Energy Basket Model : A Tool for Examining Household's Choice of Cooking Fuels and Their Switching Pattern

Sagarika Boro [1]
Manash Roy [2]

Abstract

The theoretical literature on households' choice of cooking fuels and their switching pattern was mainly dominated by the energy ladder hypothesis and fuel stacking model, where the former stated that households switch from the usage of dirty fuels to clean fuels along with a rise in income, while the latter maintained that households did not make full switching of the cooking fuels, and rather went for partial switching as they move up the energy ladder. However, in real-life propositions, both theories are relevant, and hence, it called for a new alternative energy fuel model, including the features of both energy ladder and fuel stacking under a combined shed. The present study tried to fill this research gap by developing a new approach called the 'energy basket model,' which incorporated the features of both energy ladder and fuel stacking models within a single framework and looked into the switching possibilities among different fuel combinations in both upward and downward directions. This newly developed model would serve as a key tool for understanding households' choice of cooking fuels and their switching patterns.

Keywords : **cooking fuel, switching, energy ladder model, fuel stacking model, energy basket model**

JEL Classification Codes : D10, I18, O1

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For many decades, households of most developing countries depended on traditional fuels like firewood, twigs, plant residue, etc., to satisfy their cooking needs. This was primarily because of their easy availability, accessibility, and involvement of no price. Excessive dependence on traditional fuels may seriously affect the environment and human health. In the 'State of Access to Modern Energy Services' report published in 2020, about 4 billion people rely on polluting fuels (ESMAP, 2020). It brings many health risks, especially to the women and children involved in cooking. The collection of these fuels requires lots of time, hard work, and effort on the part of the households. Some households prefer energy types like charcoal and kerosene depending upon their economic, geographical, social, and cultural conditions. These fuels have been called transitional fuels in the literature. Transitional fuels are more efficient, less time-consuming, and less polluting (Yonemitsu et al., 2014). Apart from traditional and transitional fuels, modern or clean fuels like LPG and electricity are considered the most efficient, least time-consuming, and least polluting fuels. However, many studies around the world have found that households' adoption of modern fuels is primarily constrained by income and various other socioeconomic and cultural factors.

The existing literature on the household choice of cooking fuel reveals that the decision-making on the adoption of energy type leads to fuel substitution and fuel complementation. The energy ladder hypothesis in the literature states that as income increases, households switch from traditional and transitional fuels to modern

[1] *Ph.D Research Scholar (Corresponding Author)*, Assam University, Silchar, Assam - 788 011.
(Email : sboro043@gmail.com) ; ORCID iD : https://orcid.org/0000-0003-3072-5865
[2] *Assistant Professor,* Assam University, Silchar, Assam - 788 011. (Email : manash.roy015@gmail.com)
ORCID iD : https://orcid.org/0000-0002-9754-4690

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fuels. As the transition takes place, the households abandon the use of earlier fuels and adopt modern fuels. The energy ladder model is considered as the linear model as it indicates a unidirectional process. But though the energy ladder has provided a new dimension to the study of the choice of fuels, it lacks the subjective choice of the households. This shortcoming of the model has led to the development of the 'fuel stacking model' or 'multiple fuel use' model. According to the multiple fuel use model, households do not make a full switch of the fuels; rather, there takes place partial switching of the fuel as they move up the energy ladder. The stacking of fuel takes place among traditional or transitional fuels, traditional or modern fuels, or transitional or modern fuels. In the fuel stacking model, households do not substitute fuel as their income increases, but they keep their traditional or transitional fuels as back up in order to meet their needs and also to overcome the insufficiency in the supply of modern fuels. Fuel stacking has played an important role in the transition of cooking fuels from the use of biomass to modern energy cooking. However, the practice of fuel stacking varies within the same geographical region. Fuel switching does not imply an improvement in energy use as households are found mostly using traditional biomass along with modern fuels for preparing their cultural dishes. Moreover, multiple fuel users spend a handsome amount on purchasing household cooking fuels than the one who uses only firewood. Despite this, the multiple fuel use model is still relevant in the present era as many households have still not switched to modern fuels due to lack of availability, accessibility, and many other factors (Masera et al., 2000).

It could be said that the 'energy ladder hypothesis' speaks about using a single type of fuel, whether traditional or transitional, or modern, while the 'fuel stacking model' shows the use of multiple fuels. But in reality, some households may still stick to a particular fuel type, and some may use the option of multiple fuel combinations depending upon various income and non-income factors. This means that both possibilities are still relevant, and hence, it calls for a new alternative energy fuel model which can include the features of energy ladder and fuel stacking together under a combined shed. Switching possibilities among various combinations of energy fuels are also missing in the fuel stacking model, while the 'energy ladder model' discusses the possibility of switching only in the upward direction, that is, from traditional to transitional and transitional to modern but not the downward direction. With this backdrop, the present study tries to develop a new approach called the 'energy basket model' for understanding the choice of cooking fuels and their switching pattern among rural households by considering the propositions of both the energy ladder and fuel stacking model within a single framework and by looking into the switching possibilities among different combinations of fuels in both upward and downward directions.

Choice of Cooking Fuels and Their Switching Pattern – Review of Existing Theories

The Energy Ladder Model

The energy ladder model has been the standard model used in describing the household fuel use pattern in developing countries. An interest in the idea of an energy ladder emerged with the perception of a fuel wood crisis in the 1970s and 1980s (Kowsari & Zerriffi, 2011; Taylor et al., 2011). The energy ladder concept served as a process of transition from less efficient fuels to more clean fuels with the increase in the household's socioeconomic status. This model is an income dependency model where it is claimed that as the income of the household increases, then the household will move up to more efficient and sophisticated energy carriers. Most empirical studies tend to agree that income is the key determinant of total energy demand (Adamu et al., 2020). As the households attain higher socioeconomic status, they abandon the use of less efficient and more polluting fuels and adopt modern ones, which are relatively cleaner and less polluting. The model assumes that the fuel use pattern follows a hierarchical relationship along with an increase in income. The model further assumes that higher-income households will use clean cooking fuels instead of polluting alternatives due to increased capacity and willingness to pay (Price et al., 2021). Although the model considers these assumptions, in reality, it contradicts the aspect as households with higher incomes are found using polluting fuels encircled by traditional beliefs, especially in rural areas. The model follows the perfect substitution of one fuel for another depending on the household's economic position instead of a mix of fuels. The energy ladder hypothesis states that income is the most influential factor behind households' cooking fuel choices. However, the choices of households differ from one another, for example, the fuel use pattern of the rich and the poor are not the same. The model characterizes wood, which is in the lower lung of the ladder, as an inferior economic good — the fuel which is meant for the poor. This implies a strong correlation between income and fuel choice. However, empirical evidence suggests that the relationship between fuel choice and income level is not as strong as the energy ladder assumed. The findings in urban Kenya supported the energy ladder hypothesis, which stipulated that income increase will lead to the use of clean energy (Heltberg, 2003).

The energy ladder concept lies on the microeconomic theory of rational choice (Kowsari & Zerriffi, 2011). The model assumes that there exists a set of fuel preferences for households from where they are free to adopt any fuel for household energy depending upon their affordability. Further, it is assumed that all forms of fuel are available, and households move up the energy ladder for better fuel, giving up inferior fuels. Moreover, the sophisticated extension of technology implicitly depicts the division of fuels into necessary goods and luxury goods from consumer preferences.

Stages of the Energy Ladder Model

The energy ladder model envisages a three-stage fuel transition process. The bottom or lower rung of the ladder contains traditional fuels, followed by the intermediate stage, where the households shift towards transitional fuels. At the top and advanced stage, the household switches to the most sophisticated energy carrier, that is, modern fuels. The lower ladder consists of fuel wood, biomass fuels such as twigs, straw, crop residue, agricultural waste, and peat. In this stage, households derive energy from the use of these fuels, which are least efficient, less costly, and more polluting. The intermediate stage is composed of coal, charcoal, and kerosene that burn more easily and efficiently, but at the same time, emit smoke (Van der Kroon et al., 2013). With the improved socioeconomic status and increased income, households move up to the top of the energy ladder and shift their dependence on the cleanest, more efficient, and more costly fuels. The high-ranked fuels usually comprise LPG, electricity, and bio-fuels (Barnes & Floor, 1996). These modern fuels consume less time and labor. In reality, the idea of the three-tier energy ladder model is very limited. The linear energy model of fuel adoption contradicts many empirical studies. The studies found that households do not abandon inferior fuels for superior fuels as they move up the ladder. Instead, they use multiple fuels for household energy, termed as 'energy stacking.' In the case of multiple fuel use patterns, households adopt combinations of fuels from the lower rung and upper rung of the energy ladder. Thus, the choice of household energy and its switching would not only depend upon income but many other factors implicitly. The energy ladder model is criticized on different grounds of fuel preferences that give rise to alternative energy models (Masera et al., 2000).

The evidence from empirical studies argues that the energy ladder is not a linear simplification of the model. In the model, the assumption of perfect substitution of fuels is rarely accepted in reality. The model assumes strong income dependency on fuel use which could not be accepted as different factors influence it. As assumed by Kowsari and Zerriffi (2011) that there exists a universal set of fuels that are readily available in urban areas, but their study does not cover rural areas where all forms of fuels may not be available. Moreover, the model shows that with an increase in economic well-being, the use of inferior fuels is abandoned, but it is not appropriate as many households using superior fuels also use inferior fuels depending upon the circumstances. Even a poor household also adopts modern fuels due to the influence of the surrounding areas. Although the model shows its dependency upon income, but it totally ignores the supply and demand side. The model only emphasizes fuel switching in the forward direction, but the downward switching of fuels has been disregarded. It is also assumed that with the increase in income, there is *n* uptake of cleaner fuels where it is not identified whether the increase in income is real income or nominal income. Thus, the model requires further research for its validity and relevance in developing nations.

The Fuel Stacking Model

Empirical studies on the choice of energy or fuel use defined the energy ladder hypothesis as not a unidirectional process; rather, it signaled a multidimensional transition process. The limitations of the linear energy ladder model paved the way for an alternative model, 'fuel stacking,' to describe the energy transition patterns. The fuel stacking model portrays that the households consumed combinations of energy options chosen from the lower and upper rungs of the energy ladder. Even though the households moved forward along the energy ladder with an increase in income, they did not entirely displace the traditional fuels, but a variety of fuels are used potentially and simultaneously. This pattern of combining both traditional and modern technologies is mainly observed in the case of mechanization of agriculture in developing countries (Masera et al., 2000).

As described in the energy ladder model, as households moved up the ladder, they abandoned traditional fuels for modern fuels, but in the fuel stacking model, fuels serve as partial rather than perfect substitutes for each other. The decision to stack fuels may not always be affected by income or financial concerns (Rogers, 2020). To meet their energy needs, households adopt multiple fuel types. Fuel stacking or multiple fuel use came to the scene due to energy prices, the cost of new technologies, shortages or lack of adequate supply, accessibility, income, household preferences, domestic constraints, and fuel characteristics. In developing nations, instead of completely or totally switching to modern fuels, households continued to use traditional fuels in order to mitigate the risks associated with the dependence on fuel choice.

However, technical, social, and cultural factors play a vital role in the process of partial fuel switching. Multiple fuel use pattern is typical in urban, semi-urban, and rural areas (Uhunamure et al., 2017). Indeed, fuel stacking is interpreted as focusing mainly on the factors of consumers' constraints instead of emphasizing on the choice of the household fuel use pattern. Understanding the fuel stacking behavior is necessary to progress toward a clean and sustainable energy transition. Many studies revealed that households switch to multiple fuel strategies by combining inferior fuels with superior fuels and improving their socioeconomic status. The degree of stacking might differ from area to area. Mixing of fuel takes place to reduce the uncertainties, act as a 'backup' for cooking, consumption habits, or even for socializing. The reason for stacking is usually for time costs and practical limitations. Regardless of health awareness, households still use dirty fuel stacks with transitional fuels because of their socioeconomic constraints. It is well recognized that the household characteristics for the choice of household energy sources strongly influence the adoption or rejection of new technology or the mixing of various fuels. In an empirical study, Swarup and Rao (2015) demonstrated that at low levels of income, households consumed only the inferior fuels; at a certain intermediate level, they consumed both inferior and superior fuels, and at higher levels of income, they shifted to the superior fuels, especially in urban areas. However, in rural areas, the households used solid fuels irrespective of the level of income. They were left with no choice but to stack due to the dominance of fuel availability and affordability. As households in rural areas have easy access to alternate energy sources, they stack fuels or fuel mix instead of switching to a higher rung of the energy ladder. In lieu of fuel substitution, there is partial switching with the mixture of different cooking fuel options.

Research Gaps

The critical research gaps arising out of the review of previous studies related to the choice of cooking fuels and their switching pattern are identified as follows:

- There is a shortage of research studies on cooking fuel usage in rural households by combining the features of the energy ladder and fuel stacking model.
- The conceptual framework for assessing the quality of cooking fuel choice is missing.
- The meaning of switching in the context of using cooking fuels is unclear.
- Earlier studies discussed the possibility of switching to better cooking fuel options over time. Still, they ruled out the possibility of switching back to relatively inferior options.

The Energy Basket Model – A New Approach for Understanding the Choice of Cooking Fuels and Their Switching Pattern

The present study consists of the integrated features of energy ladder and fuel stacking models under a single energy basket. Unlike the energy ladder model, which talks about the usage of a single fuel option, and the fuel stacking model dealing with multiple fuel combinations, the present study tries to develop an alternative model called the 'Energy Basket' model, which takes care of both the options dealt under the earlier models. In this sense, the 'Energy Basket' model is more general and applicable in any rural households' context around the globe. This model has two parts – in the first case, it represents all possible options for cooking fuels and categorizes them into two bundles, that is, 'inferior' and 'superior,' and in the second stage, it tries to represent the switching possibilities between different bundles of cooking fuels by the rural households over time.

The Energy Basket Model – Part I

According to the first part of the energy basket model, a household is open to choose either a single cooking fuel option or multiple fuel combinations subject to income, price, and supply of the fuels, demographic and cultural factors, etc. In this way, a household can subjectively reveal its choice of cooking fuels under certain constraints. However, it should be noted that all subjective choices of cooking fuels may not be health, time, and environment-friendly for households. Hence, it calls for providing some objectivity in the case of the choice of cooking fuels. With this objective kept in mind, the energy basket model tries to define two different bundles of fuel options within the same energy basket, that is, the inferior bundle and superior bundle, which greatly help assess the quality of households' choice of cooking fuels.

Inferior Bundle

It refers to any single cooking fuel option other than modern fuels and also all those fuel combinations which have no place for modern fuels. This means that a household's choice of cooking fuels is considered inferior if it chooses any one of the following three options (Table 1).

Table 1. ***Inferior Bundle of Cooking Fuel***

Quality of Choice of Cooking Fuel	Single/Multiple Cooking Fuel Options
Inferior	1. Traditional fuels like firewood.
	2. Transitional fuels like kerosene.
	3. Combination of traditional and transitional fuels.

Table 2. *Superior Bundle of Cooking Fuel*

Quality of Choice of Cooking Fuel	Single/Multiple Cooking Fuel Options
Superior	1. Modern fuels like LPG, electricity.
	2. Modern fuels and transitional fuels.
	3. Modern fuels and traditional fuels.
	4. Modern fuels, along with traditional and transitional fuels.

Superior Bundle

It refers to modern fuel and all those fuel combinations that have a place for modern fuels. This means that a household's choice of cooking fuels is considered superior if it chooses any one of the following four options (Table 2).

It may be questioned how options 2, 3, and 4 are considered superior as they do not imply exclusive space for modern fuel. The justification behind this framework is that rural households may use traditional and transitional fuels along with modern ones even if they can use them sustainably. Some households may be rich but still prefer to cook some food items using typical fuels. We have come across this situation even from the review of literature also. Thus, hardly any significant difference exists between households with the usage of modern fuels exclusively and those with the usage of modern fuels in combination with other fuels. Hence, according to our framework, a superior bundle of cooking fuel contains modern fuels either solely or in combination with others.

The Energy Basket Model – Part II

The energy ladder model exerts switching possibility only in the upward direction, that is, from the usage of relatively worse fuel options to a relatively better one but not the reverse direction, while the fuel stacking model is totally silent about the possibility of switching. The second part of the energy basket model tries to cover these limitations by conceptualizing switching and no switching and their various types as given below :

- ***Switching.*** It refers to the movement of rural households from one fuel bundle to the other. It may be of two types: forward switching and backward switching.

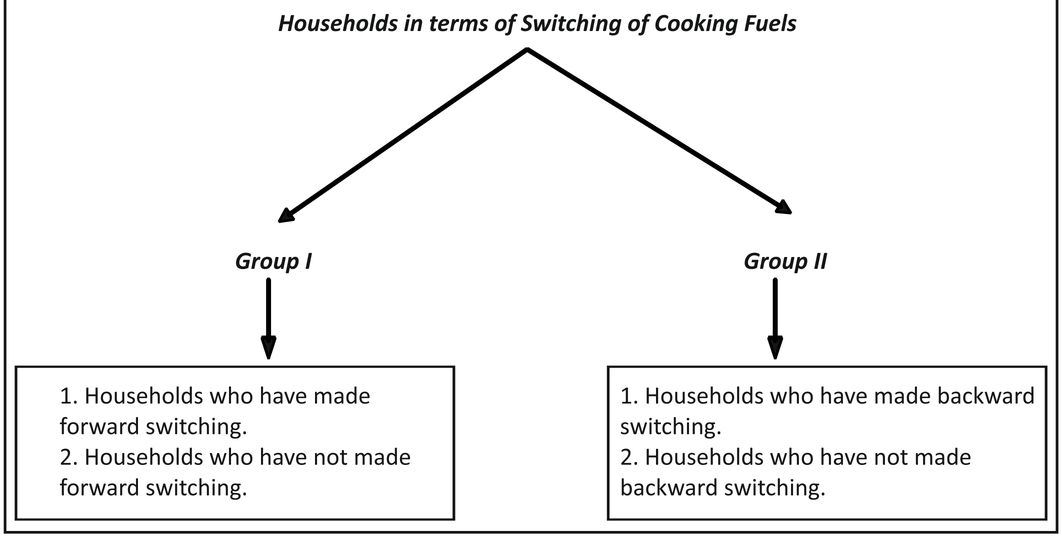
- ***Forward Switching.*** It shows a situation where a household shifts from using an 'inferior' fuel bundle to a 'superior' fuel bundle over time.

- ***Backward Switching.*** It stands for a situation where a household shifts from using a 'superior' fuel bundle to an 'inferior' fuel bundle over time.

- ***No Switching.*** Earlier studies defined 'no switching' in the context of cooking fuels as a situation where households do not switch over to modern fuels. This gives only a partial idea of no switching. It is partial in the sense that it focuses upon those households only who are using traditional or transitional fuels, but are not switching over to modern fuels. However, plenty of households in society have been using modern fuels since long and are not switching back towards non-modern fuels over time. This means that no switching of cooking fuels actually implies two concepts : (a) no forward switching and (b) no backward switching. We have defined these two concepts as follows :

- ***No Forward Switching.*** It shows a situation where a household uses an inferior cooking fuel bundle during both past and present times.

Figure 1. ***Arrow Diagram for Switching of Cooking Fuels***



➭ ***No Backward Switching.*** It shows a situation where a household uses a superior cooking fuel bundle during both past and present times.

Given the above definitions of switching and other related concepts, households under study in terms of switching of cooking fuels can be broadly divided into two groups, as shown in the arrow diagram (Figure 1).

In order to study the fuel-switching behavior of the households and their determinants, we have to deal with the above two groups separately. The conceptual framework developed in the present study is thus an improvement over earlier works as it can explore switching possibilities both in the forward and backward directions. The practical understanding of this framework can be easily comprehended from the following arbitrary illustration. For this purpose, let us first introduce some symbols as follows :

t = Year of field survey,

x = Time span for comparing the current cooking fuel options of households with that of past ones,

$(t-x)$ = Reference year of switching, [1]

n = Total sample households during $(t-x) = n_I + n_S$,

n_I = Households using an inferior bundle of cooking fuel during $(t-x)$,

n_S = Households using a superior bundle of cooking fuel during $(t-x)$.

Switching Possibilities for n_I at time t:

➭ **Possibility 1 :** All the households are still using an inferior bundle of cooking fuel, i.e., $n_I \rightarrow n_I$. This indicates a situation of absolute no forward switching.

➭ **Possibility 2:** All the households have currently switched over to the usage of a superior bundle of cooking fuel, that is, $n_I \rightarrow n_S$. This shows a situation of absolute forward switching.

[1] The present study has defined it as a year with which comparison of current cooking fuel options of the households gets started with the past ones.

↳ **Possibility 3 :** Some households currently use superior fuel bundles while the rest are still stuck to inferior bundles, i.e., $n_I \rightarrow n_S + (n_I - n_S)$. This is indicative of a combined group of households where some have made forward switching while others have not made it yet.

Switching Possibilities for n_S at time t:

↳ **Possibility 1 :** All the households are still using a superior bundle of cooking fuel, i.e., $n_S \rightarrow n_S$. This represents a situation of absolute no backward switching.

↳ **Possibility 2 :** All the households have currently switched back to using an inferior bundle of cooking fuel, i.e., $n_S \rightarrow n_I$. This depicts a situation of absolute backward switching.

↳ **Possibility 3:** Some households have currently moved back towards an inferior fuel bundle while the rest are still stuck to a superior bundle, i.e., $n_S \rightarrow n_I + (n_S - n_I)$. This shows a group of households comprised of both backward switching and no backward switching.

Research and Policy Implications

The present study contributes to the literature by developing an energy basket model related to the choice of cooking fuels and their switching patterns. The framework of the energy basket model is more general as it consists of the combined features of energy ladder and fuel stacking models under a single shed. This new model also offers solidity in clarifying the meaning of fuel switching for the first time in the literature to the best of our knowledge. The model is expected to be of tremendous worth to the research fraternity in dealing with the issue of households' fuel choices and their switching behavior.

Limitations of the Study and Scope for Further Research

There is no study without its limitations, and the present study is also no exception to it. The importance of any study's limitations shows the direction of future research. The major limitations/future research scope of the present study are as follows :

↳ It is a theoretical work where a model is developed, but no attempt is made to test its empirical validity. Thus, to examine the suitability of this model in the arena of households' choice of cooking fuel and its switching behavior, future research works should concentrate upon its application empirically.

↳ There also exists a research scope in exploring the determinants of the choice of cooking fuels and their switching in light of the energy basket model.

Authors' Contribution

Sagarika Boro reviewed the literature and background of the study in the paper. Dr. Manash Roy developed the energy basket model and the study's objectives.

Conflict of Interest

The authors certify that they have no affiliation with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or material discussed in this manuscript.

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About the Authors

Sagarika Boro is enrolled as a PhD Research Scholar in the Department of Economics, Assam University, Silchar, Assam. Her research areas of interest include energy economics, development economics, and environmental economics.

Dr. Manash Roy is working as an Assistant Professor in the Department of Economics, Assam University, Silchar, Assam. His research interests include the areas of inclusive finance, energy economics, and demography.