IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

QUEST FOR CLEAN ENERGY: CRITICALLY ASSESSING ENERGY CHOICES AND LADDER THEORY

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Abstract

The energy ladder theory suggests that as household income increases, there is a transition from cheaper but less clean fuels to cleaner but more expensive options for cooking and heating. Economic progress plays a significant role in shifting households from wood to kerosene and electricity. However, factors beyond economic status also influence fuel choice, limiting the impact of policies promoting substitutions. Access to modern energy is distributed unevenly, with significant portions of the population lacking it, especially in rural areas. The lack of access to modern energy is attributed to institutional, regulatory, and pricing challenges, requiring government intervention. Rising petroleum-based fuel prices in peri-urban areas make fuelwood an attractive alternative for lower and middle-income households, potentially affecting woodland resources and rural ecology. The shift towards modern energy comes with considerable expenses, and the challenges faced by the poorest households as conventional fuels become more expensive need to be addressed. Promoting clean fuel adoption offers benefits like reduced deforestation, lowered emissions, improved health, time savings, and enhanced education outcomes

Keywords: Energy ladder theory, Fuel choice, Clean fuel adoption

I. Introduction

Energy, a fundamental concept in natural science, social science, and engineering, plays a crucial role in shaping economic activities. Its impact on economic development is evident through indicators like Gross National Product (GNP) and per capita GNP. Essential in various processes such as chemical reactions, cellular functions, and transportation, energy consumption serves as a metric for gauging economic development according to energy economists. Ensuring a consistent energy supply across all economic sectors is imperative for comprehensive national economic progress. Additionally, within the broader infrastructure category, energy holds a significant position, crucial for fostering economic development and capital formation. **(Ramaswamy and Sathis Kumar, 2009)**. The precise definition of energy centres on its capacity to perform work. Energy takes on different forms, and when used or depleted, it signifies a transformation into a more practical state. The fundamental principle asserts that energy is not created nor destroyed but undergoes various transformations. Experts elucidate the concept in diverse ways: a commodity to the common person, heat to engineers, matter to physicists and chemists, ability to biologists, synergy to sociologists, emotional to psychologists, and input to economists. **(Ramaswamy and Masillamani, 2005)** Energy is doubly significant as a vital commodity and a key development issue. Its critical commodity status arises from the demand exceeding its supply. Simultaneously, it becomes a development issue due to the direct link between development, measured through economic growth or improved quality of life, and energy accessibility. As a result, the role of energy in promoting economic development, spurring technological innovations, and contributing to human welfare is profoundly impactful. **(Kaushik and Verma, 1996)** Moreover, energy is pivotal for socio-economic development. Future economic growth relies on a consistent, long-term supply of accessible, socially acceptable, and environmentally friendly energy.

II. The Links Between Energy and Development

While the availability of contemporary energy is not the sole guarantee for economic development, it is difficult to conceive of success without it. Improving the accessibility of modern energy and reducing poverty go hand in hand, and the combined delivery of electricity and education yields a more substantial impact. The shift towards modern energy comes with considerable expenses, and access is distributed unevenly, especially in rural areas where significant portions of the population lack it. The lack of access to modern energy is attributed to institutional, regulatory, and pricing challenges, requiring government intervention. Several theoretical and empirical studies indicate the presence of a fuel continuum that fluctuates following the degree of economic development. **Bruce (2005)** observes the existence of an energy ladder specifically in the realms of cooking and lighting, which are the predominant energy-consuming activities for impoverished households. In the realm of cooking, the energy ladder spans from traditional biomass or solid fuels (such as fuelwood, dung cake, crop waste, charcoal, and coal) to liquid fuels (like kerosene) to gaseous fuels (including LPG and gas) and ultimately to electricity. Similarly, for lighting, the energy ladder extends from lanterns, candles, and torches to kerosene lamps and, eventually, to electricity. As households progress up the energy ladder, the fuels become more efficient but also more expensive. Concerning lighting, lanterns, candles, and torches often exhibit weak illuminating power or light intensity. Candles and inefficient lanterns may also emit smoke. While kerosene lamps provide better light, they are associated with certain health and fire risks **(IEA/UNDP/UNIDO, 2010)**. The transition to electricity addresses and mitigates many of the associated risks while also enhancing lighting efficiency.

It is crucial to emphasize that the focus should not solely be on the type of fuel itself but also on the capital equipment and technology employed in burning the fuel. For example, the use of more efficient woodstoves can significantly improve the energy efficiency of burning wood. While traditional woodstoves typically achieve an efficiency ranging from 10 per cent to 15 per cent, stoves utilizing charcoal can reach up to 25 per cent. The efficiency of LPG and electric stoves surpasses even these figures, ranging between 55 per cent and 75 per cent. Considering these substantial differences in efficiencies, it is not always evident that the cost of traditional fuels—adjusted for efficiency—is consistently lower than that of modern fuels. Advancing up the energy ladder is frequently associated with enhancements in income or various stages of economic development. In the initial phases of economic and social development, cooking energy sources typically derive from harvested sources. As societies progress to intermediate stages, the significance of energy sources such as charcoal, animal power, and certain commercial fossil fuels like kerosene becomes more pronounced. It is only in the most advanced stages of development that fossil fuels, including natural gas, and ultimately electricity, become predominant in the energy mix. **(Toman and Jemelkova, 2003; Barnes and Toman, 2006).** The rate of transitioning from traditional biomass to electricity exhibits variations. Access to electricity frequently expands more rapidly than access to modern fuel, primarily due to government policies that often prioritize electrification to a greater extent **(IEA/UNDP/UNIDO, 2010).** While income serves as a crucial facilitator in ascending the energy ladder, the causality also operates in the reverse direction — that is, enhanced access to energy can contribute to improvements in incomes. The literature identifies numerous channels through which ascending the energy ladder could foster productivity and development. The inability to harness modern forms of energy results in low productivity and the production of poor-quality output, subsequently leading to lower income. **(Gupta and Sudarshan, 2009)**. **Schurr's (1984)** findings indicate that improvements in the quality of energy services contribute to enhanced economic productivity, even when considering the physical availability of energy (**Schurr, 1982 and 1984)**. More specifically, the heightened utilization of more adaptable energy forms, such as liquid fuels and electricity, elevates productivity by facilitating "the discovery, development, and utilization of new processes, new equipment, new systems of production, and new industrial locations."**.** Access to energy can bring about structural socio-economic transformations, as economies shift towards large-scale industrial projects, and workers leverage efficient capital stock and new technologies to enhance output and productivity. Numerous studies indicate an interrelation between electricity use and wealth creation, although the evidence on causality is mixed **(Ferguson et al. 2000)**. For instance, **Altinay and Karagol (2005)** find unidirectional causality going from electricity consumption to GDP growth in the context of Turkey, while **Yoo (2005)** finds evidence of bi-directional causality in the context of Korea. On the other hand, **Stern (1993)** finds no relationship between energy or electricity consumption and economic growth in the USA. Unreliable infrastructure leading to power outages causes economic losses, primarily affecting industrial and commercial sectors, and acts as a deterrent to employment growth (**I-Iallward-Driemeier and Aterido 2007)**. Energy access plays a pivotal role in expanding market size and accessibility by reducing transportation and communication costs. Although traditional fuel sources like fuelwood may be acquired at no financial cost, particularly in rural areas, the process of collecting fuelwood is time-consuming. This frequently leaves households with limited time for engaging in productive activities, investing in human capital, and enhancing their overall quality of life **(Barnes and Floor, 1996)**. As women are primarily responsible for collecting fuelwood, the connection between energy and poverty holds a significant gender dimension **(Clancy et al. 2003**). There is evidence indicating that households with greater availability of women and children, who serve as labour resources, tend to use biomass at a higher rate **(Barnes et al. 1994)**. Male household members typically become involved in the collection process only when there is a requirement to transport wood over long distances or in large quantities **(Grogan and Sadanand, 2009**). Access to modern forms of energy can enhance productivity gains by boosting labour inputs and building human capital. For example, the use of modern fuels can improve the productivity of educational inputs. The decision to read and dedicate time to studying is, in part, linked to the availability of a reliable energy source for lighting. The authors provide empirical evidence from Guatemala in support of their hypothesis. They find that electrification causes women to spend substantially less time cooking and more time working outside the home. Research indicates that households with electricity are associated with higher rates of reading, leading to better educational achievements and increased accumulation of human capital **(Ramon and Toman, 2006). Kammen (1995)** proposes that the adoption of improved stoves and the use of modern cooking fuels can diminish the time spent on collecting fuelwood. This, in turn, allows children to spend more time in school, ultimately contributing to enhancements in human capital. Numerous studies have demonstrated that modern fuels offer cleaner and safer alternatives. As depicted in ***Table 1*** below, health-damaging pollutants per unit of energy delivered are significantly higher for traditional fuels compared to LPG. Additionally, in impoverished households, inadequate airflow into the stove leads to indoor air pollution, posing serious health risks such as bronchitis, emphysema, and other respiratory diseases **(WHO, 2005; Ezzati and Kammen, 2001)**. Considering that women are primarily involved in the combustion of biomass, they bear the highest exposure to health risks among all members of the household **(Gupta and Sudarshan, 2009)**. The World Health Organization (WHO) estimates that indoor air pollution resulting from inefficient biomass consumption is responsible for causing 1.45 million deaths annually. The International Energy Agency (IEA) projects that unless this issue is addressed, the number of deaths due to indoor air pollution could exceed 1.5 million per year by 2030. Cross-country studies indicate that good health has a positive, substantial, and statistically significant effect on aggregate output. Therefore, at the macro level, the deterioration in health due to the use of traditional forms of energy has a negative impact on economic growth. **(Bloom et al. 2004)**

Table 1 - Health Damaging Pollutants per Unit Energy Delivered by Fuel: Ratio of Emissions to those of LPG

	LPG	Kerosene	Wood	Roots	Crop Residue	Dung
Carbon Monoxide	1.00	3.1	19	22	60	64
Hydrocarbons	1.00	4.2	17	18	32	115
Particular Matter	1.00	1.3	26	30	124	63

***Source**: Bacon (2010), Oxford Energy Forum, May 2010*

Table 1 provides information on the amount of health-damaging pollutants emitted per unit of energy delivered by different types of fuels. The ratio of emissions is compared to those of LPG (liquefied petroleum gas), which is considered a cleaner fuel option. The pollutants considered in the table are carbon monoxide, hydrocarbons, and particulate matter. Each fuel type is compared to LPG in terms of the emissions of these pollutants.

III. Review and Appraisal of Literature on Clean Energy for Societies

The lack of access to clean fuel contributes to indoor air pollution, causing an estimated 2.5 million premature deaths annually **(IEA 2022a)**. Biomass combustion, as highlighted by **Armah et al. (2015)**, releases pollutants like carbon monoxide, nitrogen dioxide, particulate matter, and sulphur dioxide. Mainly impacting women and children, the use of unclean fuel in cooking stoves, especially in chimney-lacking impoverished households **(Akunne et al. 2006)**, has significant consequences. Despite biomass's affordability and availability, its use by poor rural households entails an opportunity cost in terms of time. Women and children involved in collecting unclean fuel sacrifice time for household tasks, childcare, and education **(Ankrah Twumasi et al. 2021)**. Additionally, adult males collecting unclean fuel forego potential income, impacting household well-being **(Bofah et al. 2022)**. Promoting clean fuel adoption offers benefits like reduced deforestation, lowered emissions, improved health, time savings, and enhanced education outcomes. Access to clean fuel for cooking vs. GDP per capita in 2020 is presented in **Figure 3**.

Figure 3 – Access to clean fuels for cooking vs. GDP per capita, 2020

The correlation between clean fuel use for cooking and GDP per capita is influenced by a complex interplay of economic, social, and geographical factors. Economically developed nations like Ireland, the USA, Argentina, and Brazil, with higher GDP per capita, invest in advanced cooking technologies and cleaner fuels, driven by robust infrastructure and energy policies. Higher urbanization further contributes to access to clean energy. In contrast, lower GDP per capita nations, such as Burundi, Niger, Uganda, Ethiopia, Sao Tome and Principe, may face income disparities, leading to reliance on traditional cooking methods. The availability of clean energy sources, cultural preferences, and education levels also shape adoption patterns. In summary, the relationship is multifaceted, reflecting economic, infrastructural, cultural, and educational influences.

Numerous studies have documented the welfare benefits associated with access to and the use of clean fuel for societies. **(Duflo et al. 2008; Holdren et al. 2000)**. This section provides a detailed review of studies in developing countries, emphasizing fuel choice. Limited literature explores factors influencing household fuel selection, mainly through the energy ladder hypothesis. **(Narasimha Rao and Reddy, 2007; Reddy, 1995; Song et al. 2018; Sudhakara Reddy and Nathan, 2013)**. The energy ladder hypothesis suggests that lower-income households primarily use dirty fuel, shifting to cleaner sources like electricity as income rises. **(Mottaleb et al. 2022; Poddar et al. 2021; Rahut et al. 2017a, b)**. At this juncture, a crucial discussion emerges regarding the impact of various socio-demographic and economic variables on the selection of fuel type. **(Golumbeanu and Barnes, 2013; Masera et al. 2000; Özcan et al. 2013)**. Moreover, previous literature contends that households continue to use dirty fuel even after transitioning to clean alternatives. **(Ngui et al. 2011)**. **Van der Kroon et al. (2014)** argue in the literature that as income rises, households don't fully shift to clean energy but use a mix of multiple fuel types.

Additionally, the recent concept of a "ladder within a ladder" has been proposed. **(Rahut et al. 2017a, b)**. **Mekonnen and Köhlin (2009)** study using Ethiopian panel data for 2000 and 2004 found that urban households prefer a combination of clean and dirty fuels. **Maria de Fátima et al. (2012)** in Mozambique found that firewood and charcoal are less price elastic than kerosene and electricity. Previous research also highlights beliefs and religion as non-economic factors influencing the shift to clean fuel. **Poddar et al. (2021)** examined 601,509 Indian households from the National Family Health Survey data, revealing that religion and caste significantly impact fuel choices. Upper-class Hindus are more inclined to use clean fuel than the lower class, and there are notable differences in fuel choices between Hindu and Muslim households across India. In prior studies, income is considered a key factor influencing fuel selection **(Kapsalyamova et al. 2021; Khandker et al. 2012; Pachauri and Spreng, 2004)**. **Rahut et al. (2017a, b)** found a "ladder within the ladder" in four African countries, indicating that households may not entirely transition to electricity for all their energy needs. In rural settings, factors such as livestock and farm size are key determinants of energy consumption and fuel choice **(Kwakwa et al. 2013; Rao and Reddy, 2007; Wassie et al. 2021)**. A recent study discovered a negative association between landholding and the choice of clean fuel. **(Wassie et al. 2021)**. The household head is a key decision-maker influencing fuel and economic choices. Factors like age, education level, and gender of the head play a crucial role in determining fuel choice, as shown in studies by **Ishengoma and Igangula (2021)** and **Mperejekumana et al. (2021)**. Education, connected to income and influencing fuel choice through awareness and time opportunity costs for firewood collection, is positively associated with a preference for clean fuel in earlier studies **(Mensah et al. 2016; Özcan et al. 2013; Rao and Reddy, 2007)**. Educated females increase the likelihood of households adopting cleaner fuel, according to **Pandey and Chaubal (2011)**. **Huang (2015)** found, through quantile-based regression analysis, that the education variable's coefficient increases monotonically from lower to higher quantiles. In Bhutan, **Aryal et al. (2019)** found that the gender of the household head influences the household's choice of fuel. **Paudel et al. (2018)** found that in Afghanistan, households led by males are less likely to adopt clean fuel. In Tanzania, **Ishengoma and Igangula (2021)** found that a female-headed household doesn't consistently prefer clean fuel unless the head has fixed-term employment. In contrast, **Abebaw (2007) and Ouedraogo (2006)** found that the gender of the household head is insignificant in influencing fuel choice. The gender of the household head and the total number of females in the household impact fuel choice **(Israel, 2002)**, with higher female numbers associated with a negative correlation to clean fuel use. **Link et al. (2012)** discovered that in Nepal, a higher proportion of females in the household increases the likelihood of using fuelwood. The argument is simple: more women in the household mean more available labour for collecting firewood **(Heltberg, 2005)**. In India, **Gupta and Köhlin (2006)** found that the number of non-working women in a household has no significant impact on fuel choice, contrary to the aforementioned argument. However, the presence of children in the household lowers the likelihood of using clean fuel due to reduced labour availability for firewood collection **(Nepal et al. 2011)**. The marital status of the household head is a variable in models explaining fuel choice. **Paudel et al. (2018)** found that in Afghanistan, households with a married head are more likely to adopt clean fuel. Comparable results were obtained in empirical studies conducted in China **(Liao et al. 2019)**. Family size, among various measurable and comparable household characteristics, is a significant factor influencing fuel choice **(Alem et al. 2016; Ngui et al. 2011)**. The relationship between family size and fuel choice can be both linear **(Pandey and Chaubal, 2011)** and non-linear **(Rao and Reddy, 2007)**. A larger family necessitates more fuel and ensures an adequate labour supply for firewood collection **(Lee, 2013; Nepal et al. 2011)**. Results from another study indicate that larger family sizes are less likely to adopt clean fuel **(Paudel et al. 2018)**. **Yadav et al. (2021)** recently discovered a negative association between family size and the use of clean fuel.

Choumert-Nkolo et al. (2019) analysed Tanzania's energy-use statistics, noting low industrialization. In 2016, only 16.9 per cent of rural and 65.3 per cent of urban residents in mainland Tanzania had electricity. Using a 2008–2013 panel dataset, the study explored household energy decisions, finding higher incomes correlated with a shift to modern fuels, particularly for lighting, amid significant fuel stacking. Despite government efforts to connect households to the grid, the study suggests diminished benefits due to substantial fuel stacking. Women's bargaining power proxies indicate the spouse's education level influences the shift to modern fuels.

Hanna et al. (2015) examined the impact of increased household wealth on fuel consumption in rural India using a transfer program. The study found higher total fuel consumption after the transfers, with a shift from kerosene to electricity for lighting, resulting in increased kerosene usage. However, no transition to cleaner cooking fuels was observed.

Hosier and Dowd (1987) introduced the 'energy ladder,' illustrating households moving to advanced fuels with economic improvement. Analysing Zimbabwean data, they found economic progress shifts households from wood to kerosene and electricity. However, factors beyond economic status significantly influence fuel choice, limiting the impact of policies promoting substitutions. Urban areas with higher incomes show more flexibility in adopting such policies.

Hiemstra-van der Horst and Hovorka (2008) examined urban energy use in Sub-Saharan Africa's rapid urbanization context. Despite expectations from the "energy transition" theory predicting a shift to modern fuels with urban growth, the study, based on a case in Maun, Botswana, challenges the theory's practical relevance. It argues that the theory doesn't accurately capture energy-use patterns at lower levels, neglecting active decision-making by urban consumers and their responsiveness to factors like fuel prices. The Botswana case highlights how overlooking these aspects can distort expectations and policies regarding urban fuelwood use.

Maconachie (2009) studied the region around Kano in northern Nigeria, exploring the connections between vegetation modification, fuelwood production, and consumption. While some praised the sustainability of Kano's rural-urban interface, others were less optimistic. Recent evidence suggests that, in peri-urban areas, rising petroleum-based fuel prices make fuelwood an attractive alternative for lower and middle-income households. Shifting away from commercial fuels increases the demand for biomass alternatives, potentially affecting woodland resources and rural ecology around Kano. The paper highlights challenges faced by the poorest households as conventional fuels become more expensive, without perpetuating crisis narratives.

Ranjan and Singh (2023) analysed domestic energy consumption and cooking fuel preferences in rural and urban India over 25 years. The study noted a shift in the household fuel mix with increased income and urban development. Affluent households prefer cleaner fuels, while firewood remains prevalent in rural areas due to its easy availability. Logistic regression showed that the likelihood of LPG being the main cooking fuel rises with higher education levels and affordability among household members.

Shrestha and Kakinaka (2022) investigated the link between remittances and residential energy transition in developing countries, aligning with the United Nations' Sustainable Development Goal 7. Analyzing data from 1995 to 2018 for 27 nations, the study utilized a pooled mean group autoregressive distributed lag (PMG-ARDL) model. The findings reveal that a 1 per cent increase in remittances (ratio to GDP) corresponds to a 0.24 per cent increase in the share of high-efficiency energy sources in residential energy consumption over the long term.

Nawaka et al. (2020) compared cooking fuel choices in Nigerian households, specifically male-headed households (MHHs) and female-headed households (FHHs). Using the ESTER technique, the study found that de-jure FHHs tend to use more biomass, while de-facto FHHs and MHHs exhibit different patterns. If MHHs had similar attributes as FHHs, the probability of biomass use would have dropped by 1.3 per cent, and for FHHs, kerosene use would have increased by 2 per cent. No gender gap was found in kerosene use. Adjusting attributes of de-facto FHHs to de-jure FHHs would have reduced the gender gap in biomass and kerosene use to 6.7 per cent and 2.8 per cent, respectively, indicating the influence of the gendered division of labour on FHHs' energy choices due to limited economic opportunities for cleaner options.

Kroon et al. (2013) emphasize the critical role of modern fuels in driving social and economic development, highlighting that over 2 billion people still rely on traditional biomass for daily energy needs. To mitigate the adverse effects on health and the environment and uplift the conditions of the poor, a transition to cleaner energy is essential. The paper contributes to energy transition literature by introducing a novel conceptual framework for analysing energy and fuel choices. Additionally, it conducts a meta-analysis of existing models exploring energy switching and stacking behaviour in developing countries, revealing a focus on socio-economic characteristics rather than the external decision context.

Rahut et al. (2020) highlight the widespread reliance on solid fuel for cooking in developing countries, posing environmental and health risks. The study, utilizing the 2014–2015 Pakistan Social and Living Standards Measurement Survey, employs robust econometric methods to examine cooking energy types in urban Pakistani households. Despite gas being the primary choice, solid fuels persist, particularly in poorer and less educated households. The findings affirm that education and wealth correlate with the use of clean energy, emphasizing the need for ensuring a clean energy supply to meet growing middle-class demand while enhancing affordability and awareness among households still dependent on solid fuels.

IV. Origins of the 'Energy Ladder'

The energy ladder concept emerged during the 1970s-1980s fuel-wood crisis, signifying a hierarchical link between household economic status and fuel choices for cooking and heating. Consumer economic theory suggests that as income increases, consumers tend to favour more "superior" goods and reduce the use of "inferior" goods **Toole (2015)**. Energy researchers subsequently connected consumer economic theory with energy, demonstrating that households behave like consumers, striving to maximize their energy utilities based on their economic status **(Kroon et al. 2013)**. Consequently, with an increase in household income, the household begins to use different types of fuel located on higher rungs of the energy ladder.

As per **Paunio (2018)**, Kirk Smith, an expert in indoor air pollution (IAP), introduced the energy ladder concept to the World Health Organization (WHO) in the early 1990s. Introduced to comprehend the prevention of annual deaths due to indoor air pollution (IAP), the energy ladder concept serves as a simulation of a country's development status. As nations become more affluent, households transition from biomass to national electric grids or district heating systems. Thus, the energy ladder mirrors the economic development of a country through the energy behaviour of households. **Toole (2015) and Nansairo et al. (2011)** categorize fuel types on the ladder based on factors like cost, cleanliness, energy efficiency, convenience, and higher lifecycle costs. However, various literature and theories differ in their division and construction of ladder rungs. **Hosier and Dowd (1987)** proposed a five-rung ladder: Gathered fuelwood, Purchased fuelwood, Transition fuels, Kerosene, and Electricity. In contrast, **Reddy (1995)** introduced a six-rung ladder: Dung/waste, Fuelwood, Charcoal, Kerosene, LPG, and Electricity.

V. Energy Ladder Hypothesis

The widely used concept for illustrating energy poverty is the "energy ladder," representing the percentage of the population transitioning from simple biomass fuels to fossil fuels and electricity **(John and Kirk, 2000)**. The energy ladder arranges energy sources from basic to modern, reflecting efficiency. Traditional fuels like wood are at the bottom, while advanced options like electricity are at the top. Efficiency drives the hierarchy; for instance, kerosene is 3-5 times more efficient than wood, and liquefied petroleum gas is 5-10 times more efficient than crop residues and dung. The energy ladder organizes energy sources from basic to modern, reflecting efficiency. Traditional fuels like animal power, candles, and wood are at the bottom, while advanced options like electricity or refined gasoline are at the top. The ladder is categorized by efficiencies, where more efficient fuels or sources occupy higher rungs. For instance, kerosene is 3-5 times more efficient than wood, and liquefied petroleum gas is 5-10 times more efficient than crop residues and dung **(Barnes and Floor, 1996)**.

Table 2 - Energy Ladder

Sector	Energy Service	Developing Countries			Developed countries
		Low-Income Households	**Middle-Income Households**	**High-Income Households**	
Household	Cooking	Wood (including wood chips, straw, shrubs, grasses, and bark), charcoal, agricultural residues, and dung	Wood, residues, dung, kerosene, and biogas	Wood, kerosene, biogas, liquefied petroleum gas, natural gas, electricity, and coal	Electricity and natural gas
	Lighting	Candles and kerosene (sometimes none)	Candles, kerosene, paraffin, and gasoline	Kerosene, electricity, and gasoline	Electricity
	Space Heating	Wood, residues, and dung (often none)	Wood, residues, and dung	Wood, residues, dung, coal, and electricity	Oil, natural gas, or electricity
	Other Appliances	None	Electricity, batteries, and storage cells	Electricity	Electricity
Agriculture	Tilling or Plowing	Hand	Animal	Animal, gasoline, and diesel (tractors and small power tillers)	Gasoline and Diesel
	Irrigation	Hand	Animal	Diesel and electricity	Diesel
	Post-harvest Processing	Hand	Animal	Diesel and electricity	Diesel
Industry	Milling and Mechanical	Hand	Hand and animal	Hand, animal, diesel, and electricity	Electricity
	Process Heat	Wood and residues	Coal, charcoal, wood, and residues	Coal, charcoal, kerosene, wood, residues, and electricity	Coke, naphthene, and electricity
Primary Technologies		Cookstoves, three-stone fires, and lanterns	Improved cookstoves, biogas systems, solar lanterns, and incandescent and compact fluorescent light bulbs	Improved cookstoves, biogas systems, liquefied petroleum gas, gas and electric stoves, compact fluorescent light bulbs, and light-emitting diodes	

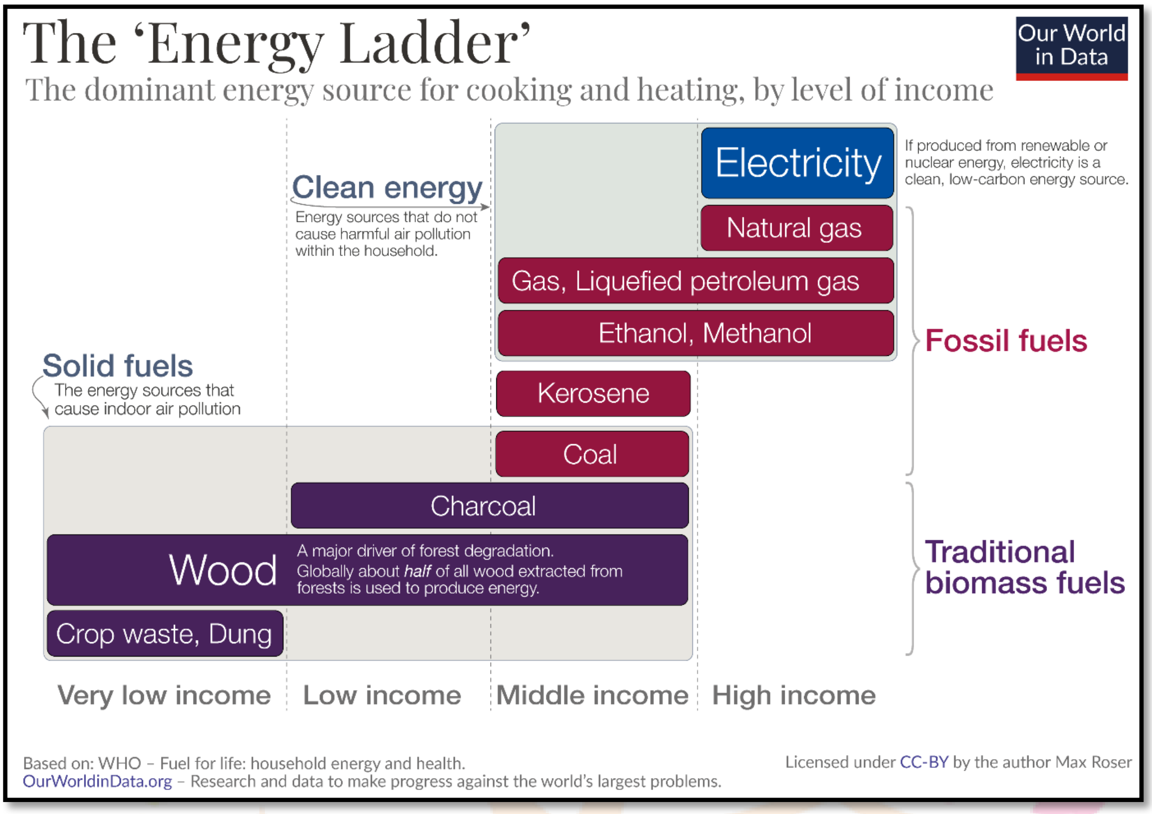
***Source**: Sovacool and Drupady (2012)*

Table 2 depicts the energy ladder as discussed in a variety of academic studies **(International Energy Agency, United Nations Development Programme, United Nations Industrial Development Organization 2010; Jones 2010; Legros et al. 2009)**.

The energy ladder hypothesis **(Leach 1975, 1992)** links income or wealth to energy source choices. The energy ladder categorizes fuels based on quality and ease of use, with solid fuels at the bottom, liquid fuels in the middle, and electricity at the top **(Leach 1992, 1975)**. Poor households in South Asia commonly use wood, cow dung, and crop residue, whereas more affluent households opt for electricity, gas, and liquid petroleum gas (LPG) **(Behera et al. 2015)**. The energy ladder hypothesis suggests that as income rises, households shift from biomass to more efficient fuels like LPG, gas, and electricity. However, studies in Mexico and elsewhere indicate that energy transition, due to energy stacking—using multiple energy sources—is a complex process **(van der Kroon, Brouwer, and van Beukering 2013; Masera, Saatkamp, and Kammen 2000)**. The ladder-within-a-ladder energy hypothesis **(Figure 1)** elaborates on the shift to using electricity for various purposes beyond lighting, such as cooking **(Rahut et al. 2017; Rahut et al. 2017)**. It offers a more intricate perspective on energy transition complexities compared to the basic energy ladder hypothesis, which mainly links energy choices to income **(Leach 1975, 1992)**. The primary driving forces guiding upward movement on the energy ladder are believed to be household income levels and the relative prices of fuels **(Barnes, et al. 2010; Leach, 1992; Barnes and Floor, 1999; Rahut et al. 2014)**. As income rises, households shift to cleaner fuels, particularly increasing electricity usage **(Daioglou et al. 2012; Hills 1994)**. As income increases, poor households tend to transition from using harmful solid fuels to cleaner alternatives, although this shift is not universal **(Masera et al. 2000; Nansaior et al. 2011)**. The energy ladder and the factors driving households to adopt cleaner fuels with increasing income have been studied in various developing countries **(Özcan et al. 2013; Karimu 2015; Rahut et al. 2017; Mottaleb et al. 2017; Hou et al. 2017)**. Family demographics, habits, and the gender of the household head play crucial roles in determining a household's cooking fuel choice, emphasizing the need for policymakers in Pakistan to understand the relative importance of these factors.

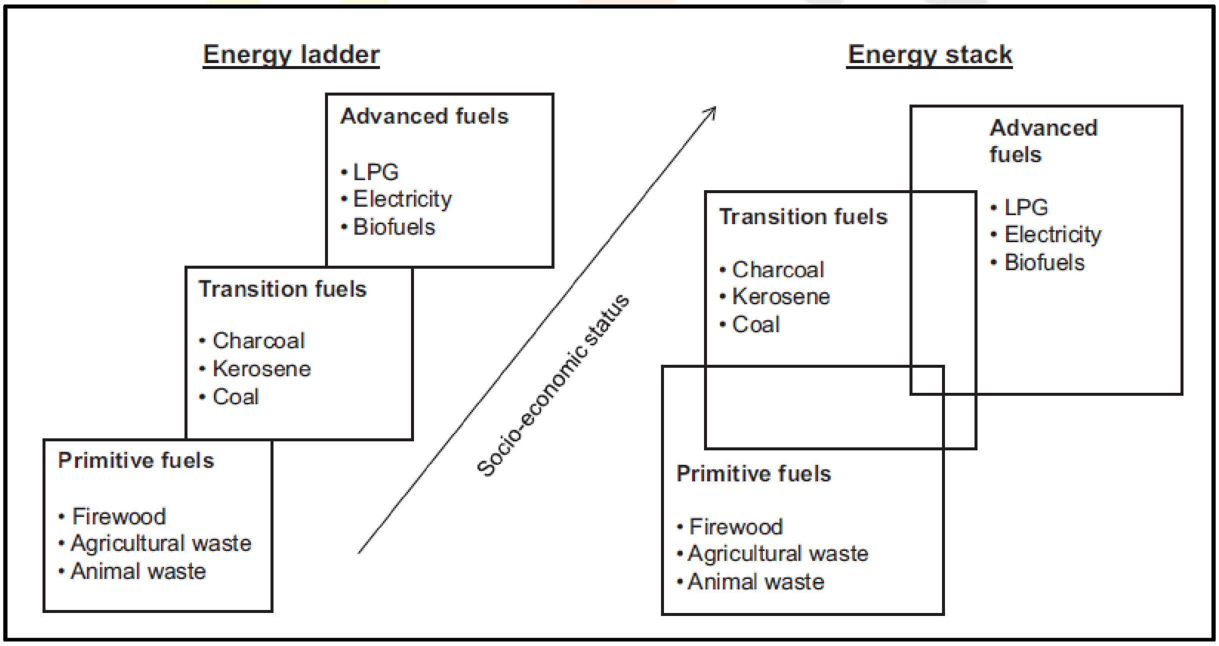
As household income increases, there is an expected transition along the energy ladder, moving from cheaper but less clean and efficient fuels at lower income levels to cleaner but more expensive options, ultimately reaching electricity. Despite this expectation, the transition has been slow, and a substantial portion of the global population, particularly in Asia and Africa, still relies on biomass fuels and coal for energy needs. The World Bank reports that biomass usage has remained consistent at around 25 per cent since 1975, highlighting the challenges in achieving a rapid shift to cleaner energy sources with rising incomes.

Figure 1 – Energy Ladder Hypothesis



Two primary approaches elucidate households' energy-use behaviour and economic development: the energy ladder and the concept of energy or fuel stacking **(Figure 2)**.

Figure 2 – Energy Ladder Nexus Energy Stock



Source: Van Beukering et al. (2013)

VI. Climbing the Energy Ladder

Existing literature widely examines factors influencing the shift from traditional to modern fuels. Studies suggest that this transition is shaped by a complex interplay of elements, including income, fuel accessibility, capital costs, fuel prices, household size, gender roles, wage rates, and cultural preferences **(Gupta and Sudarshan, 2009)**. In the energy-ladder model, income is a significant factor in determining fuel choices. The prevailing argument is that as incomes increase, households not only consume more of the same fuel but also ascend the energy ladder, opting for higher-quality fuels **(ESMAP, 2000; Barnes and Toman, 2006).** Recent evidence challenges the assumption that as incomes rise, households exclusively shift from traditional to modern fuels. Instead, households engage in fuel stacking, using multiple fuel types concurrently, suggesting that traditional fuels like fuelwood are not rendered inferior, as posited by the energy-ladder hypothesis (**Heltberg, 2005; Masera et al. 2000; Mekonnen**

and Kohlin, 2008). Households may resist transitioning to modern energy sources due to factors like preferences, fuel supply reliability, price volatility, and high switching costs. In many developing countries, affluent households might lack access to modern fuels due to inadequate infrastructure, especially in rural areas. Factors such as the low penetration of natural gas and the high upfront costs associated with purchasing modern stoves or connecting to the grid can impede households, particularly those with lower consumption levels, from adopting more efficient energy sources **(Barnes and Toman, 2006)**. High or volatile fuel costs can discourage poor households from transitioning away from traditional biomass, as it provides an energy source without significant financial costs. As the price of kerosene rises, households, particularly in rural areas, tend to quickly substitute kerosene with more readily available fuelwood. **Ghouri's (1996)** findings in Pakistan indicate a relatively high short-run and long-run price elasticity for kerosene, surpassing that of gasoline and diesel. As kerosene prices rose from 1994 to 2001, households, especially in urban areas, responded by shifting from kerosene to biomass for cooking, with the most significant percentage increase observed among the lowest 40 per cent of urban households **(Kojima, 2006)**. In Nigeria, increasing prices of kerosene and other petroleum-based fuels have led to fuelwood becoming a more attractive option for domestic fuel, exerting additional pressure on woodland resources **(Maconachie et al. 2009)**.

VII. What suggests the Energy Ladder hypothesis

The Energy Ladder hypothesis suggests that as households' income and awareness increase, they gradually transition from using traditional biomass to cleaner energy sources such as kerosene and eventually to ultra-clean and renewable energy sources like electricity **(David et al. 2022)**. However, empirical evidence shows that even households with higher incomes and education levels may only use electricity for lighting and not for cooking, indicating a "ladder within the energy ladder" **(Eshetie et al. 2021)**. The determinants of household fuel choices include income, cost of fuel, socioeconomic factors, age, family size, education, and access to infrastructure **(Luan et al. 2023)**. With an increase in income and awareness, households gradually switch from biomass to kerosene and finally to ultra-clean, renewable, green energy sources such as electricity **(Dil et al. 2017)**. Ladder within the energy ladder hypothesis: In some cases, households with higher incomes, wealth, and education levels use electricity only for lighting but not for both lighting and cooking, creating a ladder within the energy ladder **(Dil et al. 2017)**. The energy ladder model assumes that with increasing income, households will have a preference for cleaner energy sources. The energy ladder theory provides a limited view of reality in households, as other socio-economic factors drive household energy transition. The dependence on energy sources at the lowest rung of the energy ladder by most households in Nigeria is accentuated by rising poverty levels. **(Adamu et al. 2020)** It is important to consider households' preferences and willingness to pay for renewable energy alternatives when implementing energy options. Current approaches to measuring energy poverty based on income and accessibility to modern energy may not accurately capture the energy mix and preferences of households, especially in countries with varied residential energy sources. Therefore, energy poverty alleviation programs should consider the disutility associated with using polluted energy and the tradeoffs between energy and other demands. The energy ladder model developed by Shell's scenarios team is used to project energy demand based on economic development. The energy ladder model describes the relationship between energy demand and economic development. The energy ladder model has implications for long-term energy demand in the world. **(Erdmann and Haigh, 2015)** Belonging to a marginalized community in the Hindu religion significantly reduces the likelihood of households moving up the energy ladder compared to upper-caste households. **(Prashant et al. 2021).** The energy ladder hypothesis suggests that electricity is at the top of the energy ladder for household energy use, which is influenced by factors such as wealth status, income, and education levels of the users. However, it is observed that households with higher income, wealth, and education levels do not use electricity for all domestic activities, creating a ladder within a ladder. The paper also examines the "ladder-within-a-ladder" phenomenon, where some households at the top of the energy ladder use electricity for lighting but still rely on other solid fuels for cooking. This suggests that there is a gradient of quality, convenience, and cost in the use of different energy sources, with electricity being the highest on the ladder. The "energy transition ladder" hypothesis postulates that as households experience higher income and other factors, they will shift from traditional biomass and solid fuels to more modern and efficient cooking fuels such as electricity, liquefied petroleum gas (LPG), and natural gas. **(Dil et al. 2017)**

VIII. Conclusion

The energy ladder model suggests that wood is often seen as a lower-quality economic good, linked to lower incomes. This shows a clear connection between income levels and fuel choice. When comparing countries globally, there is a noticeable positive relationship between economic growth and the use of modern fuels. As a nation industrializes, there is a shift towards using petroleum and electricity, while relying less on biomass. Micro-level studies also support the link between income and fuel choice. However, empirical evidence challenges the assumption that the connection between fuel choice and income level is always strong. Some studies suggest that the demand for fuelwood may not be significantly influenced by income. Promoting sustainable development involves evaluating technical and policy options to encourage the use of energy-efficient and less-polluting cooking stoves and practices. The transition from traditional to modern fuels and devices is explained by the energy ladder model, which predicts a progression towards cleaner fuels with increasing affluence. The multiple fuel model considers economics, technical characteristics, cultural preferences, and health impacts in household decision-making for fuel and stove type. This model provides better estimates of fuelwood demand and indoor air pollution in rural households. Achieving goal seven of the Sustainable Development Goals relies on access to clean fuel, regardless of financial, regional, and household factors. Understanding the factors that influence clean energy selection and use at the household level is crucial for widespread access to clean and modern energy. Various socio-economic and cultural factors affect fuel choice for subsistence consumption, which vary across households.

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