Energy Policy 39 (2011) 7505–7517

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Three dimensional energy profile: A conceptual framework for assessing household energy use

Reza Kowsari [a,*], Hisham Zerriffi [b]

[a] Resource Management and Environmental Studies, University of British Columbia, Vancouver, BC, Canada
[b] Liu Institute for Global Issues, University of British Columbia, Vancouver, BC, Canada

ARTICLE INFO

Article history:
Received 10 July 2010
Accepted 14 June 2011
Available online 12 July 2011

Keywords:
Energy analysis
Rural energy
Integrated model

ABSTRACT

The provision of adequate, reliable, and affordable energy has been considered as a cornerstone of development. More than one-third of the world's population has a very limited access to modern energy services and suffers from its various negative consequences. Researchers have been exploring various dimensions of household energy use in order to design strategies to provide secure access to modern energy services. However, despite more than three decades of effort, our understanding of household energy use patterns is very limited, particularly in the context of rural regions of the developing world. Through this paper, the past and the current trends in the field of energy analysis are investigated. The literature on rural energy and energy transition in developing world has been explored and the factors affecting households' decisions on energy use are listed. The and the factors affecting households' decisions on energy use are listed. The gaps identified in the literature on rural household energy analysis provide a basis for developing an alternative model that can create a more realistic view of household energy use. The three dimensional energy profile is presented as a new conceptual model for assessment of household energy use. This framework acts as a basis for building new theoretical and empirical models of rural household energy use.

1. Introduction

While energy is not generally considered a basic human need, the provision of adequate, reliable, and affordable energy is a precondition for meeting these needs. Given its strong links to economic growth and social objectives, energy service provision is a cornerstone of development. Having access to modern energy systems (e.g. electricity or liquefied petroleum gas (LPG)) impacts human wellbeing by reducing health and safety risks associated with traditional energy use (Agarwal and Bina, 1986; Bruce et al., 2000; IEA, 2002, 2006; Smith, 1987), decreasing time budget constraints on household members, particularly women and children, increasing labor productivity and income (Barnes et al., 1996; ESMAP, 2003; IEA, 2002), and improving gender inequality and literacy (Cecelski and Elizabeth, 2002; ESMAP, 2004; Rukato, 2002).

More than one-third of the world's population has limited access to modern energy services. Almost two and a half billion people rely entirely on traditional biofuels as their cooking fuel and suffer from its various negative socioeconomic impacts such as adverse health impacts, accounting for over 1.6 million deaths annually. Projections estimate that both the number of biofuel dependent households and demand for energy will increase even as the share of traditional biofuel dependent households drops (IEA, 2006).

Approximately 1.6 billion people, or one quarter of the world population, have no access to electricity, 80% of whom reside in rural areas of the developing world. Sub-Saharan Africa and South Asia have the highest number of people without access to electricity. Despite the apparent large drop in the number of people without access to electricity globally (2 billion in 1990–1.6 billion in 2005), this fall is mainly caused by swift development in China. For the rest of the developing world, the number of people without access to electricity has steadily grown in the same period, and without any new policy implementation, this number will be around 1.4 billion people by 2030 (IEA, 2010; Saghir, 2005).

Household energy consumption in developing countries was about 1090 Mtoe[1] in 2004, accounted for approximately 10% of total world primary energy demand. Most of this energy is used for cooking, as well as heating and lighting (IEA, 2006). Household energy use has unique characteristics that make it harder to assess and analyze compared to other sectors. For instance, there is diversity in energy systems at both the household energy demand side and the energy supply side. There is insufficient

* Corresponding author. Tel.: +1 778 386 7383.
E-mail address: rkowsari@interchange.ubc.ca (R. Kowsari).

[1] Mtoe: Million tons of Oil equivalent is a unit of energy. One tones of oil equivalent is the amount of energy released by burning one tone of crude oil which is approximately 42 GJ (Giga Joule).

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.06.030

data due to lack of recorded household energy transactions. Particularly in rural areas, traditional biofuels are also often part of a complex and interrelated household production system that produces food, fodder, construction material, income, as well as fuel (Leach, 1987).

Researchers have been exploring various dimensions of household energy use in order to design and implement strategies not only to provide secure access to energy services but also to facilitate the transition to modern fuels, eradicate energy poverty, address environmental concerns and mitigate green house gas emissions. Yet despite more than three decades of effort, our understanding of household energy use patterns and the variables associated with household energy use remains limited, particularly with reference to the developing world (Elias et al., 2005; ESMAP, 2003; Farsi et al., 2007; Heltberg, 2004; Leach, 1992; Masera et al., 2000; Pachauri, 2007). In order to achieve development goals through energy, we require better knowledge of how people make decisions related to their energy use. A lack of information on this decision making process is the most challenging problem facing energy analysts, particularly when trying to predict response to major perturbations in energy systems and consider new alternative interventions that are very dissimilar to the past experiences (Stern and Paul, 1986).

This paper builds upon current knowledge of household energy use and develops a new conceptual framework to guide analyses of household energy choices. It focuses on the household energy transition process. Past and current trends in the field of energy analysis are investigated. The objective of this paper is not to provide a detailed household energy analysis; rather, it reviews current knowledge on energy analysis and identifies factors affecting the energy requirements and energy use patterns among households with a particular focus on inhabitants of rural regions of the developing world.

1.1. Organization

Section 2 provides a brief overview of the literature on household energy use and a review of different types of energy analysis used to understand household energy. Section 3 focuses on the process of household energy transition in the developing world. The factors affecting household energy use are categorized and listed. In a final section, the shortcomings in the literature are identified and a new conceptual framework is presented.

2. Energy analysis and underlying assumptions

Following the 1970s' oil crisis, energy scholars devoted substantial effort to understanding household energy usage. In the developed world their efforts focused on reducing oil consumption, increasing energy efficiency, and investigating the impacts of oil price fluctuation on the economy. Energy research in the developing world focused on the perception of a fuelwood crisis. Increasingly research in the developing world is conducted with a view to understanding the impacts of energy use on the environment, human welfare, and security of supply (ESMAP, 2003). Engineering, economics, psychology, sociology, and anthropology have been the main contributors to the field of household energy use and each approach has its own biases, frameworks, and techniques (Keirstead, 2006).

2.1. Physical–technical–economic models (PTEM)

The field of energy analysis has been dominated by physical–technical–economic models (PTEM) of consumption. In such models, changes in consumer demand and energy use patterns are determined by changes in technologies, which are mainly driven by the cost of energy relative to consumer income (Lutzenhiser, 1993). Technical models make detailed estimations of energy flows though physical systems and calculate the energy requirements based on physical laws. Studies on overall household energy use (Leach, 1987), lighting (Stokes et al., 2004), and appliance usage (Hart et al., 2004) are examples of technology based studies. The drawback is that their estimates do not match well with real world measurements because they fail to recognize humans as active energy users who manipulate energy devices and interact with energy devices and energy flows at all stages of energy systems (Wilhite et al., 2000). Economic models try to go further than technical models in exploring human decisions regarding energy usage. They seek to understand the implications of energy prices, taxes, income and expenditure on household energy use (Farsi and Pachauri, 2007; Gundimeda and Köhlin, 2008; Heltberg, 2005; Hosier et al., 1987; Saboohi, 2001; Tiwari and Piyush, 2000). For example, discrete choice modeling and economic engineering analysis apply the economic theory of rational choice, in which individuals are considered to be rational actors who seek constantly to maximize their utility under certain budget constraints, have a set of ordered, well-defined, invariant and consistent preferences, and choose the alternative with the highest utility among the consumption choices (Wilson et al., 2007). Yet a large body of empirical evidence shows that people do not respond rationally to economic and technical opportunities (Cogoy and Mario, 1995; Fernandez, 2001; Frederick et al., 2002; Kooreman, 1996). In addition, household consumption is influenced by non-economic factors and social context. For instance, personal commitment is a key determinant of the household decisions to adopt energy saving measures (Lutzenhiser, 1993). Thus, policy analyses have tended to exaggerate the importance of energy prices and technologies while undermining the importance of non-economic factors (Stern and Paul, 1986). As Stern described, heavy reliance on economic theories has not only misinformed many policies but also mislead analysts by focusing attention on economic concepts and away from many critical and important social and psychological concepts (Stern and Paul, 1986).

2.2. Psychology based approaches

Energy analysis has focused largely on the physical and technological dimensions of energy use as well as on the effects of energy price fluctuations; the human dimension of energy use has been largely overlooked (Laitner, 2007). Schipper confessed that "those of us who call ourselves energy analysts have made a mistake… we have analyzed energy. We should have analyzed human behavior" (Cherfas, 1991).

The most routine forms of energy use involve complex behavioral, cognitive, and social processes, yet these processes are poorly understood (Keirstead, 2006; Lutzenhiser, 1993; Stern and Paul, 1986; Wilhite et al., 2000). Incorporating social variables into economic and technical models has been found to significantly improve the accuracy of these models in estimating household energy demand. Social psychology is the first discipline that tried to address human behavior in an energy context by focusing on individual motivation and information. Technology adoption theories are the result of sociologists' and psychologists' attempts to understand why people adopt or do not adopt new and more efficient conversion technologies Wilhite et al., 2000. The Diffusion of Innovation (DOI) model has a broad empirical basis and describes a social communication process through person to person and media channels that influence individuals' decisions in adoption of new technologies. The theory assumes a linear progression of knowledge, awareness, intention, and behavior that results in the adaptation of technologies (Rogers, 2003).

DOI models are not able to properly address cases where "adoption of new technologies is constrained by situational factors such as lack of resources and lack of access to these technologies" Wilson et al., 2007, as is the case where there is no access to a particular energy carrier. Similarly, other behavioral models try to describe how knowledge will result in action; in the theory of cognitive dissonance, individuals strive for consistency between their knowledge, attitudes, and actions; in the theory of planned behavior (TPB), attitudes are formed from an individual's believe about a behavior as well as the evaluation of the outcomes of that behavior (Ajzen and Icek, 1991). While these theories have been successfully applied to explain human choices in a wide variety of contexts, their application in the energy field has been limited.

2.3. Sociological and anthropological models

People do not simply change behavior or adopt new technology based on awareness and attitudes (Wilson et al., 2007). Sociologists and anthropologists believe that human behavior is social and collective, and that energy models that intend to include behavioral dimensions should consider the social context of individual actions (Lutzenhiser, 1993). They believe individuals decisions are determined by social and technological systems and any transformation in energy use is caused by broader social transformation; for example the work of Shove on changing our perception of comfort and cleanliness (Shove, 2003). Therefore, focusing on individual behavior as the only predictor of energy use is oversimplistic and counterproductive. Household energy demand is not the product of individual decisions but rather a product of social demand (Guagnano et al., 1995). To date, most theories and models do not account for the relationships between individual behavior and socio-technical arrangements (Wilhite et al., 2001).

2.4. Integrated approaches

The failure of energy conservation programs to meet their anticipated energy saving targets was the first sign of limitations to disciplinary approaches to energy analysis (Keirstead, 2006). Integrated approaches to household energy use analysis are required to provide a more realistic and comprehensive understanding of energy usage than isolated and disciplinary studies. Such an approach needs to simultaneously address the social and behavioral determinants of energy use as well as economic and technological aspects of energy use. It should consider individuals and institutions and their complex relationships as well as adequately account for social networks which contribute to change (Stern and Paul, 1986; Wilhite et al., 2000). Many researchers have tackled the integrated approach to decision making; examples of such models are the behavioral model (Van Raaij et al., 1983), the multigenic model (Wilk and Richard, 2002), and the model of environmentally significant individual behavior (Stern and Paul, 2000). The integrated model proposed by Stern incorporates both individual variables (including attitudinal and habit and routine) and contextual variables (including external conditions and personal capabilities) that influence environmentally significant behavior (Stern and Paul, 2000; Wilson et al., 2007). However, there has been limited progress in developing such models Wilson et al., 2007. A number of underlying factors hindering the development of integrated approaches have been identified by researchers including:

1. *The institutional barriers to integrating disciplines*: While most energy research is considered "too applied" by social scientists, among technically trained energy analysts, social science research is often perceived as "too theoretical" (Lutzenhiser, 1993); Achieving integration between social scientists and technically trained energy analysts requires "greater openness on the part of the dominant economic-engineering tradition and a more applied focus on the part of behavioral scientists" (Wilson et al., 2007).
2. *Poor communication*: Integrated models often communicate in qualitative terms while a successful approach should be able to communicate policy options and inform other models quickly and transparently (Keirstead, 2006).
3. *Limited scope and scale*: Integrated approaches have been concerned mainly about small scale issues, which limits their ability to provide insight at a larger scale (e.g. at the sectoral level). A proper approach requires being inclusive to be able to address broad scale issues whilst flexible to be able to address the specific issue at the small scale (Keirstead, 2006).
4. *Lack of objective behavioral data*: There is a significant lack of qualitative studies on household energy use in developing countries (see Section 4). Insufficient understanding of household behavior with regard to energy use hinders attempts to test such integrated models, limiting the applicability and the development of such models.

Despite evidence that purely economic and technical models perform poorly, they are still the dominant models in energy analysis and influence policy makers (Lutzenhiser et al., 2009; Webler et al., 2010; Wilhite et al., 2001). Further improvement of integrated approaches is vital to make them more credible and to make them a viable alternative to the existing PTEM-based decision making (Keirstead, 2006).

2.5. Studies on rural household energy use in the developing world

Most of the approaches discussed so far are drawn from research conducted in developed countries. These include developed country studies that collect disaggregated (e.g. household) level data and incorporate a behavioral dimension. Such data is very limited when it comes to the developing world.[2]

The studies conducted in the developing world that do exist for a large part take place in urban areas (see Barnes et al., 2005; Barnes and Qian, 1992; Chambwera and Muyeye, 2004; Dube and Ikhupuleng, 2003; ESMAP, 1999; Farsi et al., 2007; Fitzgerald et al., 1990; Guptaa and Kohlin, 2006; Tiwari and Piyush, 2000). Although these findings provide insight on household energy use patterns, applying the findings of these studies to rural areas should be done with caution due to the unique characteristics of rural regions. Rural areas differ from urban regions in that: (a) the prevalence of freely gathered traditional biofuels and their cost (in monetary term) is zero; (b) modern fuels are not available and in many cases their distribution is unreliable; (c) the price of modern fuels as well as their transaction cost is usually high; (d) a large portion of income in rural regions is non-cash and often the cash income of rural households is too low to offer upfront payments associated with modern energy systems; (e) income in rural regions is uncertain and variable (e.g. seasonal) and therefore regular payments that require commercial energy sources or pay-back of loans are difficult to manage; and, (f) local customs related to cooking practices and methods are stronger in rural regions than in urban centers (Masera et al., 2000).

Studies on energy use in rural households in developing countries are mainly based on descriptive statistic analysis (see Bhatt and Sachan, 2004; Davis and Mark, 1998; ESMAP 2002, 2003; Masera et al., 1997, 2000), econometric analysis (see Barnes and Qian, 1992; ESMAP, 2003; Fitzgerald et al., 1990; Heltberg, 2004, 2005;

[2] The author was not able to find any behavioral research that focused on energy consumption in rural households in poor developing nations.

Heltberg et al., 2000; Hosier et al., 1987; Jiang, 2004; Leiwen and O'Neill, 2003; Wuyuan et al., 2008), and, to a much lesser extent, computational models (see (Alam et al., 1997; Howells et al., 2005, 2002)). A majority of the quantitative studies in this field are based on economic theories, such as the household energy model developed by Howells et al. (2005).

3. Energy transition in the developing world

One of the larger questions that analyses of household energy have tried to address is the nature of the transition from one set of energy choices to another. This is a particularly important area of inquiry as moving from traditional fuels to modern energy carriers is associated with welfare improvement and is on the agenda of planners and policy makers (IEA, 2010; Legros et al., 2009).

3.1. Energy ladder

The "energy ladder" hypothesis was the prominent model of explaining household energy choice in developing countries (Hosier et al., 1987; Leach, 1992) until a decade ago (Elias et al., 2005). The energy ladder describes a pattern of fuel substitution as a household's economic situation changes (Hosier et al., 1987). The model was developed based on the correlation between income and uptake of modern fuels (e.g. electricity). The energy preference ladder ranks fuels—modern fuels such as electricity and LPG are considered superior fuels due to their high efficiency, cleanliness and convenience of storage and usage and are located higher up the ladder than traditional fuels, or inferior fuels (see Fig. 1) (Leach, 1992).

According to this concept, households switch from traditional energy systems to modern energy systems up the ladder at the speed and extent allowed by factors such as household income, fuel and equipment costs, availability and accessibility of fuels, reliability of modern fuel distribution, and, to a lesser extent, relative fuel prices (Masera et al., 2000).

The energy ladder concept relies on the microeconomic theory of rational choice. It assumes that all forms of fuel (traditional and modern) are available, that there is a universal set of fuel preferences, and that households will choose to move up the ladder as soon as they can afford to do so. The major achievement of the energy ladder is its ability to capture the strong income dependency of energy choice in households, particularly in urban areas. However, the energy ladder concept assumes a linear progression of fuel adoption that implies moving up the ladder means a corresponding abandonment of the lower level fuels. This assumption is inconsistent with the findings from field research (Barnes and Douglas, 1992; Heltberg, 2004; Hosier et al., 1987; Masera et al., 2000); thus, the energy ladder concept can only provide a very limited view of reality.

3.2. Energy stacking model

During the past decade, a growing number of empirical studies on household energy consumption have shown that fuel switching is not unidirectional and people may switch back to traditional biofuels even after adopting modern energy carriers; fuels are imperfect substitutes and often specific fuels are preferred for specific tasks; instead of simply switching between fuels, households choose to use a combination of fuels and conversion technologies depending on budget, preferences, and needs (Davis and Mark, 1998; ESMAP, 2003; Heltberg, 2004; Leiwen and O'Neill, 2003; Masera et al., 1997, 2000; Pachauri and Spreng, 2003). Based on this concept, once a modern fuel is adopted, traditional fuels and devices are normally kept (e.g. charcoal stove) and households only partially switch (see Fig. 2). Empirical studies such as the study done by Leiwen in rural China (Leiwen and O'Neill, 2003) indicate that some forms of traditional energy are still used by the wealthiest households. Barnes proposed a "rural energy ladder" that illustrates the steps through which rural households generally move from traditional biofuels and human and animal power to a mix of traditional and modern fuels (Barnes et al., 1996). Studies have demonstrated that despite the common perceptions, LPG is not a perfect substitute for traditional biofuels and that there are clear fuel preferences based on cooking practices (Masera et al., 2000). Even in places such as Brazil where the share of traditional biofuel in overall energy consumption has dropped as income has risen, the complete switch to modern fuels (fossil fuel and electricity) has occurred only at the highest income level (ESMAP, 2003).

A study of Mexican households by Mesera et al. confirms this model by showing that, as households get wealthier, the change in energy use can be characterized as an "accumulation of energy options" rather than as a linear switching between fuels. This process is termed "fuel stacking"(Masera et al., 2000). Fuel stacking is commonly practiced in rural regions of the developing world and, to a lesser extent, in urban centers (Heltberg, 2004). In some countries, such as Ghana and Nepal, it is practiced by a majority of the population (ESMAP, 2003; Heltberg, 2005).

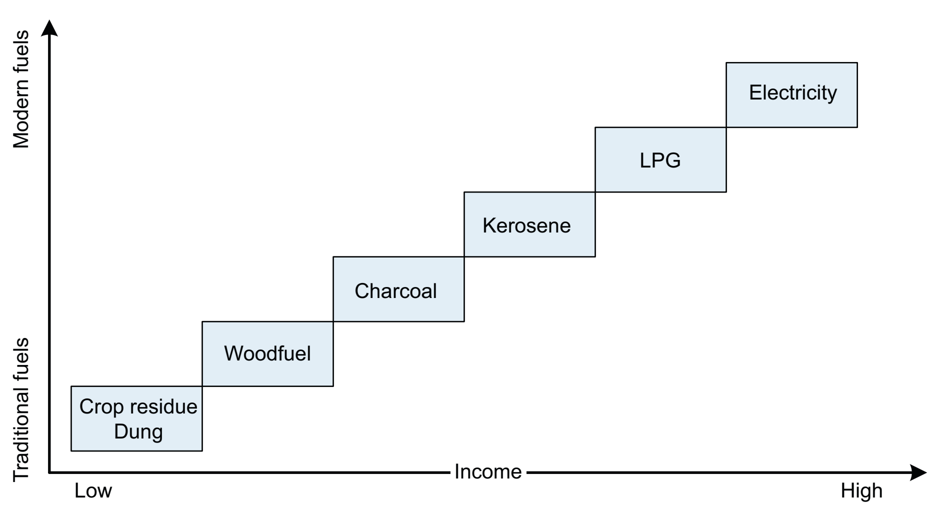

Fig. 1. The classic energy ladder.

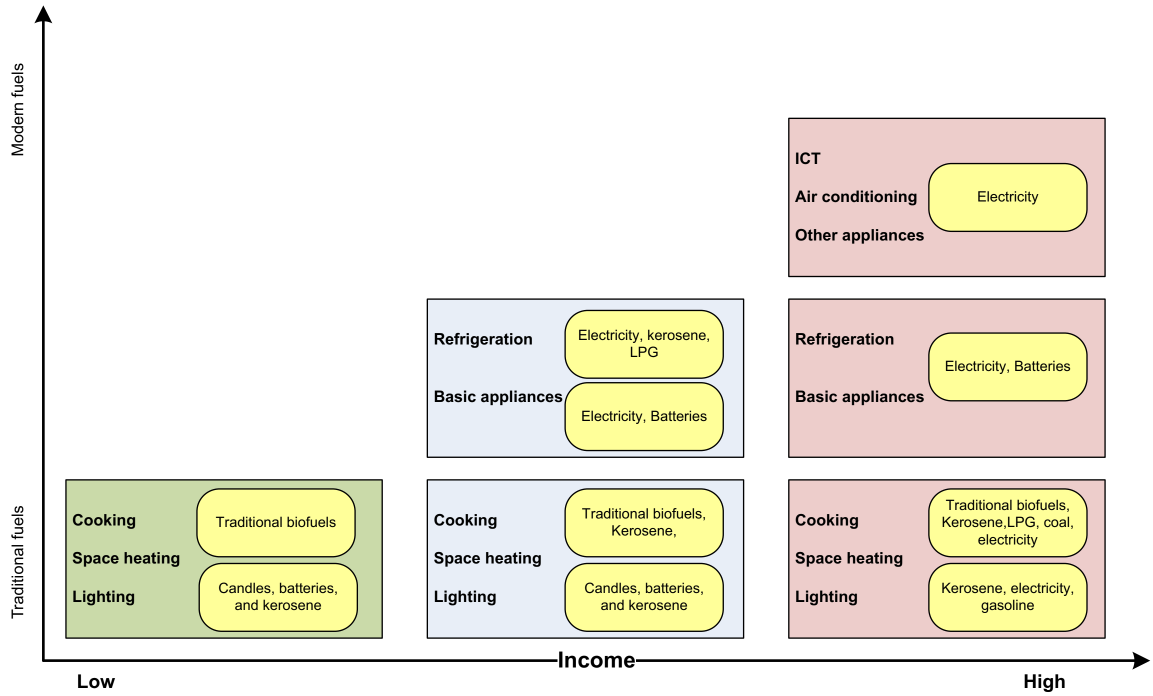

Fig. 2. The illustration of energy stacking—adopted from IEA (2002).
Note: ICT is information and communication technology.

Table 1
Summary of factors determining household energy choice.

Categories	Factors
Endogenous factors (household characteristics)	
Economic characteristics	Income, expenditure, landholding,
Non-economic characteristics	Household size, gender, age, household composition, education, labor, information
Behavioral and cultural characteristics	Preferences (e.g. food taste), practices, lifestyle, social status, ethnicity
Exogenous factors (external conditions)	
Physical environment	Geographic location, climatic condition,
Policies	Energy policy, subsidies, market and trade policies
Energy supply factors	Affordability, availability, accessibility, reliability of energy supplies
Energy device characteristics	Conversion efficiency, cost and payment method, complexity of operation,

Causes of fuel stacking include: keeping traditional energy systems as an insurance against modern energy supplier failure (ESMAP, 1999); decreasing vulnerability to modern energy price fluctuations by diversifying energy use (e.g. use electricity for lighting and fuelwood for cooking) (Leach, 1992; Thom and Cecile, 2000); inapplicability of alternative energy systems to cooking methods and preferences (ESMAP, 2003; Masera et al., 2000); high costs associated with using modern energy sources (e.g. electrical wiring and LPG containers) preventing people from fully adopting such energy systems (Davis and Mark, 1998); not having capital available to purchase modern energy conversion technologies (Elias et al., 2005).

The energy ladder and fuel stacking models are different with regards to how energy sources are adopted, yet they both assume the existence of hierarchies in household energy services (IEA, 2002). Cooking and heating are the first services to be met, followed by lighting and later entertainment. Based on this hierarchy, using electricity for services other than lighting only happens after core demands are met. However, studies show that the household energy transition is not a step-like progress; Households often use, if available, higher ranked energy carriers (e.g. electricity) even in small quantity while satisfying their bulk of demand by lower ranked fuels (Victor, 2002). The Energy stacking model suggests households adopt a portfolio of energy systems and consider a range of factors affecting the household's energy portfolio; yet, it considers income as the major determinant of fuel choice, and also relies heavily on a universal hierarchy of fuels and energy services.

3.3. *Factors determining household energy choice*

The energy portfolio of households depends on household decisions based on a complex interaction between economic factors (e.g. fuel price), social factors (e.g. gender equity), cultural factors (e.g. cooking practices) and environmental factors (e.g. access to natural resources) (Leach, 1992; Masera et al., 2000). What the existing literature shows is that there are a number of factors that affect household energy choices (see Table 1). Although these factors are presented in isolation from each other, in the real world they are closely interrelated.

3.3.1. *Endogenous factors (household characteristics)*

Three sub-categories are defined for household characteristics. Economic and non-economic characteristics reflect the capabilities of households and behavioral and cultural characteristics reflect the attitudes, preferences and experiences of households.

3.3.1.1. Household economic characteristics. As discussed earlier, a large body of literature points to income as the major driver of fuel choice and suggests that there is a strong correlation between an increase in income and uptake of modern fuels (Barnes et al., 1996, 2004; ESMAP, 2000, 2003; Johansson et al., 2004; Leach, 1988, 1992; Leiwen and O'Neill, 2003; Pachauri, 2004; Victor et al., 2002; Wuyuan et al., 2008). Researchers also use expenditure instead of income as a measure of wealth (Heltberg, 2005). However, such approximating should be done cautiously since it might not be universally applied (Elias et al., 2005), as shown in the studies by Leiwen in rural China.

In addition to fuel choice, studies find that there is a strong positive correlation between income and the amount of final energy used (Elias et al., 2005; Fitzgerald et al., 1990). However, the energy consumption for basic services such as cooking and lighting normally remains almost unchanged (ESMAP, 2003). A study in Vietnam shows that although wealthier households use almost 10 times more electricity than poor households, they continue to use approximately the same amount of energy for cooking (Tuan et al., 1996). Once people have access to all basic energy services, a fraction of the additional income goes toward switching to more efficient and cleaner energy systems as well as other services such as entertainment, refrigeration, and so on (Dube and Ikhupuleng, 2003; Tiwari and Piyush, 2000).

Primary energy use is expected to follow an inverse-U path as households adopt more efficient fuel/device combinations (Elias et al., 2005; Foster et al., 2000; Leach, 1992). However, studies indicate that although people start using more efficient energy systems as their income rises, both their primary and useful energy consumption increase as well (Mestl et al., 2009; Roy, 2000). In Brazil, energy consumption decreases in middle-income households, then increases again in higher-income households (WEC, 2004). In India, a study on the effect of increasing lighting appliance efficiency showed an increase in overall energy consumption (Roy, 2000). This "rebound effect" is mainly due to having access to new energy services at the same time as a high level of unmet demand in households and the relaxation of household budgetary constraints since more energy can be used without additional cost (Roy, 2000).

3.3.1.2. Non-economic household characteristics. Household characteristics such as household size, gender, age, composition and educational attainment have been found to influence energy use (ESMAP 2000, 2003; Farsi et al., 2007; Guptaa and Kohlin, 2006; Heltberg, 2005; Leiwen and O'Neill, 2003; Sathaye and Tyler, 1991). Household size directly affects energy use by influencing the amount of energy consumed. Although larger households have higher total energy consumption, they have lower per capita energy consumption due to returns to scale (Barnes et al., 2005; ESMAP, 1991, 2000; Fitzgerald et al., 1990; Heltberg, 2004; WEC, 2004; Wuyuan et al., 2008). Household labor has been found by many researchers to be a determining factor of household energy use, particularly in rural households (Arnold et al., 2006; Bluffstone and Randall, 1995; Cooke et al., 2008; Dewees and Peter, 1989; Hyde and Köhlin, 2000; Kohlin and Amacher, 2005; Modi et al., 2005). Household size can also indirectly influence energy use by changing income and resource availability; it also triggers fuel stacking rather than fuel switching; larger households are more likely to use multiple fuels (Barnes et al., 2005; ESMAP, 2003; Heltberg, 2004, 2005).

Gender is also found by many researchers to be a determining factor in household fuel choice and consumption (Farsi et al., 2007; Pachauri, 2007; Schlag and Zuzarte, 2008). Information, education, and social learning are also described as determining factors in adopting energy systems. Lack of information regarding the alternative energy systems (e.g. improved cook stoves, LPG) and the benefits associated with using them is found to be a barrier in adoption of these systems (ESMAP, 2003; Schlag and Zuzarte, 2008; Whitfield and Darby, 2006).

3.3.1.3. Behavioral and cultural characteristics. Household preferences and habits such as food tastes and cooking practices also influence the choice of energy system (ESMAP, 1991; Fitzgerald et al., 1990; Heltberg, 2005; IEA, 2006). For instance, a study in rural Mexico by Masera et al. found that people continue to use traditional biofuels even when they can afford to use modern fuels because tortillas are hard to cook using LPG and need to be cooked over a direct flame (Masera et al., 2000). Similarly, Indian households prefer to use wood stoves for baking traditional bread (IEA, 2006).

Lifestyle and other cultural factors strongly influence fuel choice (Guptaa and Kohlin, 2006; Heltberg, 2005). In Guatemala, indigenous ethnic groups have an energy portfolio that is significantly different from others due to their cultural differences (Heltberg, 2005). Moreover, household status also influences household energy use patterns (Masera et al., 2000; Xiaohua and Zhenmin, 2003). In rural Mexico, LPG stoves play a role as "status symbols" and purchasing them is perceived as parallel with higher social status (Masera et al., 2000).

3.3.2. Exogenous factors (external conditions)

External conditions influence household decisions regarding their energy system by affecting the choices available to households and the incentives to choose one energy technology or fuel over another.

3.3.2.1. Physical environment. A number of geographic factors are closely related to household energy use patterns. People, particularly poor people, living in colder climates consume more energy than others in warm regions (Elias et al., 2005; Jiang, 2004). Bhatt's study of mountain villages in India confirmed both seasonal variation and altitudinal variation of traditional biofuel consumption (Bhatt and Sachan, 2004). The physical environment also affects the supply of both fuels and technologies (discussed further below).

3.3.2.2. Policies and regulations. Government policies to control distribution of energy carriers and production and distribution of energy appliances directly and indirectly affect household energy choices (Barnes et al., 2005). However, following the prevalent perception of income and access as the major determinants of adopting modern fuels, most energy intervention strategies have focused on increasing the availability of modern fuels, the reliability of the fuel distribution network, reducing the price of modern fuels through subsidies, and dissemination of end-use technologies.

The cost of modern fuels is often too high for the poorest households to afford. However, highly subsidized markets in which price signals are absent often cause wasteful energy use (ESMAP, 2000, 2004). Various pricing policies such as lifeline rates, cross subsidies, and blanket subsidies have been implemented with widely different outcomes. Research has shown that the subsidies often do not target the poor properly and end up benefiting middle income and even wealthy households (ESMAP, 2000). In recent decades, there has been a growing trend toward market strategies rather than subsidies and government or NGO led initiatives. This is due to a variety of factors, including the economic effect of subsidies on state budgets, the growing realization that profits can be made in the household energy sector, the distorting incentives that subsidies can have on consumer behavior, benefiting rich people more, etc. (Dube and Ikhupuleng, 2003; Elias et al., 2005; ESMAP, 2000; Victor and David, 2009).

Other forms of market distortion such as regulating production and distribution of both energy carriers and energy appliances affect household energy choice. In China, a restriction on traditional biofuel consumption caused people to adopt coal as their main fuel (Jiang, 2004). Rationing energy carriers in Hyderabad discouraged people from choosing kerosene as their main energy carrier because the ration was not sufficient, distribution was not reliable, and the ration cards have not reached to all members of the society. At the same time, however, government policies that increased access to LPG through both public and private distribution channels caused a significant transition from woodfuel to LPG (Barnes et al., 2005).

The failure rate of such policies in reaching to the target population is relatively high, signaling the vital need for overhauling the existing policy measures and proposing innovative and effective and well informed strategies.

3.3.2.3. Energy supply factors. Energy supply factors including the affordability, availability, accessibility and reliability of energy supplies are found to influence household fuel choice.

The affordability of a fuel is determined by its price which is an important factor in household energy use, in terms of both fuel choice and also quantity of fuel consumed (Barnes et al., 2005; ESMAP, 2003; Heltberg, 2005; Leach, 1992; Schlag and Zuzarte, 2008; Wuyuan et al., 2008). The fuel price has been found to affect shifts between fuels in households using multiple fuels (Fitzgerald et al., 1990; Leach, 1992). Studies indicate the price of a modern fuel has a stronger impact on a backward substitution rather than an upward transition(Leach, 1992). This implies that households gather traditional biofuels freely and continue relying on such fuels until the cost of using such fuels exceeds adopting other alternatives. For instance, in Indonesia, when kerosene was heavily subsidized even poor households switched from woodfuel to kerosene (Fitzgerald et al., 1990). In rural areas, estimating the price of fuel is far more difficult due to the prevalence of freely gathered traditional biofuels. Self-collected traditional biofuels do not have any monetary costs and their usage depends instead on the opportunity costs of collection. The shadow price of fuel collection is unobservable and unknown except to the household itself (Heltberg et al., 2000). Therefore, an analysis based on the relative price of modern fuels to freely gathered traditional biofuels is prone to price overestimation or underestimation.

Method of payment also makes a difference. In some cases the price of modern fuels such as LPG is not higher than purchased woodfuels, but must be bought in large amounts, unlike kerosene or woodfuels that can be purchased in small amounts on a daily basis (Foster et al., 2000; Leach, 1992; Masera et al., 2000).

The availability, accessibility and reliability of energy supplies are major contributing factors to fuel choice. For instance, traditional biofuel use is prevalent in rural regions of the developing world, particularly in places where these fuels are available locally (Fitzgerald et al., 1990). Scarcity of traditional biofuels strongly affects energy use and household welfare. Households generally respond to woodfuel shortages by spending more time and labor on collection, by purchasing more of their supply, by substituting straw, dung, and less favorable fuels, by economizing on woodfuel use, and by switching to commercial fuels (Agarwal and Bina, 1986; Barnes et al., 2005; Brouwer et al., 1997; Cooke et al., 2008).

Access to reliable sources of modern fuels is also recognized as a major factor affecting fuel choice (Barnes et al., 2005; Cecelski and Elizabeth, 2002; ESMAP, 2002; Fitzgerald et al., 1990; Leach, 1992). The effect can be observed particularly in the pattern of household energy use based on settlement size and distance from major trading routes and large cities as well as reliability and availability of energy distribution channels (Chaurey et al., 2004; ESMAP, 2002). Generally, the problem of access to modern fuel is more intense in rural areas, particularly in remote and low density areas where the distribution of modern fuels is either insufficient or unreliable (Elias et al., 2005).

The problem of access to fuels, particularly those that cannot be self-collected, is closely linked to characteristics of the location's infrastructure such as roads, distribution channels, and access to markets (Fitzgerald et al., 1990; Wuyuan et al., 2008). Factors such as electrification have been used by researchers to demonstrate the quality of infrastructure or the level of development in the region. (ESMAP, 2003; Heltberg, 2004). Availability of power grids not only affects the adoption of electricity and changes the service demand of the household but also correlates with uptake of other modern fuels (Davis and Mark, 1998; Heltberg, 2005). Although, fuel price is sometime considered a primary indicator of accessibility, studies in urban Java indicate that it is not a proper determinant of fuel accessibility and availability (Fitzgerald et al., 1990).

Reliability of the energy supply is another factor affecting the household's energy use. Unreliable modern energy supply in many regions forces households to adopt multiple fuels and resort to woodfuel that is locally gathered. For example, unreliability of kerosene in Myanmar causes people to rely on woodfuel although its price is three times the price of kerosene (Barnes et al., 2005).

3.3.2.4. Energy device characteristics. Energy conversion technology is a key aspect of household energy use. Despite the advantages of using more efficient technologies (cleaner and more efficient combustion), the high capital cost (e.g. of energy end-use appliances as well as additional costs such as connection cost) associated with using modern energy conversion technologies is a major barrier to choosing to use modern energy systems. A survey in Kenya, Nairobi, in 1986 found that the cost of a LPG stove and half deposit for a gas cylinder is about 60 times more than a standard charcoal stove (Leach, 1992). The cost of electricity connection is also frequently identified as limiting adoption of this energy form (Barnes and Douglas, 1988; Barnes et al., 1996; ESMAP, 2004; IEA, 2002). Barnes et al. (2005) note that service availability and the initial cost of service is far more important than monthly electricity payments or the income level of consumers.

Even when energy devices are affordable, people may still not adopt them due to their incompatibility with their existing energy service equipment. For instance, when the energy device is not compatible with widely used cooking pots, adoption of such devices is hindered (Barnes et al., 1996).

4. An integrated approach to understanding household energy choice

Despite the large number of studies on household energy choice in general, and the more limited set of rural household energy studies, there remains much that is unknown about the household energy transition process. As Wilhite stated about 10 years ago (and still valid today), "we do not know much more about the nature of energy demand today than we did in 1980" (Wilhite et al., 2000). There is a general consensus among researchers that household energy use patterns are poorly understood and further theoretical and empirical studies are required to formulate meaningful policies and intervention strategies (Elias et al., 2005; ESMAP, 2003; Farsi et al., 2007; Heltberg, 2004; Leach, 1992; Masera et al., 2000; Pachauri, 2007).

While a number of factors that determine household choice have been examined through such studies (discussed above), there are shortcomings in the literature that require a more integrated approach to understand the energy transition process in rural households.

4.1. Shortcomings of the literature on rural household energy analysis

The shortcomings identified in the literature can be grouped into three categories: (1) methodological issues; (2) mis-estimation of the drivers of energy use and transition; and (3) incomplete specification of energy systems. These issues are discussed in further detail below.

4.1.1. Methodological issues

4.1.1.1. Predicting micro trends through macro analysis. A large number of studies explore the correlation between energy use and a number of factors such as population growth, technical advancement, urbanization and economic growth (see Ghosh, 2002; Jumbe, 2004; Leiwen and O'Neill, 2003; Victor et al., 2002). Although macro-level factors influence energy use patterns, micro-trends cannot be accurately extrapolated from national figures; particularly in the case of poor rural households, energy use patterns may easily be obscured by large industrial patterns (Elias et al., 2005). The actual determining factors of household energy use can only be found at the household level. The aggregate level of energy demand is made up of day-to-day decisions at the household level that are affected by a variety of socioeconomic factors.

4.1.1.2. Insufficient data. Where micro-level data is used, it is often not of the quality necessary to answer many questions. Much of the research on household energy use in this area is based on disaggregated data taken from large scale surveys such as the Living Standard Measurement Surveys (LSMS) or similar surveys such as Demographic and Health Surveys (DHS). These surveys include information on household energy use, but the data is insufficient to accurately describe household energy use patterns. A study by ESMAP showed that a number of such surveys only collect information on the main and secondary types of cooking fuel, the main lighting fuel, fuel expenditure associated with each fuel (rather than both expenditure and quantity). Almost none of these surveys asked specifically about energy conversion technologies adopted by households and the energy service demand (ESMAP, 2003). The field of energy analysis in developing countries still requires significantly better quantitative and qualitative data.

4.1.1.3. Correlation versus causation. Even when detailed surveys are conducted, their estimations are often based on various forms of regression analysis. The majority of studies on domestic energy use rely on econometric analyses that identify the correlation between different variables and their vector of progression (Leach, 1992). Econometric analyses are generally more prone to problems of causality than in-depth qualitative studies. Many of these studies show significant correlations yet fail to firmly establish causal relations between these factors (Stern and Paul, 1986). For instance, while the strong correlation between economic and energy growth is confirmed, no consensus on the casual relationship between these two variable has been reached (Elias et al., 2005).

Moreover, many of these studies omit variables, inter-relationships between variables, and their simultaneity. Such simplifications, in turn, limit the usefulness of these studies in policy analysis. It may result in overestimation of the impact of certain variables; for example, if access to information about the health costs of traditional biofuels is positively correlated with income but omitted from the analysis, then the coefficient for income would have an upwards bias. The impact of some variables (e.g. electrification) might be attributed to unobserved household factors that are jointly correlated with this factor. For instance, income and access to fuel may both be a function of infrastructure quality and/or proximity to markets (ESMAP, 2003).

4.1.2. Drivers of energy use and transition

Overemphasizing or underestimating the determinants of households' decisions on energy use as well as energy transition is a cause of a number of shortcomings in the literature.

4.1.2.1. Overemphasis on income. Although the impact of different variables on household energy use patterns has been explored, many researchers consider income as the main determining factor (ESMAP, 2003; Leach, 1992; Pachauri et al., 2004). Whitfield explains that "three decades of research into the determinant of fuel choice has failed to advance our understanding beyond an association between higher incomes and cleaner fuel" (Whitfield and Darby, 2006).

Overemphasizing income or expenditure may obscure other determinants of wealth, particularly in rural areas where a large proportion of households rely on free sources of energy and home production and where the barter economy is prevalent. The dominant role of traditional biofuels and the lack of access to modern fuels in much of the rural developing world result in income having a limited impact on energy choice. Traditional biofuels that are often freely gathered depend more on resource availability, labor availability, land, and livestock holdings than on income or expenditure. A study in India on the impact of income on commercial and non-commercial fuel consumption concluded that "there is little evidence of correlation between non-commercial energy use and income" (Pachauri et al., 2004).

The key determinants of energy system choice are internal to households, and also include but are not limited to the desire for more flexible energy sources, the desire for time free from fuel collection and fire attending to spend on other activities, the desire to reduce the adverse health impacts of traditional energy systems as well as the unwillingness to abandon current practices and traditions (Elias et al., 2005).

4.1.2.2. Human dimensions of energy use. Household decision making on energy use is a complex process mainly due to the interrelations between economic, technical, social and cultural issues as well as the physical environment (Masera et al., 1997). Social and cultural factors such as cooking habits and household characteristics may make households behave contrary to economic predictions based on income and relative fuel prices (Foster et al., 2000).

There are a range of non-economic variables that are central to explaining household decisions regarding energy use. Although there is a large number of studies that point out the importance of such variables, most of these studies do not provide any more insight on the dynamics of such factors and why and how these factors influence energy use. The impacts of income itself on energy use are not well understood; while it appears to relate to energy consumption directly, it also affects energy usage through other sociodemographic variables in many ways. For instance, income is an aspect of social class and can be treated as a rough proxy for "social location," which affects energy usage and household choice (Lutzenhiser, 1993).

There is limited behavioral research on energy usage in the developing world. Variables such as gender perspectives on expenditure priorities and social power relations within households are not usually considered in quantitative analyses and require qualitative study. Even in the context of the developed world, behavioral aspects of energy use are little understood.

An energy model should accurately predict the ways in which individuals (and households) behave and consume energy, react to perturbations and historical events, and respond to interventions. Such accuracy can be achieved only when individual (household) behavior is properly understood. More in depth studies on the behavioral aspects of energy use in rural households of developing countries is necessary not only to enhance existing models and theories but also to formulate proper policy and design effective intervention. Moreover, behavioral research conducted in a developed world context should be adapted and customized to inform future research in developing countries whilst accounting for the structural differences in both energy systems and socioeconomic systems (Urban et al., 2007).

4.1.3. Energy systems

4.1.3.1. Energy services versus energy quantity. Energy services have received limited attention and research often relies on the quantity of energy demand, often an aggregate number that is the lump sum of various energy requirements. However, people do not use energy but obtain benefits from the services provided by energy. The term *energy services* is used to describe these benefits, such as illumination or cooked meals (Pachauri and Spreng, 2003). As Whitile described, "graphs of increasing energy consumption are, in fact, graphs of the societal appropriation or increasingly intensive use of technologies such as cooking devices, lighting systems, refrigeration, and so on" (Wilhite et al., 2000). Estimations that are based solely on the quantity of energy demand are problematic when considering the differences in the services that are provided by technologies. The illumination of different lighting devices may differ significantly due to inherent differences between these sources. For instance, although 60 candles emit as much light as a 60 W incandescent bulb based on luminous flux, their lights are not comparable (ESMAP, 2000).

In addition, many studies assume energy service requirements are constant and estimate energy requirements based solely on fuel and conversion technology. These methods do not consider the variation in energy consuming behaviors for different energy systems. Evidence shows that adopting different forms of energy systems accompanies changes in patterns of energy use such as power setting, amount of time for cooking, the types of food cooked, and nighttime lighting hours. These shortcomings often result in underestimation of household energy requirement (Fitzgerald et al., 1990). Changes in household behavior followed by changes in energy service demand should be incorporated in energy analysis to have a realistic view of household energy use. These changes may be triggered by change in lifestyle that transforms household energy use patterns. Pointing to the impact of lifestyle on energy use, Schipper states: "lifestyle changes could eat into everything you think you've saved [by adopting efficient systems]" (Cherfas, 1991)

4.1.3.2. Reducing the complexity of household energy use. Households adopt different energy systems to satisfy their various energy service demands. An energy system is a series of processes through which primary energy[3] is extracted, converted in one or more steps to *final energy*,[4] and then converted again through energy end use devices to *useful energy*.[5] The useful energy provided by energy systems benefits consumers through energy services such as cooked food and indoor lighting and both the energy systems and energy requirements can vary significantly among households. A single energy device can be used to satisfy multiple needs (e.g. cook stoves for cooking, water heating, space heating), multiple energy systems can satisfy a single service requirement (e.g. lighting by fire in three stone stove, kerosene wick lamp, or torches), and end use energy can be produced in the home through some sort of conversion (e.g. use batteries and dry cells to produce electricity).

Engineering-based approaches have been used by researchers to estimate the energy required to satisfy the basic needs of a household; Goldemberg estimated a household's direct primary energy requirement per unit of time to satisfy their basic needs is about 500 W per person, the Advisory Board on Energy (ABE) in India estimated approximately 33 W of useful energy per capita is needed (Pachauri et al., 2004). Such estimations are based on a number of assumptions regarding energy systems adopted by households, such as the energy conversion technology used, its efficiency and intensity of use. They are additionally based on normative definitions of basic needs, which can be problematic as basic needs depend on complex factors such as climate, culture, region and period in time in addition to subjective wants (Goldemberg, 1996; Pachauri et al., 2004).

Moreover, household energy systems are often oversimplified and their different aspects examined in isolation of each other to simplify the models and analysis. A majority of existing research has focused on fuel choice and to a lesser extent on the combination of fuel and energy device used. Their focus is mainly on the energy carriers (ESMAP, 2003; Farsi et al., 2007; Masera et al., 1997, 2000; Pachauri, 2007) and to lesser extent on fuel/device mix (Chambwera and Muyeye, 2004; Edwardsa et al., 2004; Tuan et al., 1996)

However, household energy systems are really a combination of three factors: energy carriers, energy conversion technologies, and energy service demands. For instance, the energy requirement for cooking, which can account for up to 90% of household energy demand among poor populations in the developing world (Elias et al., 2005), depends on the specific cooking service requirements (i.e. boiling water for tea and slow-cooking a stew are two very different requirements), the cooking device, and the cooking fuel. Cooking service requirements change depending on multiple factors such as household size, number of meals cooked per day, meal ingredients, and cooking methods. Energy requirements for cooking also depend on the energy carrier and the energy conversion technology (i.e. cookstove efficiency). The energy delivered to a cooking pot per kilogram of fuel differs significantly, ranging from 3 MJ/kg of fuel for a three stone wood fire up to 25–30 MJ/kg of fuel for an LPG stove (Barnes et al., 1996).[6]

Similar dimensions of energy systems can be explored for lighting, space heating, water heating and other energy consuming activities. Addressing these three interrelated concepts together is necessary for a realistic approach to household energy analysis. Furthermore, these three dimensions of household energy systems need to be investigated for each energy consuming activity to be able to create a detailed profile of household energy use. Doing so will also illuminate the inter-relationships between these varying activities since devices and carriers can be used to meet multiple energy services (e.g. cook stoves provide cooking, heating and lighting services). If treated in aggregate or only according to fuel or technology, such interdependencies are not captured.

[3] *Primary energy*: The energy carrier prior to any form of conversion (e.g. crude oil).

[4] *Final energy*: An energy carrier that is suitable for use in end use energy devices such as stoves (e.g. electricity, kerosene, diesel).

[5] *Useful energy*: Also called utilized energy, energy output, end-use delivered energy, or available energy. The energy that is needed for a specific task, such as heat needed to cook a meal. Depending on the efficiency of the conversion technology it may be as little as 5–8% of primary energy input or as high as 95–100% in the heat delivered (Leach, 1987).

[6] Energy delivered to pot based on fuel's energy content and the efficiency of conversion technologies typically used in developing countries (Barnes et al., 1996).

4.2. A new approach to household energy analysis

The gaps in the literature on rural household energy analysis provide a basis for developing an alternative conceptual model that can create a more realistic view of household energy use. The *three dimensional energy profile* is presented as a new framework for assessment of household energy use (see Fig. 3). This framework acts as a basis for building new theoretical and empirical models of rural household energy use. At the center of the framework is the relationship between energy services, devices and carriers. Around that are the various factors influencing the energy profile of the household.

The framework addresses energy use at the most disaggregated level, the household, and can be used with both quantitative and qualitative data Therefore, the framework is able to capture the micro-trends based on quantitative information as well as objective qualitative data. It also provides a template for capturing the casual relations between different aspects of household energy use.

As discussed earlier, household energy use patterns depend on simultaneous decisions on the type of energy carriers and energy conversion technologies as well as energy service requirements, which together can be considered the Household Energy System. The proposed framework addresses all three dimensions of these systems simultaneously while considering the close interrelations between them and their dynamics. The framework focuses particular attention on the energy services instead of energy quantity to shed more light on the human side of energy use and create a more realistic view of household energy use.

With the three dimensional energy profile at the center, a range of influential drivers affecting these three dimensions can be enumerated and assessed. Household energy use can be affected by a range of drivers through complex, interacting, and reciprocal linkages. Meeting the cooking service requirement of a household, for instance, depends on the availability and affordability of energy carriers and conversion technologies, household characteristics (e.g. income, household size), household preferences, and so forth. The framework, while considering income as a determining factor under the category of capabilities, avoids overemphasis on income by drawing equal importance to other sets of variables and determinants. Moreover, the three dimensional energy profile framework draw together different dimensions of human behavior in order to capture the relationship between human agency and energy consumption.

Determining factors affecting household decision regarding energy consumption, located in the circle, are strongly interrelated and simultaneously affect the three dimensions of household energy use pattern. This part of the framework is adopted from the integrated model of pro-environmental behavior that is described in Section 2.4. Four types of casual variables are identified by Stern (Stern and Paul, 2000) under two main domains; *attitudinal factors* and *habits and experiences* under the personal domain, and *personal capabilities* and *external conditions* under the contextual domain.

Attitudinal factors include behavior-specific beliefs, values and personal norms. Habits and experiences such as standard operating procedures and routines are the key determinant in human behaviors since behavior change often requires breaking routings and creating new ones.

Personal capabilities include socioeconomic status, technical skills and resources required for an action. Sociodemographic factors such as gender, age, ethnicity, education, and income, can all be considered as personal capacities. External conditions include factors such as market actors, technologies, regulations, formal and informal institutions, economic performance, supply

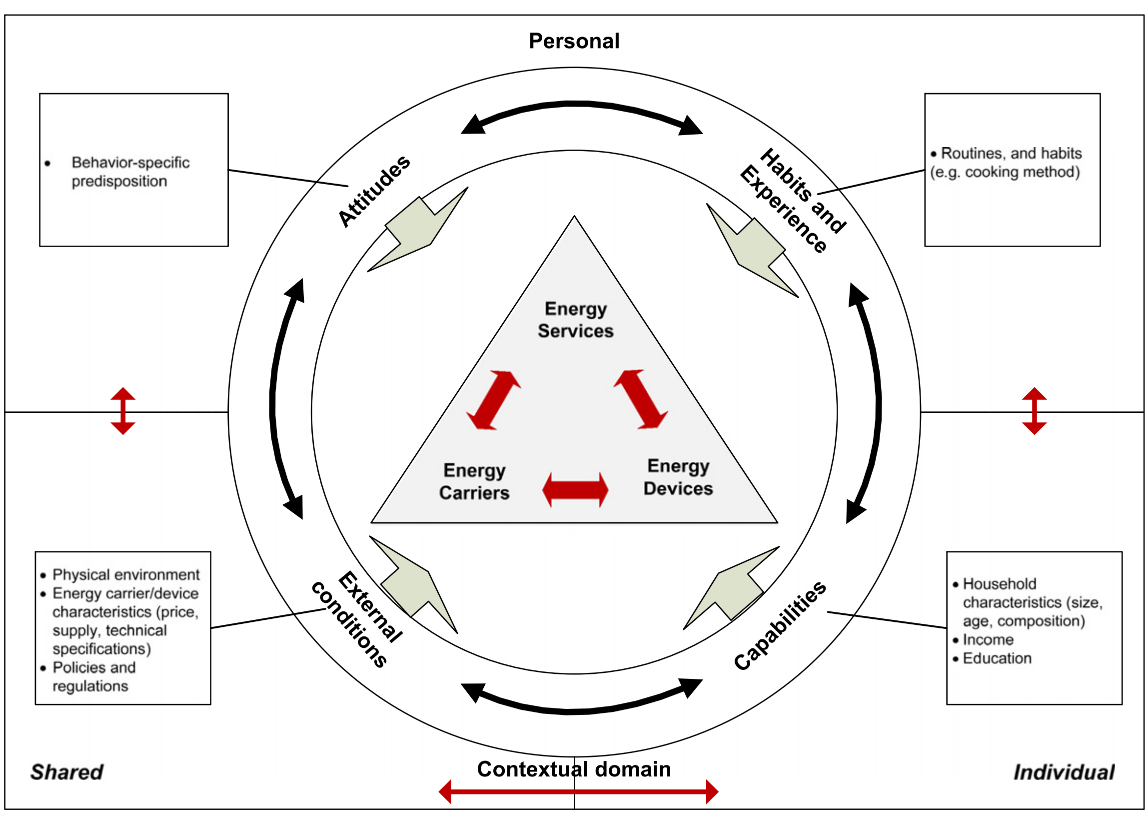

Fig. 3. Endogenous and exogenous factors influencing energy profile.
Notes: (a) only examples of variables are shown in the boxes. This is not a complete list of variables related to energy use. (b) The categories of variables affecting energy use is adopted from Wilson et al. (2007).

chains, social interactions and norms, etc. Policies are also under this category (Stern and Paul, 2000; Wilson et al., 2007). Most of the literature on human dimension of energy use has addressed the factors described under the contextual domain that includes personal capabilities and external conditions.

In this paper, instead of the set of variables suggested by Stern and Wilson et al. the determining factors reviewed in the previous section are used, except for the attitudinal variable. However, there are a number of variables associated with each category that need to be identified and incorporated in the framework. It provides a basis for further qualitative studies on energy use in rural households.

As a final note, a full assessment of these drivers and interactions between them, as well as their causal relationship with energy systems, requires a multiscale approach in order to understand how changes at different scales (e.g. household, community, national, international) affect household energy use.

4.3. Energy transition in a three dimensional energy profile model

Based on the three dimensional energy profile framework, a new method of identifying household energy transitions is proposed here. Energy transitions in this model are not limited to switching between fuels, stacking multiple fuels, or adopting improved cook stoves. Instead they include all three dimensions of household energy systems. The three-dimensional graph below provides a holistic view of household energy system characteristics and the shifts occur due to changes in any of three dimensions of household energy system (i.e. energy service demand, energy carrier, energy conversion technology). This graph is a representation of the "social appropriation" (Wilhite et al., 2001) of energy use along with increasing use of a more efficient and modern energy system.

A change along the path shown in Fig. 4 can be seen as an improvement in overall household energy usage. For instance, the improvement shown by the arrow in Fig. 4 can be the result of: increase in energy service demand that is often associated with a higher welfare level (e.g. more warm meals, brighter room, more comfortable room temperature); fuel switching to higher quality and cleaner fuel (e.g. switch from wood to LPG); adopting higher efficiency energy appliance (e.g. replacing a traditional cookstove with an improved one).

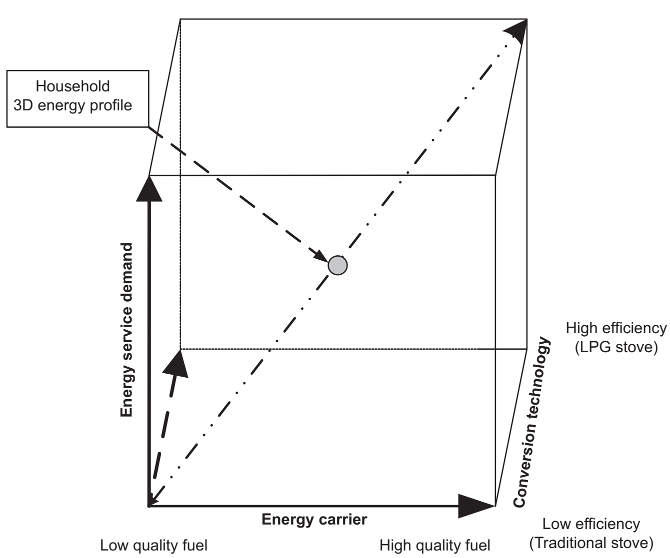

Fig. 4. Energy profile transition through a three dimensional path.

The graph of energy transition is not necessarily a smooth and continuous line. Rather, it is most likely in the shape of steps in each of the three dimensions. There are a number of drivers affecting the three dimensions of energy use, described earlier in this section that triggers such a transition. The cumulative effect of a range of drivers or the affect of each factor on the transition of energy use can be visualized through the proposed graph.

5. Conclusion

There is a large gap in the literature regarding the behavioral aspects of energy use. Although some research has attempted to include cultural and habitual factors and has confirmed their importance, there is almost no research that explores these variables and their dynamics in detail. For instance, while an econometric analysis looks at the differences between energy use in households headed by males and females, there is no explanation of why these differences exist and how they may change. As a final note, the growing concern about energy and household welfare, impacts of climate change, and energy security requires a more realistic understanding of household energy use. An in-depth study of the human dimension of energy use is a vital step for improving our understanding of household energy use in rural regions of developing countries. The proposed conceptual framework provides a basis for both qualitative and quantitative research. The framework addresses the gaps identified in the literature by focusing on household level qualitative and quantitative data in order to be able to capture micro-trends based on appropriate information and identify the casual relationship between variables. By incorporating a range of personal and contextual variables the framework avoids overemphasizing income as the major determinant of energy consumption and also addresses the human dimension of energy use. Finally, the three dimensional energy profile considers all three dimensions of energy systems (i.e. energy services, energy carriers, and energy conversion devices) and their interrelations in order to have a realistic view of household energy use.

The three dimensional energy profile framework can act as a basis for building new theoretical and empirical models of rural household energy use. Such models along with in depth study of rural energy usage are a precondition for formulating any meaningful strategy.

Acknowledgments

This work was supported by the Province of British Columbia under a Pacific Century Trust scholarship, a University of British Columbia doctoral fellowship and the Liu Institute for Global Issues Olav Slaymaker Doctoral Fellowship. We would also like to thank our two anonymous reviewers for their helpful comments and suggestions. Their suggestions have greatly improved the final paper. Of course, any errors remain our own.

References

Agarwal, Bina, 1986. Cold Hearths and Barren Slopes. Allied Publishers Private Limited, New Delhi.

Ajzen, Icek, 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes 50 (2), 179–211.

Alam, M.S., Bala, B.K., Huq, A.M.Z., 1997. Simulation of integrated rural energy system for farming in Bangladesh. Energy 22 (6), 591–599.

Arnold, J.E., Michael, Gunnar, Köhlin, Persson, Reidar, 2006. Woodfuels, livelihoods, and policy interventions: changing perspectives. World Development 34 (3), 596–611.

Barnes, Douglas F., 1988. Electric Power for Rural Growth: How Electricity Affects Rural Life in Developing Countries. Westview Press, Boulder.

Barnes, Douglas, F., 1992. Understanding Fuelwood Prices in Developing Nations. The World Bank, Washington.
Barnes, Douglas F., Floor, Willem M., 1996. Rural energy in developing countries: a challenge for economic development. Annual Review of Energy and the Environment 21, 497–530.
Barnes, Douglas F. Kerry, Krutilla Hyde, William F., 2004. The Urban Household Energy Transition: Social and Environmental Impacts in the Developing World. Resources for the Future.
Barnes, Douglas F., Kerry Krutilla, Hyde William F., 2005. The Urban Household Energy Transition: Social and Environmental Impacts in the Developing World. Resources for the Future.
Barnes, Douglas F., Qian, Liu, 1992. Urban Interfuel Substitution, Energy Use, and Equity in Developing Countries: Some Preliminary Results. World Bank, Washington, DC.
Bhatt, B.P., Sachan, M.S., 2004. Firewood consumption along an altitudinal gradient in mountain villages of India. Biomass and Bioenergy 27, 69–75.
Bluffstone, Randall, A., 1995. The effect of labor market performance on deforestation in developing countries under en access: an example from rural nepal. Journal of Environmental Econmics and Management 29, 42–63.
Brouwer, Inge, D., Hoorweg, Jan C., van Liere, Marti J., 1997. When households run out of fuel: responses of rural households to decreasing fuelwood availability, Ntcheu District, Malawi. World Development 25 (2), 255–266.
Bruce, Nigel, Rogelio, Perez-Padilla, Rachel, Albalak, 2000. , Indoor air pollution in developing countries: a major environmental and public health challenge. Bulletin of the World Health Organization 78, 9.
Cecelski, Elizabeth, 2002. Enabling equitable access to rural electrification: Current thinking on energy, poverty, and gender, in Briefing Paper, Asia Alternative Energy Policy and Project Development Support. World Bank, Washington, DC.
Chambwera, Muyeye, 2004. Economic Analysis of Urban Fuelwood Demand: the Case of Harare in Zimbabwe. Wageningen University, Wageningen.
Chaurey, Akanksha, Ranganathan, Malini, Mohanty, Parimita, 2004. Electricity access for geographically disadvantaged rural communities—technology and policy insights. Energy Policy 32 (15), 1693–1705.
Cherfas, Jeremy, 1991. Skeptics and visionaries examine energy saving. Science 251 (4990), 154–156.
Cogoy, Mario, 1995. Market and non-market determinants of private consumption and their impacts on the environment. Ecological Economics 13 (3), 169–180.
Cooke, Priscilla, Kohlin, Gunnar, Hyde, William F., 2008. Fuelwood, forests and community management—evidence from household studies. Environment and Development Economics 13, 103–135.
Davis, Mark, 1998. Rural household energy consumption : The effects of access to electricity—evidence from South Africa. Energy Policy 26 (3), 207–217.
Dewees, Peter, A., 1989. The woodfuel crisis reconsidered: observations on the dynamics of abundance and scarcity. World Development 17 (8), 1159–1172.
Dube, Ikhupuleng, 2003. Impact of energy subsidies on energy consumption and supply in Zimbabwe. Do the urban poor really benefit? Energy Policy 31 (15), 1635–1645.
Edwardsa, Rufus D., et al., 2004. Implications of changes in household stoves and fuel use in China. Energy Policy 32, 395–411.
Elias, Rebecca J., Victor, David G., 2005. Energy transition in developing countries: a review of concepts and literature. In: Program on Energy and Sustainable Development, working paper. Stanford University: Stanford.
ESMAP, 1991. Haiti Household Energy Strategy. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington, DC.
ESMAP, 1999. Household Energy Strategies for Urban India: The Case of Hyderabad. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington, DC.
ESMAP, 2000. Energy Services for the World's Poor. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP).
ESMAP, 2000. Photovoltaic Applications in Rural Areas of the Developing World. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington, DC.
ESMAP, 2000. Subsidies and Sustainable Rural Energy Services: Can We Create Incentives Without Distorting Market? Joint UNDP/World Bank, Energy Sector Management Assistance Program (ESMAP),Washington.
ESMAP, 2002. Energy Strategy for Rural India : Evidence from Six States. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP).
ESMAP, 2003. Household Energy Use in Developing Countries: A Multicountry Study. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington, DC.
ESMAP, 2004. Rural Electrification in the Developing World: a Summary of Lessons from Successfuel Programs. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington, DC.
Farsi, Mehdi, Filippini, Massimo, Pachauri, Schonali, 2007. Fuel choices in urban Indian households. Environment and Development Economics 12, 757–774.
Farsi, Mehdi, Pachauri, Massimo Filippini Schonali, 2007. Fuel choices in urban Indian households. Environment and Development Economics 12, 757–774.
Fernandez, Viviana P., 2001. Observable and unobservable determinants of replacement of home appliances. Energy Economics 23 (3), 305–323.
Fitzgerald, Kevin B., Barnes, Douglas F., McGranahan, Gordon, 1990. Interfuel Substitution and Changes in the way Households Use Energy: the Case of Cooking and Lighting Behavior in Urban Java. World Bank, Washington, DC.
Foster, Vivien, Tre, Jean-Philippe, Wodon, Quentin, 2000. Energy Consumption and Income: an Inverted-U at the Household Level?. World Bank, Washington.
Frederick, Shane, Loewenstein, George, O'Donoghue, Ted, 2002. Time discounting and time preference: a critical review. Journal of Economic Literature XL, 351–401.
Ghosh, Sajal, 2002. Electricity consumption and economic growth in India. Energy Policy 30 (2), 125–129.
Goldemberg, Jose, 1996. Energy, Environment & Development. Earthscan, London.
Guagnano, Gregory A., Stern, Paul C., Dietz, Thomas, 1995. Influences on attitude–behavior relationships. Environment and Behavior 27 (5), 699–718.
Gundimeda, Haripriya, Köhlin, Gunnar, 2008. Fuel demand elasticities for energy and environmental policies: Indian sample survey evidence. Energy Economics 30, 517–546.
Guptaa, Gautam, Kohlin, Gunnar, 2006. Preferences for domestic fuel: analysis with socio-economic factors and rankings in Kolkata, India. Ecological Economics x (57), 107–121.
Hart, Melissa, de Dear, Richard, 2004. Weather sensitivity in household appliance energy end-use. Energy and Buildings 36 (2), 161–174.
Heltberg, Rasmus, 2004. Fuel switching: evidence from eight developing countries. Energy Economics 26, 869–887.
Heltberg, Rasmus, 2005. Factors determining household fuel choice in Guatemala. Environment and Development Economics 10, 337–361.
Heltberg, Rasmus, Arndt, Thomas Channing, Sekhar, Nagothu Udaya, 2000. Fuelwood consumption and forest degradation: a household model for domestic energy substitution in rural India. Land Economics 76 (2), 213–232.
Hosier, Richard, H., Dowd, Jeffrey, 1987. Household fuel choice in Zimbabwe: an empirical test of the energy ladder hypothesis. Resources and Energy 9 (4), 347–361.
Howells, M.I., et al., 2005. A model of household energy services in a low-income rural African village. Energy Policy 33 (14), 1833–1851.
Howells, Mark, et al., 2002. Rural Energy Modelling. The Program on Energy and Sustainable Development (PESD), Stanford, p. 44.
Hyde, William F., Köhlin, Gunnar, 2000. Social forestry reconsidered. Silva Fennica 34 (3), 285–314.
IEA, 2002. World Energy Outlook 2002. International Energy Agency (IEA), Paris.
IEA, 2006. World Energy Outlook 2006. International Energy Agency (IEA), Paris.
IEA, 2010. World Energy Outlook 2010. International Energy Agency.
Jiang, Leiwen, 2004. The energy transition in rural China. Global Energy Issues 21 (1).
Johansson, Thomas B., José Goldemberg, 2004. World Energy Assessment: Overview 2004 Update, UNDP/UN-DESA/World Energy Council, 500 pages—United Nations Development Programme, New York.
Jumbe, Charles B.L., 2004. Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi. Energy Economics 26 (1), 61–68.
Keirstead, James, 2006. Evaluating the applicability of integrated domestic energy consumption frameworks in the UK. Energy Policy 34 (17), 3065–3077.
Kohlin, Gunnar, Amacher, Gregory S., 2005. Welfare implications of community forest plantations in developing countries: the Orissa social forestrly project. American Journal of Agricultural Economics 87 (4), 855–869.
Kooreman, Peter, 1996. Individual discounting, energy conservation, and household demand for lighting. Resource and Energy Economics 18 (1), 103–114.
Laitner, John A., 2007. The Contribution of the Social Sciences to the Energy Challenge, American Council for an Energy-Efficient Economy. ACEEE, Washington.
Leach, Gerald, 1987. Household Energy Handbook: an Interim Guide and Reference Manual. World Bank, Washington, D.C.
Leach, Gerald, 1988. Beyond the Woodfuel Crisis: People, Land, and Trees in Africa. Earthscan Publications, London.
Leach, Gerald, 1992. The energy transition. Energy Policy 20 (2), 116–123.
Legros, Gwénaëlle, et al., 2009. The Energy Access Situation in Developing Countries, UNDP WHO.
Leiwen, Jiang, O'Neill, Brian C., 2003. The Energy Transition in Rural China_Interim Report. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Lutzenhiser, Loren, 1993. Social and behavioral aspects of energy use. Annual Review of Energy and the Environment 18, 247–289.
Lutzenhiser, Loren, et al., 2009. Behavioral Assumptions Underlying California Residential Sector Energy Efficiency Programs. California Institute for Energy and Environment (CIEE), Oakland, USA.
Masera, Omar, R., Navia, Jaime, 1997. Fuel switching or multiple cooking fuels? Understanding inter-fuel substitution patterns in rural Mexican households. Biomass and Bioenergy 12 (5), 347–361.
Masera, Omar R., Saatkamp, Barbara D., Kammen, Daniel M., 2000. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. World Development 28 (12), 2083–2103.
Mestl, Heidi Elizabeth, Staff, Eskeland, Gunnar S., 2009. Richer and healthier, but not Greener? Choices concerning household energy use in India. Energy Policy 37 (8), 3009–3019.
Modi, Vijay, et al., 2005. Energy Services for the Millennuim Development Goals. The International Bank for Reconstruction and Development/The World Bank and the Unitated Nations Development Programme, New York.
Pachauri, S., et al., 2004. On Measuring Energy Poverty in Indian Households. World Development 32 (12), 2083–2104.
Pachauri, Shonali, 2004. An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. Energy Policy 32, 1723–1735.
Pachauri, Shonali, 2007. An Energy Analysis of Household Consumption. Springer, Dordrecht, The Netherlands.

Pachauri, Shonali, Daniel, Spreng, 2003. Energy use and energy accessin relation to poverty, in CEPE Working Paper. CEPE, ETH Zentrum: Zürich, June 2003.

Rogers, Everett M., 2003. Diffusion of Innovations, 5th edition. Free, New York.

Roy, Joyashree, 2000. The rebound effect: some empirical evidence from India. Energy Policy 28 (6–7), 433–438.

Rukato, Hesphina, 2002. Gender and energy in the South: a perspective from Southern Africa. In: Gender Perspectives for Earth Summit 2002:Energy, Transport, Information for Decision-Making, Berlin, Germany.

Saboohi, Y., 2001. An evaluation of the impact of reducing energy subsidies on living expenses of households. Energy Policy 29 (3), 245–252.

Saghir, Jamal, 2005. Energy and Poverty: Myths, Links, and Policy Issues. World Bank, Washington.

Sathaye, Jayant, Tyler, Stephen, 1991. Transitions in household energy use in urban China, India, The Phillipines, Thailand, and Hongkong. Annual Review of Energy and the Environment 16, 295–335.

Schlag, Nicolai, Zuzarte, Fiona, 2008. Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature. Stockholm Environment Institute, Stockholm.

Shove, Elizabeth, 2003. Comfort, Cleanliness, and Convenience: The Social Organization of Normality.. Berg, Oxford, UK.

Smith, Kirk R., 1987. Biofuels, air pollution, and health : a global review Modern perspectives in energy. New York Plenum Press.

Stern, Paul, C., 1986. Blind spots in policy analysis: what economics doesn't say about energy use. Journal of Policy Analysis and Management 5 (2), 200–227.

Stern, Paul, C., 2000. Toward a coherent theory of environmentally significant behavior. Journal of Social Issues 56 (3), 407–424.

Stokes, Melody, Rylatt, Mark, Lomas, Kevin, 2004. A simple model of domestic lighting demand. Energy and Buildings 36 (2), 103–116.

Thom, Cecile, 2000. Use of grid electricity by rural households in South Africa. Energy for Sustainable Development 4 (4), 36–43.

Tiwari, Piyush, 2000. Architectural, demographic, and economic causes of electricity consumption in Bombay. Journal of Policy Modeling 22 (1), 81–98.

Tuan, Anh, Nguyen, Lefevre, Thierry, 1996. Analysis of household energy demand in Vietnam. Energy Policy 24 (12), 1089–1099.

Urban, F., Benders, R.M.J., Moll, H.C., 2007. Modelling energy systems for developing countries. Energy Policy 35, 3473–3482.

Van Raaij, W., Fred, Verhallen, Theo M.M., 1983. A behavioral model of residential energy use. Journal of Economic Psychology 3 (1), 39–63.

Victor, David, 2009. The Politics of Fossil-Fuel Subsidies. the International Institute for Sustainable Development (IISD), San Diego.

Victor, David G., 2002. A Vision for Global Electrification. The Program on Energy and Sustainable Development (PESD), Stanford University, Stanford.

Victor, Nadejda, M., Victor, David G., 2002. Macro Patterns in the Use of Traditional Biomass Fuels. Stanford University, The Program on Energy and Sustainable Development (PESD), Stanford, USA.

Webler, Thomas, Tuler, Seth P., 2010. Getting the engineering right is not always enough: researching the human dimensions of the new energy technologies. Energy Policy 38 (6), 2690–2691.

WEC, 2004. World Energy Assessment: Overview 2004 Update, UNDP/UN-DESA/ World Energy Council, 500 pages—United Nations Development Programme,- New York.

Whitfield, Darby, 2006. Household Behavior and Energy Demand: Evidence from Peru, in Public Policy. Massaghusetts, Harvard, p. 143.

Wilhite, Harold, et al., 2000. The Legacy of Twenty Years of Energy Demand Management: We Know More about Individual Behaviour But Next to Nothing About Demand in Society, Behaviour, and Climate Change Mitigation. Springer Netherlands, Netherlands, pp. 109–126.

Wilhite, Harold, et al., 2001. The Legacy of Twenty Years of Energy Demand Management: We Know More About Individual Behavior But Next to Nothing About Demand in Society, Behaviour, and Climate Change Mitigation. Springer Netherlands, Netherlands, pp. 109–126.

Wilk, Richard, 2002. Consumption, human needs, and global environmental change. Global Environmental Change 12 (1), 5–13.

Wilson, Charlie, Dowlatabadi, Hadi, 2007. Models of decision making and residential energy use. Annual Review of Environment and Resources 32, 169–203.

Wuyuan, Peng, Zerriffi, Hisham, Jihua, Pan, 2008. Household Level Fuel Switching in Rural Hubei. Stanford University, The Program on Energy and Sustainable Development (PESD), Stanford, USA.

Xiaohua, Wang, Zhenmin, Feng, 2003. Common factors and major characteristics of household energy consumption in comparatively well-off rural China. Renewable and Sustainable Energy Reviews 7 (6), 545–552.