hours (Select one):

a) Mornings (6am to 11am)
b) Day (12pm to 4pm)
c) Evenings (5pm to 11pm)
d) Nights (12am to 5am)

26. Rate importance (1 = least, 5 = most) for lighting choices:

a) Affordability ____________________
b) Traditions Social Status ____________________
c) Appliance compatibility ____________________
d) Health Impact (safety, pollution) ____________________
e) Reliability ____________________
f) Policy Support ____________________
g) Environmental impact ____________________
h) Efficiency ____________________
i) Ease of Use ____________________
j) Ease of Access ____________________
k) Fuel gathering ease ____________________

Heating and Cooling Information

27. Heating and cooling appliances used:

a) Air conditioner (AC)
b) Air Coolers
c) Table/Standing Fans
d) Ceiling Fans
e) Wood-burning stove heater
f) Biogas stove heater
g) Electric blankets
h) LPG Gas Heaters
i) Electric/Infrared Room Heaters
j) Kerosene burners
k) Charcoal heaters/briquettes
l) Open fireplaces
m) Others: ____________________

Cooling and Heating Usage

28. Summer use of cooling devices:

a) 1–2 hrs
b) 2–3 hrs
c) 3–4 hrs
d) 5–6 hrs
e) More than 6 hrs
f) No use

29. Peak cooling hours:

24. Average daily lighting hours:

a) 1–2 hrs
b) 2–3 hrs
c) 3–4 hrs
d) 5–6 hrs
e) 6–7 hrs
f) More

25. Peak lighting hours (Select one):

a) Mornings (6am to 11am)
b) Day (12pm to 4pm)
c) Evenings (5pm to 11pm)
d) Nights (12am to 5am)

26. Rate importance (1 = least, 5 = most) for lighting choices:

a) Affordability ____________________
b) Traditions Social Status ____________________
c) Appliance compatibility ____________________
d) Health Impact (safety, pollution) ____________________
e) Reliability ____________________
f) Policy Support ____________________
g) Environmental impact ____________________
h) Efficiency ____________________
i) Ease of Use ____________________
j) Ease of Access ____________________
k) Fuel gathering ease ____________________

Heating and Cooling Information

27. Heating and cooling appliances used:

a) Air conditioner (AC)
b) Air Coolers
c) Table/Standing Fans
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e) Wood-burning stove heater
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g) Electric blankets
h) LPG Gas Heaters
i) Electric/Infrared Room Heaters
j) Kerosene burners
k) Charcoal heaters/briquettes
l) Open fireplaces
m) Others: ____________________

Cooling and Heating Usage

28. Summer use of cooling devices:

a) 1–2 hrs
b) 2–3 hrs
c) 3–4 hrs
d) 5–6 hrs
e) More than 6 hrs
f) No use

29. Peak cooling hours:

a) Mornings (6 to 11am)
b) Days (12 to 5pm)
c) Evenings (6 to 11pm)
d) Nights (12 to 5am)

30. Winter use of heating devices:

a) 1–2 hrs
b) 2–3 hrs
c) 3–4 hrs
d) 4–5 hrs
e) 5–6 hrs
f) More than 6 hrs
g) No use

31. Peak heating hours:

a) Mornings (6 to 11am)
b) Days (12 to 5pm)
c) Evenings (6 to 11pm)
d) Nights (12 to 5am)

32. Water heating appliances used:

a) Solar Thermal Heater
b) Electric Coil
c) Gas Geyser
d) Firewood Stove
e) Cookstove
f) Briquette Stove
g) Biogas Stove
h) Electric Gas Geyser
i) Charcoal/Coal burning
j) Others: ___________________________________
k) No water heating

Water Source

33. Do you use energy to transport water?

a) Yes
b) No

34. Weekly hours used for water pumping:

a) 1 hr
b) 2 hrs
c) 3 hrs
d) 4 hrs
e) 5 hrs
f) More

Electric Vehicle Information

35. Type of electric vehicle owned:

a) Car/Jeep/Van
b) Scooter/Motorbike
c) Others
d) No Electric Vehicles

37. Charging time for EV:

a) 1-2 hrs
b) 3-4 hrs
c) 5-6 hrs
d) 7-10 hrs
e) More

38. Factors influencing EV use (rate 1 to 5):

a. Initial Cost during purchase
b. Running cost (maintenance and electricity)
c. Range or Mileage
d. Availability of Fast charging stations
e. Environmental concerns
f. Government incentives and subsidy
g. Features
h. Brand and reliability

Electricity Information

39. Household electrical devices (select all that apply):

a) TV
b) Refrigerator
c) Mobile Phones
d) Personal Computers (Laptop)
e) Washing Machine
f) Others: ______________________

40. Monthly electricity bill cost:

a) NPR 50 to 100
b) NPR 300 to 800
c) NPR 800 to 1500
d) NPR 1500 to 3000
e) NPR 3000 to 6000
f) NPR 6000 to 10000
g) More than 10000

41. LPG monthly expenditure:

a) Rs. 3000
b) Rs. 2500
c) Rs. 2000
d) Rs. 1500
e) Rs. 1200
f) Rs. 1000
g) Rs. 750
h) Rs. 500
i) Rs. 250
j) Don't use LPG gas

Firewood and Gender Equity

42. Use of firewood for any purpose:

a) Yes
b) No

43. Firewood collection time and weight: ______________________________________

44. Monthly kerosene expense: ______________________________________

45. Who decides energy source:

a) Male Household Head
b) Female Household Head
c) Joint Decision
d) Others

46. Who manages fuel collection (select all):

a) Male adults
b) Female adults
c) Children
d) Hired labor
e) Others

Environmental and Awareness Information

47. Are you aware of health and environmental risks from fuelwood and low-grade fuels?
    a) Yes
    b) No
48. Are you aware that your energy choices affect air pollution?
    a) Yes
    b) No
49. What steps (if any) has your household taken to reduce negative energy impacts? ____________________
50. Rank the following barriers to adopting clean fuels (1 = least, 5 = most):
    a) Financial Reasons
    b) Culture and Tradition
    c) Lack of Access
    d) Lack of Awareness
    e) Policy Restrictions
    f) Others
51. Are you aware of Sustainable Development Goal 7 (Clean Affordable Energy)?
    a) Yes
    b) No
52. Has your community participated in clean energy promotion or awareness?
    a) Yes
    b) No

Household Energy Expenditure and Usage Patterns

53. How much do you spend on LPG per month? (NPR)
    a) 250
    b) 500
    c) 750
    d) 1000
    e) 1250
    f) 1500
    g) 1750
    h) 2000
    i) 2250
    j) 2500
    k) 3000
    l) 4000
    m) Other: ___
54. How much do you spend on electricity bill per month? (NPR)
    a) 0–300
    b) 300–500
    c) 500–1000
    d) 1000–1500
    e) 1500–2000
    f) 2000–3000
    g) 3000–5000
    h) 5000–7000
    i) Other: ____
55. Do you use firewood for any activities?
    a) Yes (Frequently)
    b) Yes (Sometimes, once a week)
    c) Yes (Very rarely, once a month)
    d) Does not use firewood
    e) Other: ____
56. How much firewood does your household consume per week?

a) 1–5 kg
b) 5–10 kg
c) 10–15 kg
d) 15–20 kg
e) 20–30 kg
f) 30–40 kg
g) 40–50 kg
h) ¿50 kg
i) Does not use firewood
j) Other: ___

57. Which of the following do you agree with regarding taste?

a) Firewood cooked food is tastier
b) LPG/electric cooked food is tastier
c) No difference in taste
d) Other: ___

Electric Vehicle Ownership & Preferences

58. Select all types of electric vehicles owned:

a) Car/Jeep/Van
b) Scooter/Bike
c) No electric vehicles owned
d) Other: ___

59. How many hours per day do you charge your electric vehicle?

a) 1 hr
b) 2 hrs
c) 3 hrs
d) 4 hrs
e) 5 hrs
f) 6 hrs
g) No EV
h) Other: ___

60. What factors most influence electric vehicle adoption? (1 = least, 5 = most)

a) Initial cost	1	2	3	4	5
b) Running cost (maintenance, electricity)	1	2	3	4	5
c) Range or mileage	1	2	3	4	5
d) Availability of fast charging	1	2	3	4	5
e) Environmental friendliness	1	2	3	4	5
f) Features	1	2	3	4	5
g) Brand and reliability	1	2	3	4	5
h) Government incentives	1	2	3	4	5

Energy Decision Making & Fuel Management

61. Who primarily decides energy source use in your household?

a) Male household head
b) Female household head
c) Joint decision
d) Other: ___

62. Who is responsible for fuel (LPG, firewood, etc.) collection or management? (Select all)

a) Male adults
b) Female adults
c) Children
d) Other: ___

Transition to Clean Energy

63. Are you aware of risks from low-grade energy sources (e.g., firewood)?
    a) Yes
    b) No
64. Are you aware that household energy choices contribute to air pollution?
    a) Yes
    b) No
65. What would motivate you to switch from LPG to electric cooking?
    a) Reliability of electric supply
    b) Initial cost
    c) Other: ____
66. Are you aware of SDG 7 focused on clean and affordable energy?
    a) Yes
    b) No
    c) Other: ____
67. Have you or your community participated in any clean energy initiatives?
    a) Yes
    b) No
    c) Other: ____
68. What kind of policies or support would help your household use cleaner energy? **(Open-ended)**

Tables for Appliance Usage

Cooking Appliances

Appliance	Quantity	Hours/Day	Rated Power	Remarks
LPG gas stove Traditional mud stove Improved stoves Electric Rice cookers Biogas stove Induction/Infrared Others				

Heating/Cooling Appliances

Device	Quantity	Hours/Day	Rated Power	Remarks
Electric Room Heater Fireplace/Wood burning Air Conditioner (AC) Fans (All types) Electric Blankets Charcoal/Briquettes Others				

Other Household Appliances

Appliance	Quantity	Hours/Day	Rated Power	Remarks
Refrigerator Television Mobile charging devices Laptop/Computer Iron Microwave oven Washing machine Vacuum cleaner Mixer/Grinder Water Purifier/Dispenser Others				

Agricultural and Water Pumping Appliances

Appliance	Quantity	Hours/Day	Rated Power	Remarks

Lighting Appliances

Lighting Device	Quantity	Hours/Day	Rated Power	Remarks
LED bulbs CFL bulbs Tube lights Solar LEDs Kerosene lamps Others				

APPENDIX B: SURVEY IMAGES

Figure B.1: Ramechhap Likhutamakoshi Houses

Figure B.2: Ramechhap Likkhutamakoshi House

Figure B.3: Chitwan Khairahani House

Figure B.4: Chitwan House

Figure B.5: LPG Stove in Chitwan

Figure B.6: Biogas Plant in Chitwan

Figure B.7: House in Kathmandu

Figure B.8: Cooking Appliances in Kathmandu

APPENDIX C: HETI REGRESSION ANALYSIS CODE

```
import pandas as pd
import statsmodels.formula.api as smf
import matplotlib.pyplot as plt

df = pd.read_csv("Heti anlaysis.csv")
df["Income_Level"] = pd.Categorical(df["Income Level"], categories=["A", "B", "C", "D", "E"],
ordedf["Education_Level"] = df["Education Level"] df["Gender_Household_Head"] =
df["Gender Household Head"]

model = smf.ols("HETI ~ C(Income_Level) + C(Education_Level) +
C(Gender_Household_Head) + Q('Averacoefs = model.params.drop("Intercept") conf =
model.conf_int().loc[coefs.index] pvals = model.pvalues.loc[coefs.index]

coef_df = pd.DataFrame({
        "Predictor": coefs.index, "Coefficient": coefs.values,
        "Lower CI": conf[0].values,
        "Upper CI": conf[1].values,
        "P-Value": pvals.values
}).sort_values(by="Coefficient")

coef_df["Color"] = coef_df["Coefficient"].apply(lambda x: "forestgreen" if x > 0 else "crimson")

label_map = {
        "C(Income_Level)[T.B]": "Income B",
        "C(Income_Level)[T.C]": "Income C",
        "C(Income_Level)[T.D]": "Income D",
         "C(Income_Level)[T.E]": "Income E",
        "C(Education_Level)[T.Higher Education]":
        "Education: Higher",
```

```
"C(Education_Level)[T.Uneducated]": "Education: Uneducated",
"C(Gender_Household_Head)[T.Male]": "Gender: Male",
 'Q("Average Age")': "Average Age" }

coef_df["Label"] = coef_df["Predictor"].map(label_map).fillna(coef_df["Predictor"])

fig, ax = plt.subplots(figsize=(15, 9))
ax.barh(
        y=coef_df["Label"],
        width=coef_df["Coefficient"],
        color=coef_df["Color"],
        edgecolor='black'
)
ax.axvline(x=0, color='grey', linestyle='--', lw=1.5)
ax.set_title("OLS Coefficients for Predictors of HETI", fontsize=22, weight='bold')
ax.set_xlabel("Coefficient", fontsize=18, weight='bold')
ax.set_ylabel("Predictor", fontsize=18, weight='bold')
ax.tick_params(axis='y', labelsize=16)
ax.tick_params(axis='x', labelsize=16)
fig.savefig("heti_ols_coefficients_clean_final.pdf", dpi=300, bbox_inches='tight')
```

APPENDIX D: ACCEPTANCE PAGE

Gmail   **Kritik Niraula <kritik3511465@gmail.com>**

[IOEGC16] Editor Decision
1 message

Kobid <conference-noreply@ioe.edu.np>   Wed, Apr 2, 2025 at 1:00 PM
To: Kritik Niraula <kritik3511465@gmail.com>, Anita Prajapati <anita.praj@pcampus.edu.np>, Shree Raj Shakya <shreerajshakya@ioe.edu.np>

Kritik Niraula, Anita Prajapati, Shree Raj Shakya:

We are pleased to inform you that your manuscript titled "A Comprehensive Assessement for Household Energy Choices and Clean Transition" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

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