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Energy Access, Efficiency, and Poverty

How Many Households Are Energy Poor in Bangladesh?

Douglas F. Barnes
Shahidur R. Khandker
Hussain A. Samad

The World Bank
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Abstract

Access to energy, especially modern sources, is a key to any development initiative. Based on cross-section data from a 2004 survey of some 2,300 households in rural Bangladesh, this paper studies the welfare impacts of household energy use, including that of modern energy, and estimates the household minimum energy requirement that could be used as a basis for an energy poverty line. The paper finds that although the use of both traditional (biomass energy burned in conventional stoves) and modern (electricity and kerosene) sources improves household consumption and income, the return on modern sources is 20 to 25 times higher than that on traditional sources. In addition, after comparing alternate measures of the energy poverty line, the paper finds that some 58 percent of rural households in Bangladesh are energy poor, compared with 45 percent that are income poor. The findings suggest that growth in electrification and adoption of efficient cooking stoves for biomass use can lower energy poverty in a climate-friendly way by reducing carbon dioxide emissions. Reducing energy poverty helps reduce income poverty as well.

This paper—a product of the Agriculture and Rural Development Team, Development Research Group—is part of a larger effort in the department to understand the role of energy in growth and poverty reduction. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at skhandker@worldbank.org.

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Douglas F. Barnes

Shahidur R. Khandker

Hussain A. Samad

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1. Introduction

The relationship between energy and poverty has been an issue preoccupying development specialists for many decades. Running modern economies without modern energy is impossible as it is quite well accepted that modern energy use is related in some way to economic development. The concern is whether the provision of energy services leads to economic development or economic development leads to expanding demand for energy. The generally accepted wisdom is that energy is a necessary but not sufficient condition for development. However, this begs the question as to whether the lack of energy, especially modern energy, is one of the causes of poverty. In this paper we examine the impact of energy on poverty reduction and whether it is possible to establish a level at which people can be perceived as "energy poor." In this sense energy poverty is the point at which people are using the bare minimum energy needed to sustain a healthy life. Beyond this point, energy contributes to increased welfare and higher levels of economic well being.

The most recent initiative to address global poverty and inequality involves the Millennium Development Initiative which sets goals or development outcomes that need to be achieved in order for the poor people to move out of poverty – an issue that was addressed at the United Nations Millennium Summit in 2000. This produced the Millennium Development Goals (MDGs) which outlined time-bound goals in the areas of poverty, health, education and environment. Although energy consumption was not actually mentioned in any of the goals, it was considered at the Summit as essential to achieving most of the Goals. It has been generally recognized that energy issues need to be dealt with in order to alleviate poverty in the developing world (Sachs 2005). This was also

highlighted in the Johannesburg World Summit on Sustainable Development (Modi and others 2005; DFID 2002).

The ways in which energy contributes to welfare have been well documented. For example, the burning of biomass energy such as fuelwood, dung or crop residue in conventional ways often contributes to indoor air pollution and is thus a health hazard (World Bank 2002a, 2002b).[2] The use of more modern fuels such as LPG can alleviate this problem. Collection of fuelwood also takes a lot of time in rural areas and keeps people (particularly school-going children or women) away from other productive pursuits (Saghir 2004; Barnes and Toman 2006); so ways to reduce traditional biomass energy consumption can lead to saving time and better opportunities. The use of electricity in the evening extends work and study hours and contributes to productivity and educational achievements (Brodman 1982; Cabraal and Barnes 2006; Roddis 2000; Saunders and others 1975; Wasserman and Davenport 1983; World Bank 2002c; Unnayan Shamannay. 1996).

Based on these benefits, international donors have been promoting rural energy development as part of the goals towards achieving MDGs and in general for rural development (WHO 2006; United Nations 2005). This paper intends to deepen our understanding of energy as one of the factors underpinning both economic development and poverty reduction through the study of the relationship between energy and poverty in Bangladesh.

In our empirical analysis of a comprehensive survey representative of rural Bangladesh we find that energy poverty is pervasive in rural Bangladesh in spite of the government's efforts to promote better forms of rural energy. However, there are ways to alleviate energy poverty. Both traditional and modern ways of using energy contribute to the alleviation of energy poverty. In particular, the use of electricity significantly improves household income. This study finds that

[2] Burning biomass also adds carbon to the atmosphere, contributing to Green House Gases trapping heat in the atmosphere. So an inefficient burning of biomass fuels contributes to climate change.

investments in modern energy have a very high rate of return. Finally, based on these empirical findings we address how energy interventions might contribute to reducing poverty.

The objective of this paper is to assess the role of modern energy in poverty alleviation. First, we want to assess the energy use patterns of rural households in Bangladesh and determine the factors that influence their demand for energy. The share of modern energy that households consume actually turns out to be a good indicator of the overall welfare of households in particular and of the society in general.[3] Also identifying the key determinants of energy demand, especially of modern energy, can assist in making policy decisions to influence this demand. Second, we want to assess the impacts of energy use on household welfare. Of particular interest is the impact of the different types of energy use on household welfare as this might help make informed policy decisions in the energy sector. Third, we want to estimate the basic energy requirement for rural households in Bangladesh. The goal is to define an energy poverty line based on the bare minimum needs for energy in rural Bangladesh. This will help ascertain the extent of energy poverty and the factors that might alleviate such energy poverty in Bangladesh. Finally, we will address the relationship between energy poverty and climate change. Before turning to the substantive results, the next section reviews the existing work on energy poverty in developing countries and the immediate next section lays out an economic framework underlying the relationship between energy consumption and household welfare.

2. Review of energy poverty approaches

[3] Modern and traditional energy are used to connote those types that are used in more developed societies, compared to those that are still prevalent in developing countries and have been used for probably thousands of years. In general, the liquid fuels such as kerosene and LPG along with electricity are considered to be modern forms of energy. The traditional fuels generally are biomass fuels such as wood, agricultural residue and dung, which are used in traditional stoves. However, biomass energy, if used more efficiently or transformed into liquid or gaseous fuels, can also be considered to be modern.

The concept of a poverty line is quite well accepted around the world. In fact, the methods and issues for defining a poverty line are often based on an expenditure approach for specifying a minimum level at which households can be considered as non-poor.[4] In other words, what is the minimum level of expenditures necessary for maintaining an acceptable standard of living for a given population? The idea of an energy poverty line is a similar concept, but as of yet no international or government agencies actually track energy poverty. One reason is that it has been very difficult to get an agreement on an adequate definition of energy poverty as there have been problems in dealing with the methodological and conceptual issues in defining it. For instance, those based on minimum physical levels of heating or cooking are often very location-specific due to the vast difference in climatic conditions worldwide. Others based on expenditure also have often been somewhat arbitrary in establishing what defines essential energy services. In this paper we explore a way to measure energy poverty that is similar to the concept of expenditure poverty and applicable to a wide variety of conditions. In fact, energy poverty line is based on how much energy consumption is necessary to maintain a bare minimum livelihood for households. However, in order to establish an energy poverty line it is first necessary to understand the welfare impact of energy use.

To date, there have been several approaches taken for establishing levels of energy poverty, and they generally can be classified as either based on measures of physical energy requirements or energy expenditures. Many involved in energy issues have grappled with the concept of energy poverty (Krugman and Goldemberg 1983; Pachauri and Spreng 2004; Foster, Tre and Wodon 2000; Saghir 2005) and the main approaches are reviewed in this section.

Some approaches to measuring energy poverty consider it to be analogous to consumption poverty measures that are based on food intake or calorie necessities adopted by many of the world's

[4] There is a large body of literature on how to measure poverty and the reliability of alternate measures. For extensive treatments on this issue, please see Ravallion (1998), Ravallion and Bidani (1994) and Pradhan and Ravallion (1998).

health agencies. Instead of food calorie requirements, they base their estimates on the technical provision of energy services. This is essentially the method used in the earliest approaches that classified and estimated the minimum quantities of energy to have a reasonable quality of life (Bravo et al. 1979). According to this approach direct energy includes provisions for cooking, lighting, heating/cooling, preservation of food, hot water, ironing, pumping of water, plus recreation and social occasions. Indirect energy needs refer to energy that is embodied in additional goods and services that households use. The Bravo measure goes into considerable details to quantify household's direct energy needs, considering variations in energy sources and their efficiencies, urban and rural areas, and climate conditions. This method defines the average essential household needs for direct energy requirements in rural Bangladesh to be about 27.4 kgOE per capita per month.[5] Based on another interpretation of physical energy needs, Goldemberg (1990) includes an even wider range of energy-using activities, and based on that measure the energy poverty line for rural Bangladesh is 32.1 kgOE per capita per month.[6] As indicated, these two measures are based on physical energy requirements for households.

A simpler method that is more universal examines the physical needs of daily cooking and lighting based on various surveys around the world, and the minimum energy need according to this measure is much lower at 50 kgOE per capita per year (Modi et al 2005). This is based on the absolute minimum requirement of 40 kgOE for cooking and 10 kgOE is for lighting. It is obvious that this measure is very basic and does not include energy use for other purposes such as transport, heating/cooling, and other more essential services. Thus, the energy quantity approach is very interesting, but the differing assumptions yield vastly different results. They also do not take into

[5] Bravo and others (1979) expressed it as 9.2 thousand kcal/day/person which converts to 27.4 kgOE per capita per month for a tropical country like Bangladesh.
[6] Goldemberg (1990) proposed roughly a little over 500 watt per capita which is equivalent to 32.1 kgOE per capita per month.

consideration the market conditions such as prices and other energy policies that govern the delivery of energy services.

A quite different way to estimate energy poverty is based on energy expenditures as a proportion of total expenditures (Pachauri and Spreng 2004). Many international and government agencies routinely collect expenditure data for countries. The rationale for this expenditure-based approach is that many expenditure surveys indicate that poor households spend a large part of their total expenditure on energy and this obviously would be a hardship if the expense levels are too high. Generally, as household expenditures rise, less and less money is spent on energy as a percentage of the total income. Poor households on the other hand spend higher and higher shares of their income on energy and this obviously means that there is some basic essential energy service. Rising expenditure of energy becomes more and more difficult for households and they begin to cut back on their energy use to minimum levels. Pachauri and Spreng (2004) adopt a cutoff point of 10 percent of total expenditure because it is frequently mentioned in literature as common level of expenditure for poor households.

Energy poverty can also be based on the types of energy used by households at or below the overall expenditure poverty line already estimated for a country (Foster, Tre, and Woodon 2000). The basic assumption behind this measure is that expenditure-poor households (in terms of per capita expenditure) are also likely to be energy-poor. That is, the energy poverty line is related more to consumption expenditures than to physical energy requirements. The steps involved in developing this measure are fairly simple. The expenditure poverty line is determined first, following one of the standard techniques. This information is often already available through national statistical offices. Next, households are selected, whose per capita total expenditure falls below the expenditure poverty line. Finally, the average per capita energy consumption for these households is calculated, which is deemed to be the energy poverty line.

The method of energy poverty advocated in this paper actually uses energy demand, income, and other factors to identify an energy poverty line. The relative advantage of this method over the others will be discussed later. Before turning to this method, in the next section, we examine the theoretical basis for developing an energy poverty line.

3. Energy use and household welfare: An economic framework

The assumption of all the approaches to energy poverty reviewed in the previous section is that household consumption of energy and that of other non energy goods and services are related to overall wellbeing. The relative shares of energy and other expenditures reflect the underlying price and availability of energy of different types and their impact on overall welfare. In fact, as indicated, higher shares of energy expenditures actually mean low levels of household welfare because it obviously means a lower percentage of spending on other goods and services such as food and non-food items. On the other hand, a higher monetary expenditure on energy does not necessarily imply a higher quantity of energy use as it depends on the energy price, efficiency, type of use and other factors. This may make a household worse off by lowering the observed level of its welfare. This suggests that the impact of energy use on household welfare should be examined from the demand for energy services and not from the expenditure on energy alone.

Assessing the impact of energy use on household income and non-energy consumption involves some econometric issues, as determining the direction of causality between these two is not always straightforward. A household's wellbeing certainly influences its energy use and at the same time its energy use affects household welfare. As household income goes up, this is accompanied by more choices for those expenditures. Households spend more on energy by expanding existing energy use (for instance, buying more kerosene lanterns, extending the duration of electricity use), purchasing modern energy appliances that it probably could not have afforded before (electric irons,

lamps, fans, etc.), and energy-consuming entertainment and luxury items (TVs, refrigerators, VCRs, and air conditioners). On the other hand, energy use, particularly modern energy, also can bring about tangible changes in household welfare, directly and indirectly. This leads us to conclude that household wellbeing, income, and energy use are jointly determined.

The use of lighting can illustrate this joint relationship between income and energy. High quality lighting services can extend activities beyond daylight hours. This is particularly true for an electric lamp which provides 100 times more lighting than a kerosene wick lamp (*kupi*). Higher levels of lighting can improve income generation activities by keeping a store open for longer hours or making a home business more productive. Both contribute to increased income and employment. Access to lighting services may also increase study hours for school-going children, which in turn can increase their educational achievements. How can increased energy use possibly increase household non-energy expenditure or income? The underlying hypothesis is this: there is a threshold value of energy consumption that a household must have to maintain a minimum level of welfare that is independent of its income. However, beyond that minimum threshold, energy consumption may be influenced by a variety of factors such as the availability of alternative sources of energy, prices, income gains or other changes.

The introduction of a modern source of energy such as electricity for a household that previously did not have access to electricity actually makes lighting services less expensive. With the same level of household income, this means cheaper energy services for households, which result in a higher level of energy use, and consequently, an upward shift of the budget line from I_0 to I_1 (Figure 1) where U's represent household indifference curves. Household consumption of non-food goods and services is more energy intensive than food expenditures, and this means a shift of the budget line more towards the vertical axis than the horizontal axis. For simplicity, we assume that the availability of modern energy affects the relative prices of energy mix in such a way that the

budget line moves to C_1 with a higher expenditure of non-food goods and services and a lower expenditure of food.[7] This clearly indicates a higher level of household welfare as point C_1 is at a

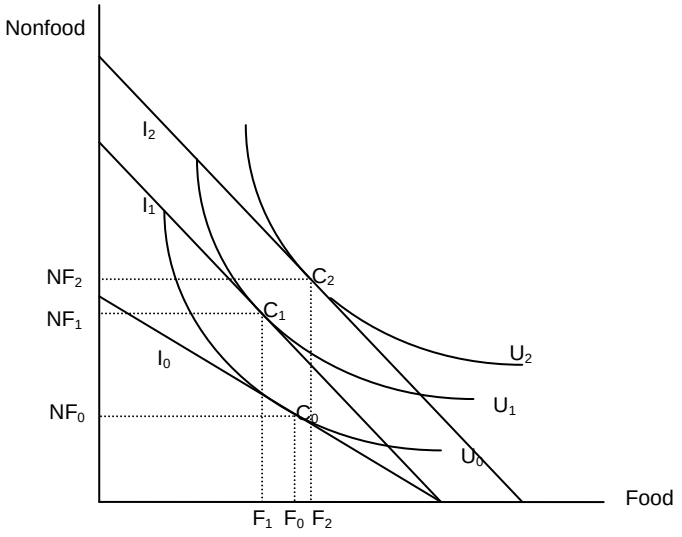


Figure 1: Dynamics of household utility function

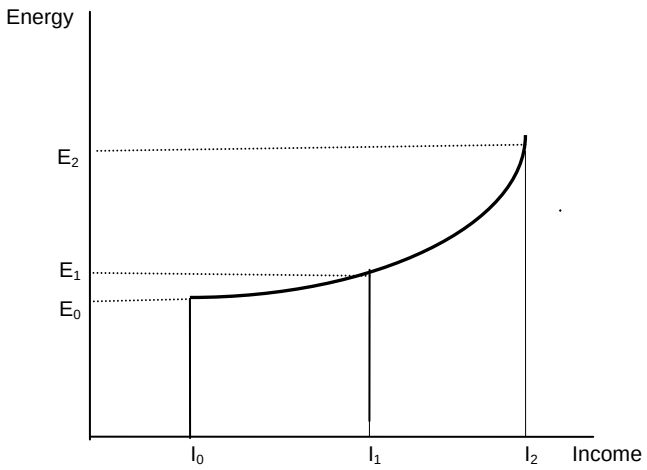


Figure 2: Household energy consumption against income change

higher welfare level than point C_0. With the introduction of modern energy such as electricity, household welfare can further be enhanced as households augment its productivity and income. Higher level of household productivity and income shifts the budget line even further, helping households to consume more food and non-food goods and services, and therefore they attain a higher state of welfare (point C_2). The shifts in budget lines indeed indicate the role of modern technology that goes along with modern energy services.

The possible energy consumption and income relationship can illustrate the state of being energy poor versus non poor (Figure 2). Consumption of energy rises with higher levels of income, but the changes in energy consumption at lower levels of income are not as responsive to slight changes of income as those with changes at higher levels of income. That is, as Figure 2 suggests,

[7] This does not need to be the case. In fact, both food and non-food consumption can increase as a result of a decrease in real price of alternative sources of energy.

$(E_1 - E_0) < (E_2 - E_1)$. As energy is necessary for living, a household tries to maintain at least some basic minimum level of energy consumption, which is the energy poverty line.[8] If this basic minimum energy consumption happens to be the energy consumption of the income poor, we are likely to find that energy poor are also the income poor or vice versa. That is, by looking at the energy consumption of the income poor, we find the extent of energy consumption needed which is a bare minimum. But this is not likely the case. For example, a household with higher level of income may have energy consumption which is even lower than the minimum energy needed to be energy non-poor. The reverse is likely to be true if a household who is income poor consumes a higher level of energy consumption to make it energy non-poor.

In an attempt to determine that basic minimum energy requirement, our approach investigates how a household's demand for energy varies with the change in other major welfare indicators such as income. One way to observe that change is to examine the energy demand function. We will see shortly that a household's energy demand is influenced by several factors – both at household level (level of education, land and non-land assets, hygiene) and at community level (energy price, village infrastructure, prevailing wage structure, and commodity prices). However, for households who are energy poor and are only meeting their basic needs for energy, the relationship between energy use and income is likely to be quite weak. These issues will be explored using a nationally representative household survey of rural energy use in Bangladesh that contains a rich set of data on energy consumption, income and other factors necessary for assessing an energy poverty line.

4. The pattern of energy use and its determinants in Bangladesh

[8] Basic minimum energy consists of energy needed for minimum quantity of lightning, cooking, and heating.

The establishment of a poverty line for a country or region requires the availability of national or regional household survey information. The research findings of this study are based on a nationally representative rural household survey in Bangladesh conducted in 2004. One reason for choosing this survey for developing an energy poverty line is that it includes a representative picture of all types of energy use in rural Bangladesh. The survey was conducted in all four traditional divisions of Bangladesh, namely Dhaka, Chittagong, Khulna and Rajshahi. From these four divisions, 40 *thanas* or *upazilas* (sub-districts) were randomly selected. From each *thana*, 3 villages were randomly selected, and from each village 20 households were randomly selected. The sample for this survey is 2,388 households from 119 villages that is representative of rural Bangladesh (Asaduzzaman, Barnes and Khandker 2007).

The survey provides information on income, education, health, housing, consumption, assets, and farm production and home enterprises. These are important variables for estimating poverty and are the main explanatory variables in the demand analysis presented later in this paper. The results from this survey are quite consistent with other surveys conducted in Bangladesh. In addition, there was a village level survey that collected information on prices for consumer goods, wages of males, females and children, village irrigation patterns, and different infrastructure information.

The survey is a rich source of information on energy, which is the main focus of this study. In rural Bangladesh the evidence from the survey indicates that there is a high degree of reliance on the biomass fuels (Table 1). As in other developing countries, in rural Bangladesh most households use biomass fuels for cooking and such fuels are commonly collected from the local environment. In fact, fuelwood is considered a superior fuel for cooking because it is much preferred over other biomass fuels such as crop residues or dung. However, other biomass fuels are burned in great quantity for cooking in rural Bangladesh. It is surprising that the use of tree leaves for cooking is so

prevalent, and this is an indication of both biomass shortage and that energy poverty levels are quite high.

Other forms of energy use are also important for rural Bangladesh. For household lighting, most people use some form of purchased energy—either kerosene or grid electricity. Grid electricity in rural Bangladesh reaches about one-third of the population, and most households use kerosene as well. However, since electricity is cheaper for per unit of light than kerosene, household expenditure for kerosene actually is higher than that for electricity. In homes with electricity, kerosene is used mainly when there are brownouts or blackouts. Apart from being used for lighting, electricity is used increasingly for operating different household appliances such as televisions, radios, and iron, electric fans. In addition, electricity has been found to improve farm production through the use of pumps to irrigate fields. However, irrigation with electric pumps is not as common in Bangladesh as in other South Asian countries.

To understand why people use various types of fuels, it is necessary to understand the factors that contribute to the overall demand for energy. Generally energy use is influenced by the household characteristics, the availability and price of the energy source, and community characteristics. Since fuelwood, kerosene and grid electricity are the major sources of energy (Table 1), the analysis is conducted separately for each one of these fuels. Given that not all households use all types of energy, we estimate the demand for energy by using a Tobit regression (Table 2) that is appropriate for this type of analysis.[9]

The demand analysis of fuel use is generally what would have been expected. Consider the price elasticity of demand for alternative types of energy sources. We find the own-price elasticity of demand is negative. For example, one percent increase in the price of fuelwood decreases biomass consumption by about 0.34 percent. The price of kerosene has a negative effect on the demand for

[9] Bootstrapping is used to correct standard errors.

kerosene but does not have a significant role in the demand for fuelwood. But the price of fuelwood has a positive cross-price effect on the demand for electricity.

Apart from energy prices, education of household members, household assets, and village electricity have a significant impact on energy demand. Higher level of education in the household leads to an increase in energy demand for most sources. Similarly, higher levels of household land and non-land asset have a positive impact in the use of all types of energy, perhaps indicating greater levels of affordability. For example, a one percent increase in household landholding increases monthly biomass consumption by 0.04 percent. **As** for electricity, as expected, the impact of village electrification leads to a large increase in the consumption of electricity and consequently a large decrease in kerosene use. This is because households that adopt electricity generally reduce their use of kerosene for lighting.

Understanding the energy use in general by the rural households is obviously important. However, the factors that lead to an increase or decrease in the expenditure on biomass also are quite relevant to energy policies on welfare. The factors that increase electricity consumption (3rd column in Table 2) include education of household males and females, the assets of the household, and the price of fuelwood. Again, these results emphasize that households with higher levels of assets have higher levels of energy demand (4th column). The relevance of the findings in this section is that energy policies (e.g., making electricity available and energy pricing) do have a significant impact on energy demand.

5. Welfare impacts of energy and the concept of an energy ladder

Before turning to the estimates of an energy poverty line for Bangladesh, it is necessary to examine the rather complicated relationship between income and energy use. The reason this is complicated is that higher incomes obviously make electricity more affordable, and there are questions of cause

and effect. Earlier in the paper we put forth the conceptual framework for analyzing this issue. This section derives the relationship between income and energy consumption based on this conceptual model.

As indicated earlier, income and energy may be jointly determined and that it is not clear what causes what. In other words, income may influence the energy demand and the energy use may influence income via improved productivity. However, using an instrumental variable (IV) regression we may resolve such endogeneity issue (i.e., joint determination of income and energy). This essentially requires a set of variables (called instruments) which affect only the energy demand but not directly the income (income is influenced indirectly through energy demand). A set of such variables could be the prices of alternative sources of energy such as fuelwood, kerosene, and electricity, which affect only the demand for energy and not income directly. This IV method essentially involves a 2 step procedure. In the first step we estimate a demand function for each type of the energy sources using the prices as instruments and predict the energy consumption from the demand function. In the second step, we use the predicted values of energy consumption to predict the effect of alternative sources of energy on income, after controlling all other factors influencing both income and energy use.[10]

Using this approach we examine now the relationship between energy use and four different measures of household welfare. The welfare measures are per capita monthly non-energy expenditure, monthly farm income, nonfarm income and total income. The reason for using non-energy expenditures is that it is necessary to net out any influence of energy decisions on expenditures. The variables for energy and income in the analysis are in log form, so that the

[10] We control for household variables such as age, education, land, and non-land assets. The prices of kerosene and fuelwood as well as whether the village has access to electricity (electricity tariff does not vary across villages) are used as instruments, meaning they are assumed to affect only the energy consumption directly but the non-energy consumption and income indirectly through energy consumption. Interactions of village access to electricity with household-level variables such as education and assets are used as additional instruments. Hausman endogeneity test indicates that 2SLS is more appropriate than OLS in estimating the impact of fuel consumption on income and non-energy expenditure.

coefficients in Table 3 involved the relationship in percentage rather than absolute terms. The first panel of Table 3 shows the elasticity relationship between fuel use and various measures of welfare. Since biomass energy is used mainly for cooking, any increase in the use of biomass energy can be interpreted as an increase in the use of cooking fuels. A 10 percent increase in biomass use increases per capita farm income by 2.4 percent. In contrast, electricity is used mainly for lighting purposes. Electricity has also applications in some appliances, for example, fan, TV, and refrigerator. Electricity is found to increase statistically both non-energy expenditure and non-farm farm income. A 10 percent increase in grid electricity increases non-energy expenditure by 0.4 percent and nonfarm income by almost 1 percent, and total income by 0.3 percent. Kerosene use has no substantive impacts on any type of income or non-energy consumption.

The results confirm that increase in the use of electricity used for lighting and other purposes is very important for generally raising the levels of income or expenditures through non-farm mechanisms. This suggests that electricity is very important for such activities as home enterprise operations, improved ability to study, and other general activities that support income generation. However, for farming activities what is required is more motive power and at the present time in rural Bangladesh, diesel is used for irrigation more than electricity. The results from the first panel of Table 3 are used to calculate the marginal return to energy source and are presented in the second panel of Table 3.[11]

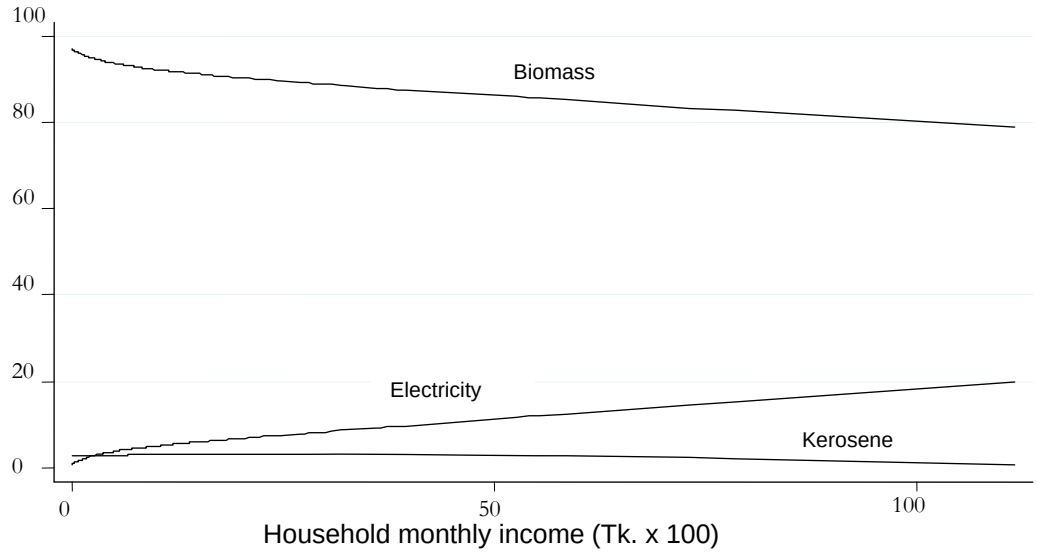
Different forms of energy actually have somewhat different impacts on income. Electricity has a quite large return to income in that for every one kWh of electricity there is a 7 taka increase in monthly household income and almost 10 taka increase in monthly household nonfarm income.

[11] The marginal estimates translate elasticity estimates (percentage change in dependent variable due to a percentage change in an independent variable) to changes in levels (actual change in dependent variable due to a unit change in an independent variable; for example, changes in income in taka due to one kgOE change in kerosene use).

This is quite a good return for an investment of less than 2 taka by the households.[12] As for biomass, one kgOE per month increase in the use of biomass energy increases farm income by about 6 taka per month. However, the market price of fuel-wood is over 4 taka per kgOE, so this is a modest return. However, it should be remembered that one kgOE is equivalent to almost 12 kWh of electricity. Thus, the use of electricity has about 20 times the return on income compared to biomass energy.

These results actually reflect the reality that in a country such as Bangladesh the promotion of electricity is extremely important, but biomass does have many advantages in rural areas. For example, it is quite abundant in the local environment and has a fairly low price which can be either a monetary cost to the household or labor involved in collecting it. Given the level and pace of modernization of rural Bangladesh, biomass is expected to be a dominant energy source for the foreseeable future. Even with a significant modernization to fuels such as electricity or LPG, biomass is most likely to be used, at least for cooking, while electricity is expected to be used mostly for lighting and other modern appliances. We can examine the trend in relative shares of various energy sources, in particular the role of biomass, in household's energy bundle as household's economic condition changes. Household shares of biomass, kerosene, and electricity use (in kgOE) are plotted against income to see how the energy composition of a household changes as its income goes up (Figure 3).[13]

[12] This is the average price households pay for one kWh of electricity in rural Bangladesh as observed from Table 1 (column 3).
[13] Predicted shares (instead of actual shares) of different energy sources are plotted to get smooth lines.



Source: BIDS Survey (2004).

Figure 3: Household energy consumption share by income

The results actually confirm much of the household energy research that was reviewed earlier in this paper. When income is low, biomass dominates the energy use, with some kerosene and very little electricity (Figure 3). As household's income goes up, share of biomass expenditure goes down and eventually becomes steady. The share of kerosene goes down too with increasing income. Finally, share of electricity rises from almost zero percent at lowest income to above 20 percent for the highest income households. This confirms the positive relationship between electricity and income. However, it is obvious that biomass remains the most dominant energy source for all income levels in rural Bangladesh.

6. Estimating energy poverty

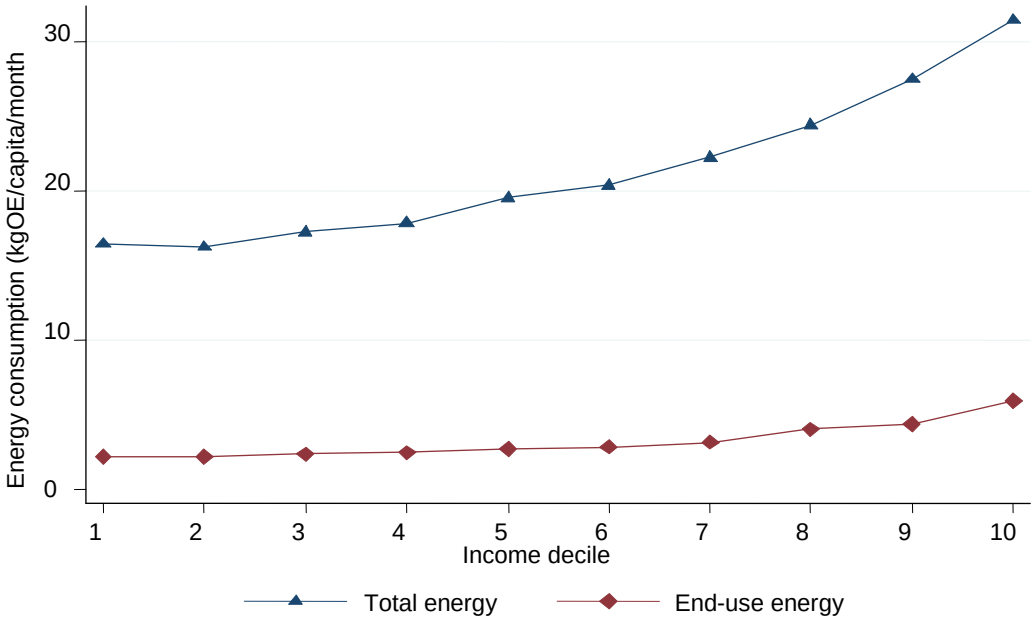
The results shown in the earlier sections clearly underscore the role of household energy consumption in a household's overall welfare. They also establish the fact that energy, besides being a determinant of various household welfare indicators, can itself be a measure of household welfare, just like consumption expenditure or income. Thus, a good understanding of a household's basic

energy requirement is important for any energy policy interventions. It is especially crucial for many poor countries where majority of the rural households get most of their energy from biomass and cannot access modern energy service to the extent they should. Those households that cannot use adequate amount of good quality energy are often referred to as energy-poor households.

As mentioned before, this paper approaches the energy poverty issue by estimating an energy demand equation. This equation, after controlling for a wide range of exogenous variables, shows the sensitivity of energy demand to household income. The idea is, there is a certain minimum level of energy necessary to maintain basic welfare, and energy consumption up to that level should be insensitive to household income. Before identifying that energy level, we would like to have a deeper understanding of a household's energy consumption in the context varying composition of different energy sources and their implication to the actual end-use energy that a household consumes.

The end-use energy that a household consumes is always less than the total energy that is available from all the physical sources that the household uses. These sources vary in their capacity to deliver what is called useful or end-use energy, depending on the type of fuel, the nature of their use and the available means and technology used to deliver such end-use energy. End use energy is based on the actual energy service that is provided by the total energy used.[14] For example, the end-use efficiency for kerosene that is burned in a wick stove is only about 35 percent because 65 percent of the heat actually escapes around the side of the pan. Similarly, traditional biomass stoves can utilize only 15 percent of the heat energy released from fuelwood, whereas improved stoves can increase that efficiency up to 25 percent. The end-use energy is thus an aggregate of all physical sources after their efficiencies are taken into account.

[14] In the conversion of total energy into end-use energy the following efficiency factors are used: fuelwood 15 percent, straw/leaves 12 percent (traditional stoves), kerosene 15 percent for lighting and 35 percent for cooking, and electricity 95 percent (from O'Sullivan and Barnes, 2006).



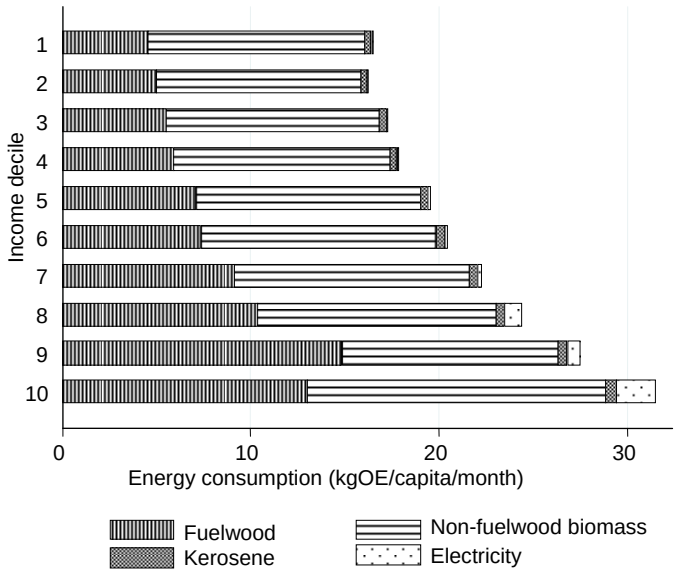
Source: BIDS Survey (2004)

Figure 4: Trend in household's total and end-use energy by income decile

As expected, a household's end-use or useful energy actually is only a fraction of the total energy that the household consumes (Figure 4). For rural Bangladesh roughly only one-seventh of the total energy is converted into useful energy. The gap between total energy and end-use energy also becomes wider as households move from low income to high income status. This is probably because as income grows rural households not only consume more biomass, but also are making a transition from traditional to modern fuels.

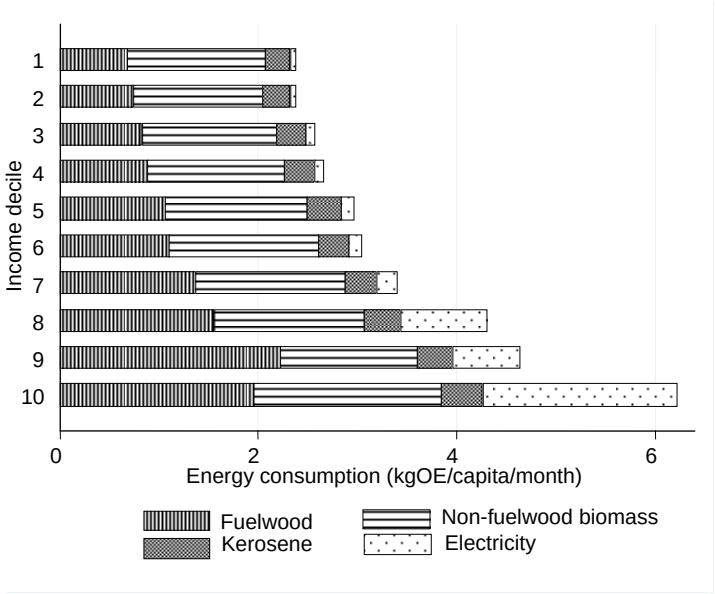
The differences between total and useful energy are further demonstrated in Figures 5 and 6. In the distribution of the total energy, biomass constitutes an overwhelmingly large share of energy use and this pattern is consistent for all households (Figure 5). As household income grows, the amount of total biomass energy per capita used by households increases consistently especially after

the fourth income group. Meanwhile the per capita use of modern energy is quite modest until the highest income group.



Source: BIDS Survey (2004)

Figure 5: Total energy consumption by income



Source: BIDS Survey (2004)

Figure 6: End-use energy consumption by income

For end use or useful energy, the patterns reflect more the actual energy service that is received by consumers. The role of electricity gains prominence due to its higher efficiency. Since electricity is not just the most efficient form of energy sources available to the households, it also provides the widest range of energy services. However, the level of end-use remains fairly constant until the fifth or sixth income categories. The patterns for biomass energy also increase with income, but for useful energy it, for obvious reasons, constitutes a lower percentage of aggregate energy consumption as income goes up.

These differences in patterns of energy consumption for useful versus total energy use are very useful. These comparisons show that total energy use may not be the best measure of energy poverty. Instead, it is the actual energy service that a household receives that matters. As is well known, energy is not purchased as an end in itself, but to provide some kind of service such as

lighting, cooking, cooling and many more. Thus, for the estimation of the energy poverty it makes sense to model the end-use rather than the total energy use. However, for the sake of comparison, the estimates using both the end use and the total energy are presented in the demand equations (shown in Table 4).

The energy demand equation used to predict the total and the end use energy include standard variables such as education, sex of the head of household, village electrification, and land assets of the household. Land assets have been used as a proxy for income since energy affordability is related to income. The presence of electricity in the village is used rather than household electricity also because of the possibility that higher energy use may cause higher income. These explanatory variables are of interest in themselves. For instance, women's education is negatively related to energy use and this would probably mean that they are more aware of the benefits of switching to modern cooking fuels or conserving biomass energy.

The variables of concern for energy poverty are the income decile dummies.[15] These income dummy variables allow us to see the extent to which the use of energy is related to income. For those income levels at which energy is not related to income we assume that people are consuming the minimum energy necessary or less to sustain a minimum quality of life. In fact, at the lower income levels household energy demand is fairly constant. However, at higher income levels there is a quite significant positive relationship between income and energy (compared to the poorest income group). Based on the model, it is not until the 6th income decile that household energy demand responds to the income. As a consequence, energy consumption up to this income decile should be considered the bare minimum that a household needs to maintain a minimum quality of life. The average end-use energy consumption for the households that belong to 5th income decile

[15] Since households' energy consumption affects their income, using households' actual income may yield biased estimates. So we use households' income net of energy contribution (instead of actual income) to construct these income deciles. The net income is calculated by subtracting from the actual income the contribution of energy (estimated from the IV estimates presented in Table 3).

is calculated (2.6 kgOE of useful energy per capita per month) and it is the energy poverty line for rural Bangladesh.

There are several reasons that this approach to determining energy poverty line, called minimum end-use energy (MEE), is an improvement over the other major methods reviewed earlier in this paper (see Table 5 for a comparison of estimates). The problem with the Bravo (Bravo et al 1970) and Goldemberg (Goldemberg 1990) approaches is that, after taking into account energy source by efficiencies and climate conditions, they are difficult to apply to a large numbers of countries with varying social, economic and climatic conditions. For example, energy for heating and cooling is hardly considered a basic need for rural population of Bangladesh but is absolutely necessary in countries with colder climates. The MEE approach does not specify any preset figure as energy poverty line – it is, on the other hand, estimated from energy demand that takes into account a host of factors.

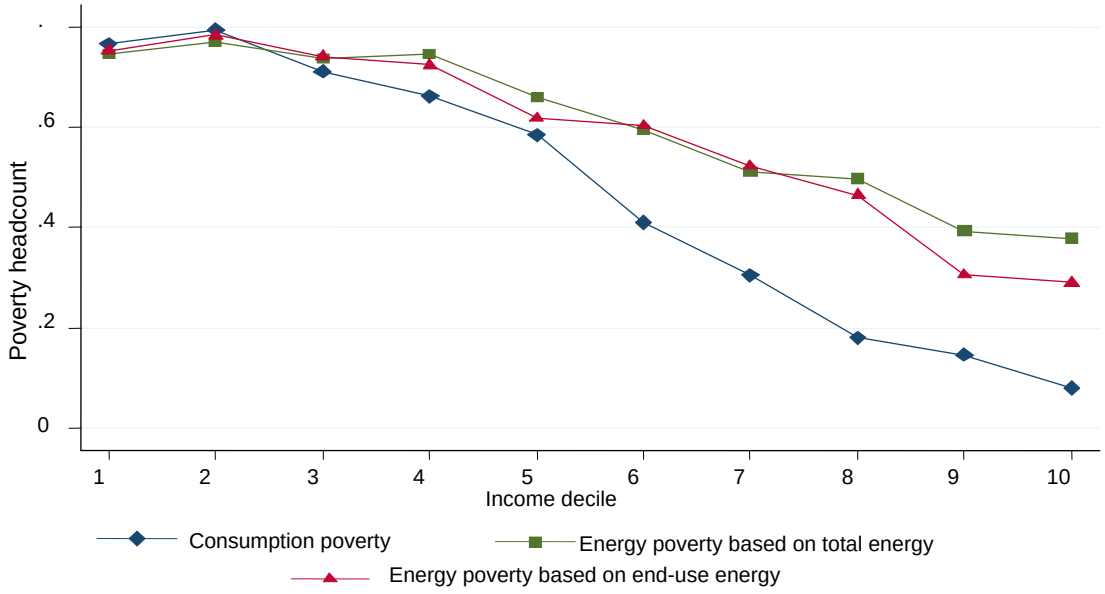
The expenditure-based approach (Pachauri and Spreng 2004) is based only on purchased fuels and may not adequately represent overall demand for biomass energy. Another disadvantage is that the cutoff point is rather arbitrary and inconsistent in quantifying energy content. The expenditure poverty based method has the advantage of including the country context, but the disadvantage is it assumes that the energy poverty follows exactly the same pattern as the expenditure poverty, which may not always hold true. Some non-poor households, based on expenditure poverty measure, may still be energy-poor. At the same time, some expenditure-poor households may not be energy poor perhaps due to the availability of natural resources such as trees from the local environment.

The MEE method is both country-specific and energy-demand-specific because it is based on actual demand for energy by households, after controlling for a wide range of exogenous variables that influence household's energy demand. This method also does not advocate any

arbitrary share of income or expenditure as energy poverty line. Based on our findings, the energy poverty situation paints a grim picture of rural Bangladesh (Table 5). That is, the level of energy poverty is high and even higher than expenditure poverty in rural Bangladesh for almost all measures. Whereas the consumption poverty is 44.8 percent in rural Bangladesh, MEE estimate shows that energy poor households constitute 58 percent of the rural population based on end-use energy and 60 percent based on total energy. [16] This finding implies that a good number of expenditure non-poor households do not consume the required minimum energy.

To further compare the trends of the two energy poverty lines, they are plotted against the income deciles of the households, as shown in Figure 7 which also shows the changes in consumption poverty. Poverty decreases with an increase in income. However, the rate of such decrease is not same for all poverty measures. More precisely, a decrease in the consumption poverty is not followed by a proportionate decrease in the energy poverty measures. That is why we observe a significant share of energy poor (about 30 percent) among the highest income-decile households who have a consumption poverty of about 8 percent. The trends in the two energy poverty measures are about the same except for the highest two income deciles which show a gap between the two, that is, more households are energy poor based on the total energy than based on the end-use energy. The gap is indicative of a high degree of inefficiency in the energy consumption of rural households.

[16] Consumption poverty has two components: food and nonfood. The poverty line expenditure for food is the cost of a specific food basket needed to maintain the per capita daily caloric requirement of 2,120 calories recommended by Food and Agricultural Organization (FAO) and the World Health Organization (WHO) (FAO/WHO 1973). For Bangladesh, the food basket contains mostly rice, and other food items including pulse, milk, meat, fish, fruits, and vegetables in specific quantities. For nonfood poverty line, a 30 percent allowance of the food poverty line is often used.



Source: BIDS Survey (2004)

Figure 7: Household energy poverty and consumption poverty measures by income decile

Why are the two measures of energy poverty almost same even when the end use energy is about one-seventh of the total energy? As we have seen, the end-use energy the households consume depends on two things: the total energy they use and the relative composition of different energy sources in total energy. For the rural households in Bangladesh, this composition does not vary much (except for the wealthy households who use more modern energy, including electricity). That is why the end-use energy for these households has almost a one-to-one relationship to their total energy, and switching between the end-use and total energy does not change the relative energy consumption pattern of one household compared to others. As a result, both measures of energy poverty yield very similar poverty headcounts. However, for a population where relative composition of the energy sources varies among the households, the same total energy may yield

different end-use energy for different households.[17] That is, a household deemed energy poor based on the total energy may not be so based on the end-use energy and vice versa. To resolve this anomaly, end-use energy should be used to determine a household's energy poverty status as end-use energy is after all the true measure of its energy consumption.

7. The energy poor: Who are they?

In the previous section it was established that the income poor are more likely to be energy poor, but the energy poor are not all income poor (Figure 7). In fact, 46 percent of the income non-poor are energy poor in rural Bangladesh, while 81 percent of income poor are also energy poor. If income is not a good predictor of energy poverty, what characterizes then the energy poor? To address this issue, we first take a look at the energy use pattern of households by their poverty status. Based on the level defined by the end-use measure of poverty, the energy non-poor households consume, as expected, more energy from all sources than the energy-poor households (Table 6). Because there is no transition to more efficient forms of energy for cooking, biomass continues to be an important energy form for non-poor households. In fact, they use it almost three times that the poor households do.

However, it is the level of electricity consumption that separates energy poor and non-poor households more than any other sources – non-poor households consume ten times the electricity consumed by the poor households.[18] Overall, the energy poor households consume 1.75 kgOE of useful energy per capita per month, compared to 5.31 kgOE used by the energy non-poor households. Energy consumption pattern by income poverty reveals a similar picture, with an important difference. Income poor households consume more than energy poor households, while

[17] This is a possibility in urban areas where households choose from a much wider range of energy sources and the relative share of the sources can vary a lot across households.
[18] Role of electrification in energy poverty is discussed in the next section.

income non-poor households consume less than energy non-poor households, not just in terms of total energy but also individual sources (except for kerosene which do not vary). This is another indication that there is no one-to-one relationship between energy poverty and income poverty. Question is, how much cooking and lighting needs can possibly be satisfied with the level of energy that the energy poor households consume?

Cooking in rural Bangladesh is done almost exclusively using biomass (mostly fuelwood, sometimes other inferior fuels, for example, leaves, crop residue, etc.). To investigate households' cooking energy need we consider an average rural household – that is, a household that has five members, uses fuelwood in traditional stoves for general purpose cooking, cooks on an average two meals a day, and those meals consist of rice, lentil, and one vegetable regularly, and fish or meat occasionally. The cooking energy need in the form of end-use energy for such a household appears to be 10.66 kgOE.[19] That is more than the biomass energy consumption of energy poor households of rural Bangladesh (8.64 kgOE per month). It thus seems that the energy poor households cook less than what is a normal practice for an average rural household in Bangladesh.

Speaking of the lighting energy need, there are typically two major sources – electricity for those who have it (with kerosene as a backup) and kerosene for those who do not have electricity. Among the energy poor households, those who have electricity consume 29.3 kWh of electricity per month, and those without electricity consume about 0.35 kgOE of end-use energy per month from kerosene, used mostly in wick lamps. For simplicity, we assume that these energy sources are used completely for lighting. The amount of electricity that the energy poor households consume (29.3 kWh) typically provides about 17 hours of lighting per day from a 60w incandescent bulb (which is

[19] This figure is based on a study of 125 households in Nepal, which carefully measured the energy requirements for cooking of main meals in those households (Pokharel, 2004). It assumes that rice, vegetables and lentil are cooked twice a day everyday, while meat or fish is cooked once a week. For an average household of six members cooking in a traditional fuelwood stove the average annual useful energy requirement came out to be 6.664 Giga Joules. For a rural Bangladeshi household (which compares well with a Nepalese household) of five members this translates to 10.66 kgOE/month.

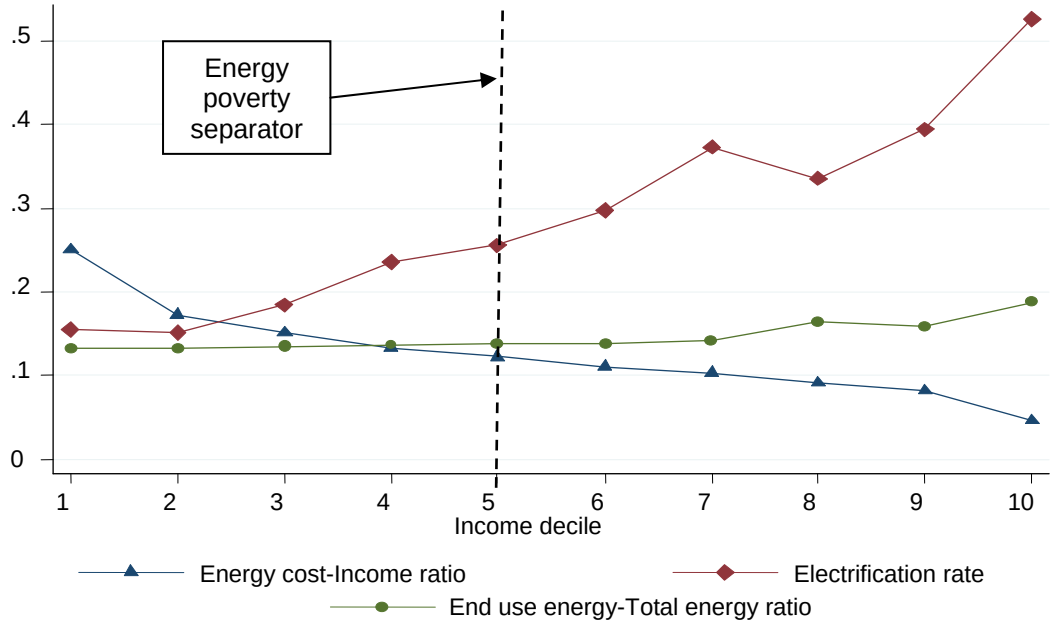
the most common in Bangladesh), or more than 4 hours of evening lighting in 4 rooms (one light bulb in each room). One the other hand, 0.35 kgOE of kerosene can provide about 8.25 hours of lighting per day using a wick lamp, or over 4 hours of lighting in 2 rooms (one lamp serving one room).[20]

Although the duration of 4 hours seems minimally adequate for evening lighting in rural Bangladesh, the question is, is the quality of this lighting good enough? A lighting source should provide, at the very minimum, a visual environment where comfortable movements, seeing one another, and some basic household tasks, for example, cooking, eating, reading etc. can be done. One recommendation for performing these activities is a minimum lighting intensity of 25 lumens/sq. meter (Bhusal and others, 2007). Unfortunately, a wick lamp provides about half of that lighting intensity, while a 60w incandescent bulb provides about 750 lumens/sq. meter. What it means is, energy poor households that are without electricity cannot meet their lighting requirement. So, we can conclude from this discussion that energy poor households, at the very least, cannot meet their cooking energy needs, and furthermore, those without electricity cannot get the lighting quality needed for basic household tasks.

There are other indicators, besides the energy needs for basic cooking and lighting that one can look at in the context of energy poverty. Figure 8 shows the distribution of households in terms of three such indicators by income decile. These indicators are electrification rates, end use-to-total energy ratio, and energy expenditure as percentage of income. Electrification, as we already have seen, is a key to improved lighting. Although electricity access rate increases with income, as expected, it is about 15 percent even among the lowest income decile households. This probably explains why some income poor households are energy nonpoor. The end-use to total energy ratio

[20] This formulation is based on the fact that one liter (or 820 gm) of kerosene releases 0.824 kgOE of energy, which, with 15 percent efficiency of wick lamps, gives out 0.123 kgOE of useful energy. So, 0.35 kgOE of useful energy that the energy poor households consume comes from 2,320.6 gm of kerosene, which a wick lamp (with a kerosene burning rate of 2.6 mg/sec) will take 8.25 hours per day to burn.

which reflects energy efficiency rate is very independent of income: it is flat up to 7th income decile and then slightly increases with income. This indicates that the rural households in Bangladesh mostly use traditional technology for cooking and lighting irrespective of income; only for the highest income households modern energy has a higher share. High income households not only have a higher rate of electrification, but they also diversify their electricity use in a wide range of appliances.



Source: BIDS Survey (2004)

Figure 8: Household electrification, other energy consumption parameters by income decile

The income-energy cost ratio is an established indicator of household welfare. It declines constantly as income rises. Poor households are very constrained and spend on energy only that much which is absolutely necessary. In addition, the types of fuels that are available to them for basic lighting and cooking are used very inefficiently because of the nature of their cooking and lighting devices.

8. Energy poverty and the role of electricity

Maintaining the minimum energy consumption is important no doubt, but it is also vital to understand how the use of modern energy such as electricity or higher levels of energy can bring people out of energy poverty. We reported in the last section that electricity consumption is one key factor in distinguishing between the energy poor and non-poor households. We have also seen in an earlier section that electricity consumption improves income and non-energy consumption, and a small increase in the consumption of electricity can make a big difference in household's wellbeing. The question is how can electrification possibly reduce energy poverty? As shown in Figure 6, higher income households consume more electricity than the lower income ones. With highest end use efficiency among all the fuels, for consumers that use electricity there is very little wasted energy compared to the households that do not have electricity. This means that households can possible have higher levels of energy services at lower prices. Furthermore, once households have electricity they use it in a wide range of appliances, resulting in the consumption of more energy than is used by non-electrified households. For example, even among the energy poor households, those with electricity consume 40 percent more energy and higher levels of energy services (such as lighting) than those who do not have electricity.

Electricity can also help reduce energy poverty. To examine this issue, we examine two simulated scenarios which assume that the electrification rate in the rural Bangladesh is raised to 50 percent or 100 percent from the current rate of 29 percent. We know households with electricity either reduce or eliminate their kerosene use altogether. In the first simulated scenario, 21 percent of the non-electrified households are randomly selected and assigned electrification to make the electrification rate 50 percent, their kerosene consumption is reduced by the difference of kerosene consumption between the current households with and without electricity. Their consumption of electricity also is increased from zero to the average kerosene consumption of the current

households with electricity of similar status. In the second scenario, the same changes are implemented for all households without electricity. Lastly, households' energy consumption in the two simulated scenarios is compared with energy poverty line to determine their energy poverty status. For almost all income deciles, energy poverty goes down consistently as a result of electrification (Table 7), and overall, in the 50% scenario, the energy poverty goes down from the current levels of 58 percent to 52.6 percent and in the 100% scenario it goes down to 41.3 percent. Thus, it appears that given the current consumption practice, as households make the transition toward electrification their energy poverty situation is likely to improve and there is no doubt that this impact will compound as households increase their electricity consumption over time.

Given such benefits on the overall welfare of households, the role of electrification should not be underestimated. It would be very interesting to test other interventions such as improved biomass stoves, renewable energy (for example, biogas systems); however such technologies were not present in enough households during the survey of this study, and so empirically it is impossible to gauge their impact. However, rural electrification in Bangladesh can be far more intensive than it has been. The fact is that 66 percent of the sample villages have electricity and only 44 percent of the households in those villages with electricity have actually grid connection. The welfare benefits would be quite high if the remaining 56 percent of the households in villages that already have electricity are connected. Furthermore, the current use of electricity in rural Bangladesh is mostly for lighting purpose, since it replaces kerosene-based lighting of the previously non-electrified households. As households diversify their electricity use pattern by acquiring various appliances (TV, refrigerator, etc.) it is sure to further improve their energy poverty situation, which in turn will lower their income poverty as well. Of course, there should be policies that encourage expansion of electricity to new villages as well.

9. Energy poverty and carbon emissions

Since the bulk of the energy needs of the rural households in Bangladesh are currently met and continue to be met in the foreseeable future by biomass regardless of their electrification status, one issue that still remains is whether biomass energy can be used more efficiently in rural Bangladesh and how this might be related to energy poverty and carbon emission—an indicator of social cost of energy use practice with implications to climate change. So far we talked about the private rates of returns and costs associated with energy consumption and access to electricity. There are also social costs of energy poverty.

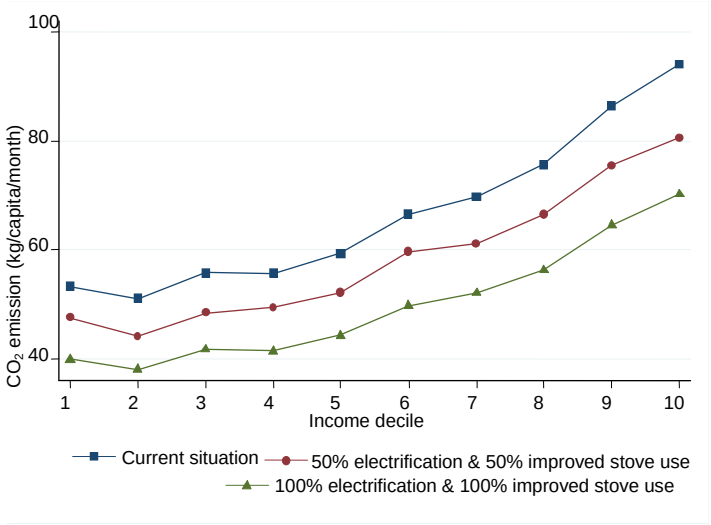
Worldwide about 2.5 billion people today rely on biomass energy. Also about 50 percent of the people in developing countries—and more than 90 percent of the rural residents in many countries—use biomass energy, including wood, dung, and agricultural residue, as their main cooking and heating fuel. Altogether, in developing countries about 730 million tons of biomass is burned every year (WHO 2006). This amounts to over 1 billion tons of CO_2 emitted into the atmosphere, which accounts for about 5 percent of the global CO_2 emissions (Yevich and Logan 2003). In addition, incomplete combustion of other products also has large greenhouse-gas (GHG) impacts. For lighting alone, about 11.5 million tons of kerosene is burned every year in the developing countries, mostly in lamps made of a tin container and a wick. That way, kerosene is very inefficiently burned and because of incomplete combustion it actually produces other greenhouse gases which stay in the atmosphere for decades (WHO 2006; Smith 2000). In spite of this, the role of household energy is often ignored in the discussions of climate change. As a result, a considerable amount of energy consumed by households worldwide is ignored or only given token recognition. In this section, we explore the climate implications of household energy in rural Bangladesh.

The situation in Bangladesh is similar to those of the other developing countries. The two major energy sources of the rural households in Bangladesh are biomass and kerosene, and their burning also emits significant levels of greenhouse gases, the most important one being CO_2. By switching from traditional to modern energy or by adopting energy efficient ways to burn biomass, households have the potential to reduce CO_2 emission. For example, it is well known that households with electricity are to consume less kerosene. In fact, the survey results for Bangladesh show that the households with electricity consume one liter less of kerosene per month than those without electricity. Such a reduction in kerosene consumption would lead to a reduction of CO_2 emission.[21] Secondly, the adoption of improved stoves enables the households to use less biomass to get the same energy content. To be precise, households burn 40 percent less biomass if they switch from traditional stoves (which are 15 percent efficient) to improved ones (which are 25 percent efficient). Again, less biomass burning can lead to a lower CO_2 emission.[22] In this section, we incorporate these changes into two simulated scenarios to investigate how they can affect both CO_2 emission and energy poverty.[23]

For the first simulation, we assume an increased electrification rate of 50 percent and adoption of improved stoves by 50 percent of the biomass using households. For the second scenario, we assume that 100 percent of the rural households in Bangladesh adopt electricity and all biomass users cook with improved stoves. In both scenarios we assume that households with improved stoves consume 25 percent less biomass than those with traditional stoves.

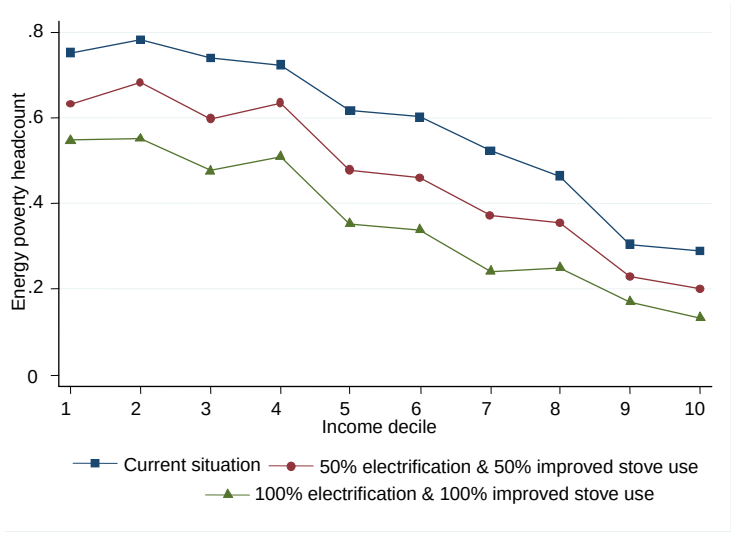
[21] Burning of one liter of kerosene can emit 2.8 kg of CO_2. However, it is also important to note that the use of electricity also results in CO_2 emissions at the site of its generation.
[22] Burning of one kg of biomass can emit approximately1.2 kg of CO_2.depending on how it is burned.
[23] Actually, there are other greenhouse gases (such as methane) emitted by cooking fire, but in this study we will only deal with CO_2 emissions.

These scenarios and corresponding CO_2 emission patterns are shown in Figure 9. As expected, there is an order of magnitude decline in CO_2 emission from the current situation to the first scenario and then to the second scenario. When all rural households in Bangladesh



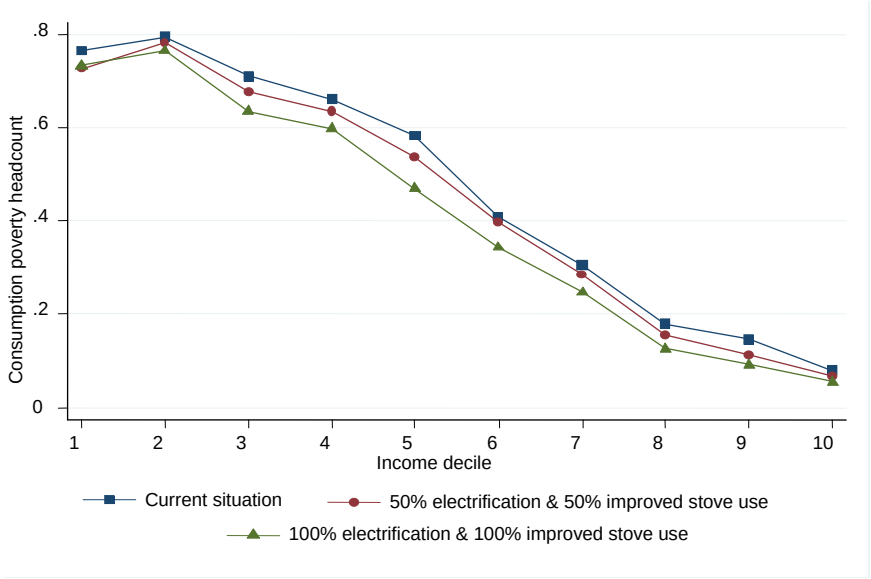
Source: BIDS Survey (2004)

Figure 9: CO_2 emission in various energy efficiency scenarios by income decile



Source: BIDS Survey (2004)

Figure 10: Energy poverty in different electrification and energy efficiency



Source: BIDS Survey (2004)

Figure 11: Consumption poverty in various energy efficiency and electrification scenarios by income decile

have electricity and all biomass users adopt improved stoves (second scenario) their CO_2 emission goes down by about 25 percent. In all cases including the current, case CO_2 emissions actually go up with rising income regardless of the scenario. For example, per capita monthly CO_2 emission goes up from 52 kg per month to almost 95 kg per month as households move from the lowest income decile to the highest one (current scenario). This is because high income households consume more energy (that means more biomass) than the low income ones, and this leads to more emission. Since higher income households use more energy, they can play more important role in lowering carbon emission than the poor households by transitioning to cleaner fuels or lowering biomass use.

The next question is how do these two simulated scenarios impact the energy poverty and consumption poverty situations? The same scenarios were used to estimate the effects on energy poverty and consumption poverty. Similar to the trend in CO_2 emissions, there is a consistent decline in the energy poverty with the adoption of more modern energy sources (Figure 10). Overall, energy poverty falls more than 22 percentage points from the current situation to the second simulated scenario. As might be expected, the drop in energy poverty is slower for the lower income households and steeper for the higher income households. The reduction of consumption poverty has been calculated from the impacts of electricity and biomass consumption as reported in Table 3. Although reduction in consumption poverty seems smaller than that in energy poverty, it is nevertheless consistent, and low and middle income households seem to benefit more than high income households.[24] These scenarios of the adoption of electricity and improved stoves do not include any spin off or compounding impacts such as improved income, education, or other factors

[24] That is expected as majority of high income households are already consumption non-poor and many of them have electricity too.

that might develop over time, but they do demonstrate the importance of both biomass energy and electricity in the energy poverty in rural Bangladesh.

The evidence is fairly clear that the adoption of efficient stoves or access to electricity or cleaner burning cooking fuels can play an important role in reducing energy and consumption poverty and the emissions that contribute to the climate change. The results are actually quite encouraging, because for Bangladesh moving to a rural electrification rate of 50 percent and a 50 percent adoption rate of high quality improved stoves is quite achievable and would save about 10 million metric tons of CO_2 per year from being emitted into the atmosphere.[25] Although this amounts to a small greenhouse gas reduction in the global picture, the point is clear that the reduction in the energy poverty in rural Bangladesh and presumably in other countries actually can be a climate-friendly policy due to the transition to more modern forms of cooking and lighting.

10. Conclusion

The concept of energy poverty is important for several reasons. For those interested in energy policies and their impact on development, the use of an energy poverty indicator can signify how well or how poorly a country is doing in meeting the basic energy needs of its poorest households. This can help track the impact of a wide variety of energy programs including sector reforms, electricity generation projects, and promotion of high quality cooking fuels. However, the energy poverty situation in a country is but one indicator of the overall household welfare. Energy interventions obviously are more effective when they are complemented by other infrastructure improvements.

Understanding the basic need for energy can also be very useful in prioritizing energy policies and investments that can help the poor attain higher levels of welfare. As an example,

[25] This is based on a CO_2 emission savings of 6.7 kg per capita per month (from Table 8) for a rural population of 120 million.

households that use electricity for lighting and other tasks have a huge advantage over other households because of the brighter lighting that is possible with electricity. The use of electricity improves income and expenditures by a level that is much higher than its cost, not to mention its role in the reduction of energy poverty. Similarly, the use of higher levels of energy including biomass for cooking also would lead to significant improvements in household welfare and this might be accomplished through the implementation of programs involving improved stove, biogas, LPG in rural areas.

One particular concern today is that all the attention paid to climate change and possible increases in the price of cleaner energy may turn attention away from the energy poverty and thus make it more difficult for poor countries to grow and prosper. A more direct approach that deals with both the demand side issues and the energy transition might be a better way to deal with the climate change and poverty issues. However, as of now it has been very difficult for the energy poor to gain access to the carbon credits available for alleviating climate change. This is unfortunate because the findings of this study indicate that CO_2 emissions will actually decrease as households adopt more efficient appliances for cooking and lighting. A more concerted effort to help the poor use fuels in more efficient and more sustainable ways may be the key to both poverty alleviation and climate friendly economic growth.

There still is further research necessary for urban areas and other countries to see whether MEE is a general method for energy poverty estimation that can be applied to those situations. Nevertheless, the MEE approach advocated in this paper has the advantage of modeling energy poverty through estimating energy consumption based on household and community characteristics. The main findings of this study are that households in rural Bangladesh do indeed have a minimum need for energy services and unfortunately about 58 percent of the rural population can be considered energy poor. The good news is that there are ways to ease the conditions faced by the

energy poor that improve their quality of life and also result in emission reductions that are climate friendly.

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Tables

Table 1: Monthly household energy use in rural Bangladesh (N=2,388)

Energy source	% House-holds using the source	Energy use[1]	Energy cost (Tk)	Price paid per unit[2]	Share of total energy (content)	Share of total energy (expenditure)
Fuelwood	84.3	37.14	169.73	4.57	38.81	36.80
Biomass excluding fuelwood	15.2	53.01	171.13	3.23	55.38	37.11
Kerosene	97.2	1.98	54.76	27.66	2.07	11.87
Grid electricity	29.0	25.72	47.09	1.83	2.27	10.21
Other sources	70.6	1.41	18.48	13.11	1.47	4.01
All energy sources	100.0	95.71	461.19	4.82	100.00	100.00

[1]Energy used is expressed in kgOE for all sources except for grid electricity which is expressed in kWh.

[2]Price paid is Tk./kgOE for all sources except for grid electricity for which it is Tk/kWh..

Note: Household's non-fuelwood biomass includes leaves, crop residue, dung and saw dust , other sources include candle, dry cell, LPG/LNG and natural gas (very little).

Source: BIDS Survey (2004).

Table 2: Tobit estimate of household's monthly per capita energy demand

Explanatory variables	Log biomass energy (kgOE)	Log kerosene energy (kgOE)	Log grid electricity energy (kWh)	Log total energy (kgOE)	Mean of control variables
Age of HH head (years)	-0.002 (-3.22)	0.001 (1.55)	0.0004 (0.66)	-0.002 (-2.14)	43.21 (13.99)
Sex of HH head (M=1, F=0)	-0.051 (-1.03)	0.074 (2.05)	-0.059 (-1.71)	-0.050 (-0.90)	0.92 (0.28)
Highest education among HH males (years)	-0.002 (-0.63)	0.006 (2.37)	0.011 (4.37)	-0.001 (-0.43)	5.02 (4.17)
Highest education among HH females (years)	-0.019 (-4.24)	0.001 (0.25)	0.010 (3.59)	-0.016 (-4.67)	4.53 (3.5)
Log HH land asset (decimals)	0.037 (4.62)	0.027 (5.20)	0.009 (1.80)	0.038 (3.24)	125.12 (222.25)
Log HH non-land asset (Tk.)	0.017 (3.78)	0.007 (1.99)	0.010 (3.50)	0.016 (3.01)	16,756.61 (55,463.36)
Log price of fuelwood (Tk./kg)	-0.337 (-9.99)	0.039 (1.15)	0.048 (1.81)	-0.279 (-3.07)	1.65 (0.68)
Log price of kerosene (Tk./liter)	0.110 (0.68)	-0.328 (-3.17)	0.009 (0.08)	0.009 (0.03)	22.94 (2.73)
If the village has electricity	0.036 (1.59)	-0.193 (-9.19)	0.204 (8.36)	0.003 (0.06)	0.66 (0.47)
R^2 (pseudo R^2)	0.157	0.187	0.191	0.264	
Observations	2,388				

Note: Figures in parentheses are t-statistics (based on boostrapped standard error) except for the last column where they are standard deviations. Explanatory variables additionally include village level prices of consumer goods, village wage of male, female and child, village infrastructure variables, and regional dummy variable. respectively

Source: BIDS Survey (2004).

Table 3: Impacts of energy use on household welfare outcomes by source (N=2,388)

Panel I: **Energy use variables**	**2-SLS IV estimates**			
	Log of per capita monthly measures (Tk.)			
	Non-energy expenditure	**Farm income**	**Nonfarm income**	**Total income**
Log biomass energy (kgOE/month)	0.051	0.235	-0.562	-0.515
	(1.43)	(2.01)	(-0.99)	(-1.12)
Log kerosene energy (kgOE/month)	0.050	-0.107	-0.675	-0.312
	(0.71)	(-0.61)	(-1.56)	(-1.10)
Log grid electricity energy (kWh/month)	0.043	-0.313	0.085	0.034
	(2.316)	(-0.96)	(2.55)	(2.18)
Adjusted R^2	0.223	0.249	0.148	0.262
	Marginal return on energy use			
Panel II	**Monthly expenditure (Tk.)**	**Monthly farm income (Tk.)**	**Monthly nonfarm income (Tk.)**	**Monthly total income (Tk.)**
Biomass energy (1 kgOE/month)	0	6.04	0	0
Kerosene energy (1 kgOE/month)	0	0	0	0
Grid electricity energy (1 kWh/month)	6.17	0	9.76	7.05
Mean of outcome variables (per capita Tk./month)	737.78	462.14	591.61	1,053.75
	(397.25)	(534.63)	(924.10)	(1,064.61)

Note: Figures in parentheses are t-statistics except for the last row where they are standard deviations. Explanatory variables additionally include village level prices of consumer goods, infrastructure variables, wages of male, female and child and regional dummies.

Source: BIDS Survey (2004).

Table 4: OLS estimates of household's energy demand (kgOE/capita/month) (N=2,388)

Explanatory variables	**Total energy consumption (kgOE per capita /month)**	**End-use energy consumption (kgOE per capita/month)**
Age of HH head (years)	-0.024 (-0.85)	0.004 (0.47)
Sex of HH head (M=1, F=0)	-3.293 (-0.99)	-0.326 (-0.71)
Highest education among HH males (years)	-0.025 (-0.26)	0.014 (0.67)
Highest education among HH females (years)	-0.644 (-4.16)	-0.076 (-1.31)
Log of HH landholding (decimals)	0.455 (0.97)	0.111 (1.22)
Log of HH non-land asset (Tk.)	0.220 (1.41)	0.073 (2.20)
Log price of fuelwood (Tk./kg)	-6.102 (-1.97)	-1.180 (-2.29)
Log price of kerosene (Tk./liter)	9.959 (0.97)	1.543 (0.97)
If the village has electricity	0.754 (0.47)	0.420 (1.53)
HH is in 2nd income decile	**0.162 (0.08)**	**0.250 (0.71)**
HH is in 3rd income decile	**0.043 (0.02)**	**0.070 (0.26)**
HH is in 4th income decile	**1.153 (0.55)**	**0.388 (1.13)**
HH is in 5th income decile	**1.680 (0.75)**	**0.596 (1.40)**
HH is in 6th income decile	**3.907(1.71)**	**0.661 (2.08)**
HH is in 7th income decile	**3.768 (1.65)**	**0.489 (1.68)**
HH is in 8th income decile	**6.242 (2.47)**	**1.123 (2.44)**
HH is in 9th income decile	**7.690 (2.80)**	**1.246 (2.95)**
HH is in 10th income decile	**12.810 (3.54)**	**2.805 (3.13)**
Adjusted R^2	0.204	0.074

Note: Figures in parentheses are t-statistics (standard error clustered at village level). Excluded category in the income decile dummies is the 1st decile. Explanatory variables additionally include village level prices of consumer goods, infrastructure variables, wages of male, female and child and regional dummies.

Source: BIDS Survey (2004).

Table 5: Incidence of energy poor and expenditure poor households

Poverty measures	Poverty line (per capita per month)	Poverty headcount
Expenditure poverty (Tk.)*	701.0	44.8
Energy poverty		
Expenditure-based measure (10-percent) (Tk.)	83.6	41.6
Bravo measure (kgOE)	27.4	79.1
Goldemberg measure (kgOE)	32.1	85.2
Expenditure poverty-based measure (kgOE)	19.2	58.5
Minimum Total Energy based measure (kgOE)	19.1	60.3
Minimum End-use Energy based measure (MEE) (kgOE)	2.6	58.0

Source: BIDS Survey (2004).

Table 6: Energy use pattern of energy-poor and non-poor households (N=2,388)

Per capita energy consumption per month	Energy poor HHs	Energy non-poor HHs	Income poor HHs	Income non-poor HHs
Biomass (kgOE)	1.60	4.31	1.92	3.34
Kerosene (kgOE)	0.06	0.08	0.06	0.08
Grid electricity (kWh)	1.04	10.85	1.77	7.68
All energy sources (kgOE)	1.75	5.31	2.22	4.07

Note: Energy variables are expressed in terms of end-use energy.

Source: BIDS Survey (2004).

Table 7: Energy poverty in various electrification scenarios (N=2,388)

Income decile	Current situation (electrification rate=29 percent)	Simulated scenario 1 (electrification rate=50 percent)	Simulated scenario 2 (electrification rate=100 percent)
1	0.753	0.745	0.717
2	0.782	0.766	0.720
3	0.741	0.724	0.632
4	0.724	0.707	0.669
5	0.618	0.580	0.487
6	0.603	0.552	0.469
7	0.523	0.456	0.301
8	0.464	0.431	0.339
9	0.305	0.276	0.243
10	0.290	0.256	0.155
Overall	0.580	0.526	0.413

Source: BIDS Survey (2004).

Table 8: Energy poverty and CO_2 emission in various scenarios (N=2,388)

Alternate scenarios	CO_2 emission (kg/per capita/month)	Energy poverty based on efficient energy
Current situation	58.9	0.580
Simulated scenario 1	52.2	0.465
Simulated scenario 2	44.0	0.358

Source: BIDS Survey (2004).