Doctoral Thesis

Characteristics of energy access to the poor and to impoverished regions in India

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CHARACTERISTICS OF ENERGY ACCESS TO THE POOR 
AND TO IMPOVERISHED REGIONS IN INDIA 

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zur Erlangung des Titels 

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Preface

Although there is a recognised link between poverty and energy access and consumption, the nature of this link is still not fully understood. The aim of this dissertation is to provide additional empirical evidence for the relationship between household energy consumption patterns and standards of living and to identify the causes for regional disparities in electrification. Knowing the determinants of use and access may help in finding new strategies to improve the situation of energy-poor households.

My intention was not to write a "classical" dissertation, that is, a dissertation that examines one comprehensive research question in one all-encompassing monograph. Instead, the monograph is based primarily on three articles in scientific journals:


At this point I would like to thank all those who were involved with my work in some way and who supported me during my time at CEPE. First of all, I would like to thank my supervisor Prof. Daniel Spreng for his motivation and for sharing his experience, knowledge, and friendly encouragement. Many thanks also to Prof. Lucas Bretschger, who generously assumed the function of supervisor during the last year. I would also like to thank all the members of CEPE, especially Markus Balmer, Kaushik Deb, Mehdi Farsi, Aurelio Fetz, David Goldblatt, Adrian Müller and Shonali Pachauri for their fruitful discussions, assistance with technical and statistical questions, editing of my English, and shared coffee breaks.
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Zusammenfassung


Andere Faktoren als das Einkommen, insbesondere die Anschlussdichte innerhalb der Dörfer und die schulische Bildung der Haushaltsmitglieder scheinen wichtiger zu sein für die Haushaltslelektrifizierung. Gemäss dem Modell wäre es zudem wirkungsvoller die Versorgungsqualität zu verbessern, als den Stromverbrauch zu subventionieren. Der Effekt des subventionierten Stromtarifs auf die Haushaltsentscheidung ist gering und von den undifferenzierten Subventionen profitieren vorwiegend jene, welche bereits einen Haushaltsanschluss haben, aber kaum die Bedürftigsten, die noch über keinen Anschluss verfügen. Ausserhalb der elektrifizierten Dörfer, aber auch in gewissen Quartieren der elektrifizierten Dörfer, scheint es für viele Haushalte noch keine Möglichkeit zu geben, ihr Haus an ein Stromnetz anzuschliessen.
Summary

A recent analysis of poverty in India suggests that 20 to 30 percent of the country’s population still lives in poverty. Many of these poor have neither the access nor the means to meet their basic energy needs. Their level of poverty is reflected in their energy consumption patterns, which show low consumption; a lack of access to clean commercial fuels, efficient equipment, and electricity; and a high dependence on traditional biomass.

We constructed a novel, two-dimensional measure of energy poverty and distribution that links information on access to different energy carriers and quantity of energy consumed per capita. Applying this measure to the data furnished by the Indian NSSO for the years 1983 through 2000, we observe a rapidly developing sub-continent. The proportion of people living in desperately energy-poor households (that is, those who have access only to biomass and kerosene and use barely enough of it to cook one full meal per day) decreased from 38% to 14% of the population, whereas the proportion of people living in households with access to electricity (and possibly LPG) and who use more energy than the quantity necessary to cook two full meals per day increased from 3.5% to 35%.

While this analysis indicates a significant reduction in energy poverty in India, energy poverty is still widely prevalent, particularly in rural areas of the country. Indeed, between 1983 and 2000 there was only a 5% reduction in the total number of people in the lower consumption segments (from 545 million to 516 million).

Because energy plays such a pervasive role in modern life, its measurement in various dimensions can accurately reflect important aspects of the reality of the poor. By comparing energy measures with various poverty and welfare measures, we show that energy indicators can be used as a general reflection of personal well-being. For instance, higher access-adjusted useful energy deciles show characteristics of higher development: individuals therein have higher levels of education, better sanitation facilities, and greater access to tap water; their houses are in better condition; and they have a higher daily caloric intake. For this reason, energy measures may form a practical basis for a proxy indicator of poverty, as the use of energy indicators is not restricted to environmental and economical issues but is significant for social issues as well. Although energy development is closely related to measures that focus on basic human needs, a single energy-based indicator cannot grasp the multidimensional quality of poverty. Energy is a factor in fulfilling each of these needs, but the extent of these needs is not completely captured by measuring energy poverty alone. Therefore, while access-adjusted useful energy correlates fairly well with most of the analysed poverty dimensions, it is only a rough approximation for poverty.

The relationship between energy and poverty, however, is a reciprocal one. Improving the poor’s access to modern energy sources can make an important difference to their welfare and can be a catalyst for human development: specifically, electricity may be an important trigger for development.
Yet, there are still about 450 million people in India without access to electricity. In this way, one observes remarkable regional differences in the electrification rate.

These observed regional disparities in electrification can be explained by a combination of factors that influence both village and household electrification. While the geographic endowment of a region was found to be relevant for village electrification, this was not the case for household electrification. A panel data analysis shows further that having a high proportion of agricultural area has a positive effect on a village’s electrification rate, while an unfavourable settlement structure and a large state area constrain its electrification rate. In particular, the existence of small but numerous villages seems to correspond to areas with lower village electrification rates. However, geographic factors merely influence the speed of erection of the regional infrastructure and act temporally as a sorting mechanism. They seem not to affect electrification rates within the villages, as they do not change the utility of electricity use.

A binary response model was employed to analyse the factors which influence a household’s decision to access electricity. Even though economically-poor areas and areas with low household electrification largely coincide, the analysis shows only a limited effect of expenditure on the household decision. Indeed, an increase in expenditure alone would hardly improve the low household access rates, although a higher overall household expenditure in a region might increase the incentive for the state utilities to expand grid infrastructure to that area (in other words, there is a positive effect of per capita SDP on village electrification). Factors other than expenditure, particularly community electrification rates and education levels of household members, are probably more relevant for determining the household electrification rate. Furthermore, the model suggests that electrification is better furthered by improving supply quality rather than by subsidising electricity consumption by a non-cost-effective tariff. The influence of the present electricity tariffs on household decisions to use electricity is small, with the undifferentiated subsidies benefiting those who are already connected to the grid rather than those who are still seeking a connection. Unfortunately, access to electricity still seems hardly a given in the hamlets surrounding the outskirts of villages, even those in regions noted for their high village electrification rates.
1. Introduction

Despite rapid and on-going economic growth in India, a recent analysis of poverty within the country suggests that 20 to 30 percent of the Indian population still lives in poverty and that the problem is more acute in rural areas of the country. Many of these poor have neither the access nor the means to meet their basic energy needs. Their level of poverty is reflected in their energy consumption patterns, which are characterised by low consumption; a lack of access to clean commercial fuels, efficient equipment, and electricity; and a high dependence on traditional biomass, which is burned primarily in inefficient and polluting stoves (WHO, 2006). However, the relationship between energy and poverty is bi-directional, and there is increasing recognition of the importance of the provision of clean and reliable energy for poverty alleviation. Improving the poor’s access to modern energy carriers can make an important difference to their welfare and can be a catalyst for human development (World Bank, 2000a). Although energy is not among the indicators proposed by the UN within the Millennium Development Project, access to energy services was acknowledged therein to be an essential element of sustainable development. Additionally, recommendations offered at the 2002 Johannesburg Summit included the following: “To implement the goal accepted by the international community to halve the proportion of people living on less than US$1 per day by 2015, access to affordable energy services is a prerequisite” (CSD9, 2002).

Indeed, electricity can be considered a particularly important trigger for development, as it provides lighting, motive power, and access to mass media and telecommunications and may even permit the cooling of rooms and preservation of edibles. However, there are still about 1.5 - 2 billion people in developing countries without access to electricity and 450 million such individuals in India alone. Despite a striking increase in power generation capabilities, India has been unable to keep up with its domestic demand for electricity, and primarily rural areas show low household electrification rates. Poverty maps additionally reveal that areas of low electrification largely coincide with areas of high economic poverty and low literacy rates.

Although the link between energy and poverty is generally recognised, its nature is still not fully understood. This dissertation aims to explore empirically the relationship between household energy consumption patterns and standards of living and to identify causes for regional disparities in electrification. It is hoped that this will aid in defining what energy poverty means and how it is related to other poverty dimensions. Indeed, a better knowledge of the determinants of energy use and access may help in finding new strategies to improve the situation for energy-poor households. The following is a detailed description of the structure of the dissertation as well as the purposes it serves:
• First, a short overview of different approaches for defining and measuring poverty in general is provided, and traditional approaches for measuring energy poverty are described. The first section also includes a description of the main data source employed in the dissertation.

• Second, a novel two-dimensional indicator of energy poverty and distribution, the energy access-consumption matrix, is introduced. This energy access-consumption matrix is then applied to assess the evolution of energy poverty and distribution in India. Because the measurement of energy in its various dimensions can reflect important aspects of the reality of the poor in a dynamic and accurate way, this measure might be a good complement to the conventional income-based measures of poverty commonly in use.

• The third purpose is to provide an analysis of the relationship between energy poverty and other poverty dimensions and to determine to what extent energy indicators can be used as a reflection of the general level of individual well-being. By exploring the accuracy and reliability of energy poverty indicators for measuring general poverty, it can be shown that the use of energy indicators is not restricted to environmental and economic issues but is significant for social issues as well.

• The fourth purpose of this work is to apply the energy access-consumption matrix. As energy indicators are reliable measures of poverty and equity, they qualify for measuring relevant topics in all three sustainability dimensions. I introduce the idea of using the energy system as a framework for linking a small set of lead indicators which can be consistently projected forward in time. I suggest such a set, employ it to illustrate the development of India over the past twenty years, and offer a possible projection into the year 2025.

• The fifth purpose of this dissertation is to investigate the causes both for spatial disparities in electrification rates and in energy poverty. As will be demonstrated in the ensuing pages, access to electricity plays an important role in defining and measuring energy poverty. Although electrification is an important development goal in India, a large share of the rural population still lacks access to electricity. As a result, one observes remarkable regional disparities in electrification: the rate of electrified households is highly variable.

Parts of chapter 2 and the entirety of chapter 3 are based on an article by Pachauri, Müller, Kemmler and Spreng (2004), published in World Development. Chapters 4 and 5 are indebted to an article by Kemmler and Spreng (2007), published in Energy Policy. Chapter 6 relies on CEPE working paper No.51, (Kemmler, 2006).
2. **Poverty and Energy**

2.1. **Poverty: concepts and measurement**

Reliable methods for determining which individuals can be construed as poor are needed in order to monitor development and identify people eligible for assistance. To this end, one first has to clarify what is meant by “poverty”. Additionally, the concepts of poverty and their measurement are closely related. On one hand, the concept determines the selection of the indicators to be employed; on the other hand, the measurement aids in understanding what poverty means and rendering the concept operational.

2.1.1. **Traditional approaches and measures**

Traditionally, it was assumed that an individual’s material standard of living largely determined his or her well-being. The poor are defined as those with a material standard of living below the poverty line, as measured by expenditure or income (Atkinson, 1987; Kumar et al., 1996). Because a large share of the households in developing countries depends on a barter economy and self-sufficiency, there is a strong preference toward using household consumption (expenditure) rather than income in these cases. Two main approaches for constructing a poverty line can be distinguished: an absolute and a relative approach. The absolute definition of poverty assumes that it is possible to define a minimum standard of living based on an individual’s basic physiological needs. This approach enables the identification of people who cannot purchase a fixed amount of basic goods and thus can be considered to be living in absolute poverty. In India, for instance, the poverty line is derived using the amount of money necessary for a minimal food consumption of 2400 kcal in rural areas and 2100 kcal in urban areas, respectively\(^1\). The relative poverty approach on the other hand defines poverty in relation to a broadly-accepted standard of living at a specific time and place. This approach allows for the identification of those who are excluded from enjoying a certain lifestyle and is a logical choice when considering countries in which absolute deprivation is not the social norm. Otherwise, relative poverty lines in countries with high absolute poverty have the advantage of permitting a focus on the poorest of the poor (Falkingham and Namzie, 2001).

In economic literature, poverty measures are described as special cases of social welfare measures that are designed both to count the poor and to diagnose the extent and distribution of poverty (Deaton, ...

\(^1\) An example of another frequently-used measure is an income of less than $1 per day and per capita, e.g. in the UN Millennium Development Goals framework.
What separates the social welfare literature from the poverty literature in terms of measurement is the latter’s having a poverty line below which people are defined as poor. The most commonly-applied measure of the incidence of poverty is the head count ratio, which is the fraction of people who live below the poverty line. The head count ratio is determined by the chosen poverty line and the actual welfare distribution. One weakness of the head count ratio is that it neglects to measure the degree of poverty. For example, the head count ratio would be unaffected by, and thus not reflect, a policy which makes the poor even poorer. Therefore, analysts often complement the head count ratio with the poverty gap measure. The poverty gap can be interpreted as the mean distance separating the population from the poverty line, with the non-poor being given a distance of zero. In other words, “It is the sum of all the shortfalls divided by the population and expressed as a ratio of the poverty line itself” (Deaton, 1996). Thus, it is a measure of the depth of poverty, capturing the resources that would be needed to lift all the poor out of poverty through perfectly-targeted cash transfers. These two poverty indices are part of a larger family of poverty measures known as the FGT measures of consumption poverty (Foster, Greer and Thorbecke, 1984). A third commonly-applied FGT measure is the squared poverty gap index, which is utilized to express the severity of poverty. It measures the squared shortfall between an individual’s level of consumption and the poverty line; the shortfall is squared for the purpose of putting a greater weight on the poorer individuals. The FGT poverty indices ($P_a$) can be expressed by the general formula:

$$P_a = \frac{1}{N} \sum_{i=1}^{q} \left( \frac{z - y_i}{z} \right)^a$$

where $y_i$ is the consumption/income of person/household $i$, $z$ is the poverty line, $q$ is the number of persons/households below the poverty line, and $a$ is a non-negative parameter reflecting the aversion to poverty. The variable $a$ differs according to the poverty measure employed: in the case of the head count ratio, $a = 0$; in the poverty gap ratio, $a = 1$; and normally $a = 2$ in the squared poverty gap index.

The traditional concept and its measures of poverty exhibit several practical limitations. First, the setting of the poverty line is largely arbitrary. For instance, the minimum adequate calorie level is itself subject to debate, and interstate variations in price levels are not taken into account. Furthermore, the accurate quantification of household income or expenditure is difficult and costly, see e.g. (Lanjouw and Ravaillon, 1995). Indeed, it is widely acknowledged that income data are often subject to problems of underreporting (Saith and Harriss-White, 2000). Other problems are recall biases (Falkingham and Namzie, 2001); recall period (Sundaram and Tendulkar, 2001; Pradhan, 2001); the valuing of home production and home-grown foodstuffs; deriving the use value of other goods and services; defining accurate deflators for inter-temporal comparisons; the conversion of local expenditure units into a common money metric, especially in environments with large relative price differences; and the economies of household scale (Lanjouw and Ravaillon, 1995; Meenakashi and Ray, 2002). Considering this array of difficulties, it is not surprising that estimates as to the precise
extent of poverty in India differ among authors. See Datt et al., (2003), Sundaram and Tendulkar (2003) and Datt and Ravallion (2002) for a discussion of the recent debate over the extent of poverty reduction in India during the 1990s.

2.1.2. New approaches and measures

Estimating income and expenditure is not only difficult but also insufficient for our purposes: theoretical considerations show that monetary measures express poverty too narrowly, as they fail to capture other important aspects of individual well-being. Over the years, poverty has evolved into a multidimensional concept in order both to overcome some of the deficiencies of purely money-based indicators and to enrich the information set, so that nowadays a plurality of well-being dimensions and poverty concepts is considered. For instance, it is now generally accepted that poverty is associated with deprivation. Deprivation can be thought of in terms of constraints on people’s choices to access certain material goods, assets, capabilities, freedoms, and opportunities. Thus, the elimination of poverty is generally associated with fulfilling the fundamental or basic needs of individuals at some minimum level. The word “need” is, however, is a controversial one. Because needs vary significantly between countries and regions and are dependent upon weather, social customs, and a number of other region- and society-specific factors, there is no universally-accepted set of minimum basic needs. It is for this reason that many countries have their own poverty lines reflecting different social, economic, and climatic conditions (OECD, 2001).

In some instances needs have been closely associated with wants and desires, as was the case with Maslow, who presented his famous Hierarchy of Needs in the shape of a pyramid (Maslow, 1954). He believed that needs could be divided and prioritised into five levels and that individuals would not seek the satisfaction of a need at a higher level until the previous level of need was met. At the lower levels of the pyramid, needs relate to concepts of physiological preservation such as safety, food, and shelter; at the higher levels, human needs relate to social interaction and self-esteem.

![Figure 2.1. A representation of Maslow's Hierarchy of Needs.](image)
Sen describes poverty in terms of the concept of human capability and functioning (e.g., Sen, 1993; 1997; Robeyns, 2001). People's capabilities involve what they are able to do and to become, whereas their functioning consists of what they actually are and do. This concept reflects the various criteria a person may value as being necessary for achieving a good life, which can range from simple things (e.g., being adequately nourished or free from avoidable disease) to more complex ones (e.g., being able to take part in the life of a community and have self-respect). Sen emphasises that income is only valuable as long as it increases the "capabilities" of individuals and thereby permits "functioning" in society. Thus, material resources are necessary but not sufficient. The concept of capability poverty focuses on an individual's capacity to live a healthy life; that is, to have adequate nourishment, be informed and knowledgeable, have a family, enjoy personal security, and be able to participate freely and actively in society. Sen's views can be considered contrary to Maslow's to some extent, as Sen does not accept a distinction between higher and lower needs. The concept of human capabilities is in some way reflected in the Human Development Index (HDI), where it is recognised that "development is about expanding the choices people have to lead lives that they value. And it is thus about much more than economic growth, which is only a means - if a very important one - of enlarging people's choices" (UNDP, 2006a). Consequently, the HDI combines information about national incomes with information about education and life expectancy.

Other approaches emphasise that traditional poverty measures based on household income or expenditure reflect a static concept and thus offer only a limited picture of household well-being. In this way, vulnerability and livelihood strategy approaches provide a more dynamic conception of poverty (Moser, 1998). These strategies focus on a household's resilience and ability to cope with shocks, with the means of resistance being the assets and entitlements that individuals, households, or communities can mobilise and manage in the face of hardship. The vulnerability approach is therefore closely linked with asset ownership and labour. However, poverty measures based solely on asset indices indicate nothing about levels of absolute poverty and are of no reliable use in monitoring changes in poverty over time: changes in household ownership of index components may occur, and this may not necessarily translate into a diminution in material poverty (Falkingham and Namzie, 2001). Thus, the application is limited to providing relative analyses of welfare (for instance, to compare the assets of the top and bottom population segments). Closely related are the participatory poverty approaches, which consider the involvement of community members in the process of defining who the poor are. These approaches lead to a more people-centred determination of poverty, in which the ranking of the poor is based upon the subjective criteria of the people in a community (Brock, 2000; Narayan et al., 2000). While this approach works well in identifying the poor at the village or community level, it cannot be used to rank larger populations, compare regions, or determine the level of absolute poverty.
This proliferation of concepts and indicators would not matter so much if the same individuals were identified by all measures. Unfortunately, there is often limited congruence among the indicators, as a specific poverty indicator does not estimate “poverty” but rather a specific poverty dimension. Due to this limited correlation between the poverty measures, a household that can be deemed “poor” in relation to one particular poverty dimension may not be considered “poor” in relation to other dimensions. Therefore, a change in the poverty indicator used results in a change in the ranking of the population as well as a different set of people being defined as poor, even if the poverty level remains the same.

This multidimensionality of the poverty concept has technical implications for poverty measurement as well. To capture the complete picture of poverty, all the relevant poverty dimensions should be included in the measurement. Such an analysis provides an in-depth view of a household’s situation but does not necessarily answer the question of whether the household is poor. Besides, if the indicators are aggregated in a poverty index, they must be weighted. However, the variables included and the weighting chosen can substantially influence the outcome of the poverty assessment (Maxwell, 1999). Therefore, many measurement approaches use just one indicator (usually expenditure) as a proxy indicator of poverty. There is nonetheless a trade-off between the comprehensiveness of an aggregated, multidimensional poverty index and the simplicity, straightforwardness, and oversimplification of a single proxy indicator of poverty. In addition, there is another trade-off in poverty measurement between the challenge of measurability, which requires standardisation, and local complexity. Objective income and consumption measures can be used to give a picture of the extent of poverty at a national level and can be aggregated internationally. For analysis and detailed planning, though, additional qualitative measures and participatory approaches are more appropriate (Moser, 1998).

2.2. Poverty drivers, regional disparities, and inequality

2.2.1. Descending into and escaping from poverty

Observed changes in poverty rates at the aggregate macro level as described by FGT measures are only a summary of what happens at the individual level. While development may go along steadily with economic growth at the aggregate level, the relationship is not so straightforward at the household level. The group constituting the “poor” is constantly changing. Ravaillon reports that while some people have escaped poverty, others have concurrently declined into poverty (Ravaillon, 2001). Similarly, Sen observes in a Bangladeshi study that gross movements in and out of poverty were much larger than net changes in poverty ratios (Sen, B. 2003). Obviously, identical patterns of national economic growth and state policies have affected different households to very different extents. A
factor which results in growth for some households may have no effect on another household or may even become a reason for economic descent.

Work by Sen, B. (2003) and Krishna (2004) attempts to explain movement into and out of poverty and to identify the driving factors, with both highlighting that declining into and escaping from poverty are not symmetrical. Indeed, a different set of factors is associated with escape from poverty than with decline into poverty. Moreover, a single factor rarely causes a descent; more often, a combination of various factors is at play. Krishna, who analysed the movements of households in villages in Indian Rajasthan, cites poor health, high healthcare expenses, high-interest private debt, and large social and customary expenses (such as death and wedding feasts) as the most important factors for households’ declining into poverty. Sen, on the other hand, emphasises other factors including a lack of infrastructure, diseases, illiteracy, and natural disasters. Other regularly-named factors for decline are social exclusion (Mehta, 2003) and exclusion from job markets (Beteille, 2003).

Combining routes is also critical in the orchestration of an escape from poverty. Indeed, the poor adopt multiple strategies to cope with their difficult situations and to escape from poverty. Krishna stresses the importance of income diversification and access to information. Information is critical in various areas: it affords access to new job opportunities, it may prevent individuals from becoming ill, and it allows for a control of risk (for instance, in investments in irrigation projects). Others, referring to the livelihood approach, emphasise the accumulation of a mix of assets as the relevant key for escaping poverty (Sen, B. 2003). Sen notes that an escape from poverty is mainly achieved using structural factors, whereas a downfall seems to have its origins in particular drivers, with non-structural factors playing a more pronounced role. However, the differences in the identified factors between the studies point to the fact that the drivers are not universal: they vary between states and regions depending upon culture, policy setting, geography, and so on.

Some analysts do distinguish between chronic and transitory poverty, which differ as to the extent of time a household stays poor. The chronic poor are those who experience poverty for long periods, whereas the transitory poor are frequently oscillating into and out of poverty. As Mehta observes, this distinction is rarely made in the literature on poverty in India (Mehta, 2003). The primary factors cited for remaining in chronic poverty in India include dependence on wage income and low wage rates, particularly among casual agricultural labourers. See e.g. Datt and Ravaillon (1998) and Mehta (2003).

2.2.2. Regional disparities and poor areas

Significant geographic variations in household consumption levels are observed in all countries, resulting in areas in which the incidence of economic poverty is unusually high. The case of India is illustrated in Figure 2.2. The Indian state comprises both regions of rapid development and regions of persistent extreme poverty. Inequality exists between individuals, as it does between regions.
Krishna reports that it is not only districts but villages within these districts as well that vary substantially in terms of their poverty patterns, and that poverty has a distinct local flavour (Krishna, 2004). Economic theory offers two modes of explanation for regional disparities in economic poverty. These modes differ primarily in their assumptions about migration behaviour and the role of structural factors such as infrastructure, access to services, and geographic endowment (Crump, 1997).

*Individualistic explanations* focus on human capital (an individual’s education, skills, etc.) and assume that people are highly mobile. Researchers using an individualistic model attribute no causal significance to spatial inequalities in resource endowments (geographic capital), although differences in geographic endowment may function as a sorting mechanism that leads to spatial poverty concentration (Henninger, 1998). Causes for poverty are identified at the individual level, and poor areas are described as consequences of personal decisions. Poor people tend to remain in poor areas because of specific price incentives, or because they believe that they have a better chance of making a living in a less competitive environment. Characteristics of poor areas such as low rents, inexpensive and low-grade infrastructure, and limited but cheap services are regarded as a reflection of personal decisions on the part of the poor to live in those areas.

*Figure 2.2. Spatial disparities in economic poverty (year 1999/2000). Percentage of households below the monetary poverty line of per capita Rs. 219/month (rural) and Rs. 272/month (urban), respectively (real values, base year 1993-94).*
Structural explanations, in contrast, argue that free migration is normally not possible and suggest the existence of a causal link between the geographic endowment of a region and the general level of well-being of the people living in that area. It is assumed that local factors such as land-use type, climate, infrastructure and access to services influence the marginal returns on investments. Because of limited mobility, structural differences between regions in terms of natural resource endowment tend to persist and intensify. Consequently, poorly-endowed areas may become poverty traps (Ravallion, 1996). The possibility of a nexus between geography and development is also highlighted in work done by Bird et al. (2001), Sen, B. (2003) and Mehta (2003). For instance, Sen mentions that residents in areas with low geographic capital might derive fewer benefits from the economic and social opportunities created by economic growth. Some empirical work has been done on the nature of spatial disparities in income poverty and has addressed the matter of why poor areas exist. For instance, Jalan and Ravallion analysed the influence of geographic factors on the productivity of a household’s own capital and found some evidence that households indeed show a higher capital productivity in better-endowed areas (Jalan and Ravallion, 1997, 2002).

Each of the two theoretical models has shortcomings for explaining the spatial clustering of the poor, and a combination of individual, structural and geographic factors are often identified as causes for poverty and its spatial concentration (Miller, 1996). The degree to which individual, structural, or geographic factors cause poverty has implications for developing a strategy to improve the situation of the poor. If geographic factors play an important role, then it makes sense to employ geographic targeting in poor areas. On the other hand, if individual characteristics explain most instances of local poverty, and individuals are free to migrate, then the mobility of people and capital will limit the success of targeting poor areas. Consequently, anti-poverty programs should target households with personal attributes that foster poverty, regardless of where they are located (Ravallion and Wodon, 1997).

2.2.3. Inequality

When the dependence of head count poverty ratio on welfare distribution was mentioned previously, it was also indicated that there is a relationship between poverty and inequality. Unfortunately, the nature of this relationship is neither clear nor direct. Although both concepts are associated with issues of economic and social change, they are distinct and may vary independently of each other. As Beteille notes, "The divergence of views regarding the relationship between poverty and inequality is largely due to the fact that there are different conceptions of poverty and different kinds of inequality" (Beteille, 2003). When an absolute concept of poverty is adopted, the distinctness of the concepts becomes evident. For instance, economic growth may lead to a decrease in poverty but not to a
decrease in distribution (inequality). On the other hand, relative deprivation is central to the conception of relative poverty, and thus the concepts of poverty and inequality are closely associated. Traditionally, inequality has been quantified in monetary measures. For instance, inequality in the distribution of income is reflected in the percentile distribution of populations across specific income classes. Another common illustration of the income (or expenditure) distribution is the Lorenz curve, which plots the cumulative percentages of total income against the cumulative number of households or people. Closely related to the Lorenz curve is the Gini index, which provides a summary measure of the degree of inequality. The Gini index measures the area between the Lorenz curve and a hypothetical line of absolute equality, expressed as the rate of the maximum area under the line expressed by the equation:

\[
Gini_{\text{index}} = \frac{A_g - A_{ug}}{A_g}
\]

[Eq. 2.2]

where \(A_g\) is the area under the Lorenz curve of a uniformly distributed society and \(A_{ug}\) is the area under the curve for the observed society. In this way, a Gini index of 0 corresponds to perfect income equality (that is, a situation in which everyone has the same income), while an index of 1 corresponds to perfect income inequality.

These briefly-outlined measures of inequality are crude and may often be misleading. To this end, their careful interpretation is required. Moreover, income inequality is not the only form of inequality: a plurality of inequality dimensions analogous to poverty is considered today. In particular, gender, ethnic, and age inequalities have become relevant topics for analysis. Moreover, changes to the political and legal order are no less significant for poverty and inequality than changes in the economic order (Beteille, 2003).

### 2.3. Energy and poverty

To illustrate the relevance of energy for development or well-being, one often plots the GDP or HDI as a function of per capita energy consumption; see for instance Figure 2.3. From this calculation, it is apparent that higher development goes along with higher per capita commercial energy consumption. The correlation is particularly high for lower energy consumption quantities and lessens with higher quantities.

Energy services are the result of a combination of various technologies, infrastructure, labour, materials, and primary energy, and they are required for virtually every activity (Goldemberg cited in UNDP, 2006b). Thus, while energy itself is not generally recognised as being one of the basic needs, it is clearly necessary for the delivery and provision of basics like food, clean water, shelter, health and educational services, etc. (WEC, 1999; Toman and Lemeckova, 2003).
Figure 2.3. Energy consumption and development. Only commercial energy resources are considered (UNDP, 2004a).

2.3.1. Defining energy consumption at the household level and the appropriateness of useful energy for poverty measurement

While the centrality of the position of energy to the provision of basic needs is recognised, there is no consensus as to the amount of energy needed to meet basic human needs, as there is no universally-accepted set of minimum basic needs. In addition, “necessary” energy consumption can be measured at various levels of the energy supply chain:

- **Primary energy** is the energy embodied in natural resources (e.g. coal, crude oil, sunlight, and uranium) that have been mined, collected, or extracted but have not undergone any anthropogenic conversion or transformation.

- **End-use energy** is the energy content of energy supplied to the consumer at the point of end-use (e.g. electricity at the electricity meter).

- **Useful energy** is the energy that has been transformed into the form required for actual use (e.g. the heat generated from a hot plate, or the mechanical energy applied to air for air circulation).

- Finally, there is the direct demand by households on energy services (e.g. a cooked meal, a well-lit room, a hot shower, transport from point A to point B, etc.).

While all the preceding levels are of importance for energy analysis, they have different explanatory powers, and thus the choice of level depends on the purpose of the analysis. For poverty assessment, the level of energy services appears to be most appropriate. The problem for the analyst is that these
so-called energy services often cannot be measured in energy units and, as mentioned above, their delivery requires many other things in addition to the energy carriers themselves. Thus, there is no way of distinguishing energy services from other services and products. In the absence of the possibility to directly measure energy services, a measurement of consumption at the level of useful energy proves a promising approximation.

Analysing useful energy makes much sense when one compares various ways of providing one kind of useful energy for one specific energy service. However, summing useful energy employed for different energy services may be problematic. For instance, adding “heat supplied to a cooking pot” and “the energy of light coming from a light bulb” involves the combination of two energy flows of very different physical quality, form, and utility, which are produced at different technical, economic, and resource-related costs. In this way, comparing or summing them often produces irrelevant results. In the case of measuring energy poverty, however, cooking is such a dominant energy service that the applicability of useful energy is not overextended, and it was therefore decided to include it in what follows.

2.3.2. The importance of non-commercial energy

The importance of traditional non-commercial sources of energy for meeting household energy needs is still very significant in developing countries. In fact, about 80% of the energy consumed in Indian villages comes from non-commercial sources, which comprises more than 30% of the total energy consumed in the country (Pachauri, 2002). Including non-commercial energy in an analysis has the welcome effect of considering the consumption of non-monetised goods. In some cases, households following a traditional agricultural lifestyle might be considered fairly well-off if they are self-sufficient in meeting their basic food and energy needs, even if all energy used is non-commercial biomass.

Although biomass fuels are generally collected freely by the women and children of the household, the time required for the collection can be quite significant, depending on the nearness of sources of supply, and has an opportunity cost associated with it (Kanagawa and Nakata, 2006). For instance, the woman could spend the time more productively in income-earning activities, the children in education, respectively. Thus, a switch from traditional biomass fuels to modern commercial fuels also involves a further saving in time, as the ease of using these modern fuels is much greater and there is less time needed to ignite and tend the stove, resulting in greater convenience and speed of cooking.

The inclusion of non-commercial energy has important implications for the nature of the relationship between energy consumption and expenditure levels. In general, in the absence of any non-commercial use, there is a strong positive correlation between energy consumption and expenditure levels. However, since non-commercial energy is often collected freely in nature, constraints in terms
of resource availability, labour availability, land and livestock holdings have a larger impact on the amount of total energy used rather than the per capita expenditure levels or budget constraints of the household. Moreover, there is an upper consumption limit for non-commercial energy, because its use is restricted to cooking and heating purposes. This is in contrast to electricity, where no such limit exists. Additional consumption of electricity provides additional services; additional use of fuel wood only provides extra benefit as long as there is food to cook. Contrary to expectation, an analysis of the household survey data from India shows that average consumption of biomass does not decline with increasing expenditure (Figure 2.4). The literature on fuel switching suggests that in general people switch to commercial fuels with an increase in income, if they are able to (Smith, 1987; UNDP/WB, 2003a). Yet, households with no access to markets are unable to purchase and therefore switch to commercial fuels. These households continue to use non-commercial biomass, even when they have high per capita expenditure levels. In addition, many households actually do not switch, but rather stack their fuels (Masera et al., 2000). In such cases, with increasing income additional superior fuels are bought, but at the same time the use of the inferior fuel (biomass) is not abandoned. These households therefore continue to use biomass along with commercial fuels.

As a result, there is little evidence of correlation between non-commercial energy use and income (Figure 2.4.). In this case, measuring poverty in monetary terms alone by assessing the per capita expenditure levels of individuals could be misleading. A household with low expenditure levels that has access to sufficient non-commercial energy can be considered "richer" in energy terms than a household with higher per capita expenditure but poor access to non-commercial energy and no access to other commercial energy forms. Thus, by the inclusion of non-commercial energy an important non-monetary dimension of poverty is taken into account.

Figure 2.4. Per capita useful energy plotted against the per capita expenditure (bold lines depict useful energy plotted against the mean per capita expenditure for expenditure demi-percentiles). Calculations based on unit level data from the National Sample Survey Consumer Expenditure Survey, round 55 for the year 1999-2000.
There are, however, some problems that generally arise with the inclusion of non-commercial energy in the analysis. For instance, the available data for non-monetary exchanges of goods is usually not recorded with the same accuracy as monetary exchanges. The latter are recorded by vendors and buyers, often are then registered in formalised balance sheets of traders and banks as well as on tax forms. For wood and other biomass collected in nature, nobody is obliged or much interested in recording the amounts. Thus, the quality of employed survey data depends on the good will and memory of the respondents, who do not have the possibility of looking-up any bills or bank statements.

2.3.3. Approaches to measuring energy poverty

This subsection gives an overview of different approaches that have been used in the literature to measure energy poverty. The first two classes of approaches presented below make use of information regarding the expenditure on and quantity of energy consumption, the third the access to different energy sources.

Economics based approaches

One approach aims at deriving an “energy poverty line” or “fuel poverty line” from a conventional income or expenditure poverty measure. This can be done by determining energy use as a function of income (or expenditure), and by calculating the average level of energy consumption corresponding to an amount of income or expenditure specified by the official income or expenditure poverty line (i.e. the level specified as the minimum money amount needed to meet basic needs). Foster et al. (2000) calculate a “fuel poverty line” using household survey data from Guatemala. They compute the average energy consumption of households whose overall per capita monetary expenditure level falls within a plus or minus 10% range of the official expenditure poverty line. This average energy consumption value is then assigned as the “fuel poverty line”. In addition to deriving an “energy poverty line” as a function of the income poverty line, some authors have attempted to do the same by looking at energy consumption at the aggregate national level in relation to other broader measures of poverty such as the human development index (HDI) (Goldemberg and Johansson, 1995) or physical quality of life index (PQLI) (Krugman and Goldemberg, 1983). While such approaches are computationally fairly simple, they only provides a single energy or fuel poverty line, i.e. a single number that is basically a transformation of the monetary poverty line, and does not, by itself, add any new insight.

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2 The indicator Physical Quality of Life is a composite index, ranging from 1 to 100. The index is calculated for a given country by rating figures for life expectancy, infant mortality, and literacy each on a scale of 1 to 100 and averaging the three components, giving equal weight to each of them.
Other approaches define energy poverty in terms of energy budget shares i.e. the share of household expenditure or income spent on fuels and electricity. For instance, studies such as those by Leach describe that for the poorest groups the share of income spent on energy is normally much greater than that of middle and upper income groups (Leach, 1987). The trend of declining energy budget share with rising income is observed in developed countries as well. The government of the United Kingdom, for instance, defines a fuel poor household “as one which needs to spend more than ten percent of its income on all fuel use and to heat its home to an adequate standard of warmth” (DTI, 2002). The problem with such a measure is that the energy budget share of a household is often dependent not only on the type of fuel or energy used and its market price, but also the efficiencies and the costs of appliances needed for burning/using the specific energy types. In addition, a large budget share could also be a result of high consumption, either due to high prices or large household size, and this further complicates the interpretation of this indicator (Foster, 2000).

In order to take into account the different efficiencies of the wide range of fuels used by households, another approach for comparing poor and non-poor households adopted by some authors such as Leach (1987) and Foster et al. (2000) is to estimate the “effective price”, or “net price” defined as the price per unit of useful energy consumed. It is often the case that poorer households use the most expensive fuels in terms of the price per unit useful energy. This is because poorer households commonly use the most inefficient fuels and devices. Some authors have even suggested comparing the average total cost of energy, inclusive of the amortised capital costs of the equipment and appliances used to avail energy services, for different groups of households (Hosier and Kipandya, 1993; Reddy, 2003). Results of such studies also indicate that poorer households, that are dependent on more inefficient fuels, are often at a disadvantage compared to better off ones.

Poorer households are at a further disadvantage as compared to richer ones when a comparison of the effective cost of energy per unit useful energy consumed also includes the time costs and transaction costs of gathering or acquiring fuels. Thus, while there may not be any monetary value or price associated with certain non-commercial fuels, such as wood or dung, there is still a significant opportunity cost in terms of the value of the time spent in collecting the fuel wood. Dutt and Ravindranath (1993) report that it is often the case that poor households spend more money buying, or more time collecting, each unit of energy they consume compared to wealthier households. They estimate that the time involved in fuel wood gathering is very significant and varies from less than one hour to more than five hours per day in different regions of India.

**Engineering based approaches**

In addition to these economic based approaches at comparing the energy poor and non-poor, another approach to measuring energy poverty uses engineering type estimates for determining the direct energy required to satisfy basic needs, based on some subjective assessment of what constitute basic
needs. The use of engineering type calculations for estimating basic energy needs is reported in early studies by Revelle (1976), Bravo cited in Krugman and Goldemberg (1983) and Goldemberg et al. (1985, 1987, 1990). Goldemberg et al. estimated that the requirement of direct primary energy per time unit to satisfy basic needs is about 500 watt per person. This kind of a calculation rests on a number of assumptions regarding the type of energy consuming equipment (stove, light bulbs etc.), their sizes, efficiencies and intensity of use. In addition, the approach requires as a first normative step the definition of a set of basic needs. This is a problematic endeavour since basic needs vary with subjective wants, as well as with climate, region, period in time, age and sex.

<table>
<thead>
<tr>
<th>Category</th>
<th>Per capita energy needs in rural areas [watt]</th>
<th>Per capita energy needs in urban areas [watt]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hot climate</td>
<td>Temperate climate</td>
</tr>
<tr>
<td>lighting</td>
<td>21.8</td>
<td>27.1</td>
</tr>
<tr>
<td>space heating</td>
<td>0</td>
<td>290.9</td>
</tr>
<tr>
<td>space cooling</td>
<td>9.7</td>
<td>3.9</td>
</tr>
<tr>
<td>food preservation</td>
<td>44.5</td>
<td>33.9</td>
</tr>
<tr>
<td>cooking</td>
<td>252.2</td>
<td>302.5</td>
</tr>
<tr>
<td>water pumping</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>hot water</td>
<td>81.8</td>
<td>156.3</td>
</tr>
<tr>
<td>ironing clothes</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>recreation &amp; social communication</td>
<td>29.5</td>
<td>29.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>447.2</strong></td>
<td><strong>851.7</strong></td>
</tr>
</tbody>
</table>

Table 2.1. Minimum direct primary energy needs as proposed by Bravo et al., cited in Krugman and Goldemberg (1983). Hot, temperate and cold climate are characterised by mean annual temperatures of 25°C, 18°C and 10°C, respectively.

A similar engineering approach for estimating the basic energy needs for cooking, lighting and heating was adopted by planning agencies in India in fixing “norms” that where then used while forecasting and evaluating energy demand, especially in rural areas. The Advisory Board on Energy in its 1984 report on energy demand modelling for India (ABE, 1984) assumed that about 30 watts of useful energy is needed per capita to meet cooking energy needs. Similarly about 1.5 watts of useful energy per capita is required to meet space heating needs and the same amount again, 1.5 watts of useful energy per capita, to meet lighting needs. These values are calculated on the basis of various assumptions regarding what is considered as the basic minimum required to meet human needs. Thus a total of some 33 watts of useful energy per capita was assumed by ABE to be required at the household level to meet the three basic direct energy services, cooking, lighting and space heating. This converts to almost 250 watt of primary energy, which is about half of Goldemberg’s estimate, which is based on his own stipulations of basic needs. A similar engineering type estimate of the end-
use energy per capita required to meet basic needs for the average Indian, assuming that LPG is used for cooking and electricity for lighting is approximately 100 watts per capita (Reddy, 1999).

Figure 2.5. Distribution of per capita useful energy. The bold bar represents the by the ABE (1984) proposed energy poverty line of 33 watt. Persons on the left side of the fuel poverty line are considered as energy poor.

Poverty and access to energy

A number of authors have defined energy poverty in terms of access to energy services (see for e.g. Alam et al., 1991; Mark, 1998; or Barnett, 2000 for a discussion on how access to more efficient energy sources is related to an improvement in people’s level of well-being). This is an important complement to a consumption based measure of poverty. For instance, whether a household chooses to use a number of different electrical equipments or not is a matter of choice, what is important however, is that the household has that choice to make and for that the households must have access, i.e. physical access to electricity (the electrical grid and a home connection), physical access to markets where it can buy electrical equipment, and the purchasing power to buy the equipment and the electricity at a competitive price. Thus, what distinguishes a poor household from a better off one is also the wider range of choice in terms of which fuels to use (more efficient, more convenient, less polluting), and which equipment and appliances to buy.

However, finding data on access to energy services can be quite difficult. One needs data not only on the physical access to different energy types, but also data on whether the household has access to markets that sell different energy using equipments and information on the purchasing power of the
household, as well as the market prices of the fuels and equipments. Using data on coverage to indicate access can therefore be problematic as coverage says little about whether households in fact have the ability to access the particular fuel or electricity. In addition, there is often little information available on the quality and security of supply of different fuels and electricity.

2.4. Main data source

The analyses presented in this dissertation depend mainly on unit-level budget survey data from the National Sample Survey Organisation (NSSO) of India from several different rounds of its household consumer expenditure survey. Unit-level data from four of the large quinquennial rounds of the survey, including the rounds 38 (1983), 43 (1989-90), 50 (1993-94) and 55 (1999-2000) are used. The wealth of information provided by these large representative surveys, has so far been used largely for conventional monetary poverty measurement at the all-India or regional level (for different states, rural and urban). However, information collected via the survey provides also a rich basis for studying other dimensions of well-being of Indian households, particularly those relating to their energy profiles. Data from the surveys include information on monetary expenditures and physical quantities of consumption of a number of household items, including electricity and fuels (including non-commercial biomass fuels). The data also include information on a host of other socio-economic, demographic and infrastructural characteristics of households. Data are collected both regarding cash purchases of these fuels and consumption out of home grown sources or from that collected from common lands, forests, etc. Unfortunately, no information is collected on the time taken to gather fuel wood and other biomass by the household or the nearness of sources of supply. A further constraint of the data is that not all energy forms are captured equally well. Data on dung are particularly unreliable, while data on crop residues are not included at all.

Each round of the survey collects information from a cross-section of households covering the entire area of the country over a period of one year. Details regarding the survey methodology and sample are provided in the “Sarvekshana” publications (NSSO, 1986; 1990; 1996; 2002). Information is not collected from the same set of households across different rounds of the survey and therefore, it does not constitute a panel. However, the sample for each of the quinquennial rounds employed in the analyses is very large and representative of the nation as a whole.

It has to be kept in mind that the household surveys were not designed specifically to collect information on energy consumption and therefore estimates are not based on direct measurements, but instead on the recall of the respondents. In addition, the survey does not provide a break down by purpose of purchase or end-use. Hence, there might be some measurement errors and inaccuracies in the estimates of consumption inferred from the survey. However, given the very large sample size of the surveys, in the average one might expect that the data are fairly accurate. In particular, the level of
reliability for estimation of energy poverty at the national level is high. A comparison of data from the surveys, pertaining to the percentage of users of different fuels and electricity, with census data (Census of India, 2001) also indicates that, at the aggregate state and national level, the survey data are representative. A recent World Bank study on the access of the poor to modern household fuels in India, also compares data from the National Sample Surveys on energy consumption with data on official supplies of household fuels and finds the consumption data match fairly well at the aggregate level (UNDP/WB, 2003b).
3. Measuring energy poverty in Indian households

This section discusses the construction and application of a novel measure of energy poverty and distribution. It is a two-dimensional measure, which links information on access to different energy carriers and quantity of energy consumed per person. Thus, it is a combination of an engineering based approach with one that defines energy poverty in terms of access to energy services. This measure allows assessing the evolution and nature of energy poverty and distribution in India by describing development in terms of the net movements over time of households grouped by the type of energy they have access to and by the quantity consumed. One main advantage of this novel approach is that it measures not only consumption, but also, in some sense, capability. Even though the two dimensions are not synonymous with Sen’s functioning vector and capability space, they are constructed in the spirit of his approach. The amount of energy consumed resembles the functioning vector and energy access the capability space. By the inclusion of non-commercial energy, the approach also takes into account the non-monetised part of household transactions and by looking at different combinations of fuels/equipments and consumption levels that might provide the same energy services it captures to a greater extent the diversity of the poor and non-poor. Moreover, the presented approach allows for defining any number of different normative energy poverty lines rather than a single static one.

Section outline

Subsection 3.1 presents some key issues and the methods that are adopted for constructing the novel energy poverty and distribution measure. The measure is compared with engineering type calculations for a list of basic energy services consumed by households, to assess whether the individual has sufficient energy to meet basic needs. Subsection 3.2 describes the shifting numbers of the energy poor and non-poor that emerge from the application of this measure over the period from 1983 to 2000 in the context of Indian households. The subsection also analyses the characteristics of different energy access and consumption groups in terms of their access to other assets and services such as education. Subsection 3.3 concludes with a summary of major findings, a discussion on some of the advantages of this measure and some general lessons that emerge from this work.

Data source

For an illustration of the novel measure for the case of India, the NSS data described in subsection 2.4 are employed. The data on household expenditures and physical consumption from different rounds of the survey form the basis for defining access and calculating end-use and useful energy associated with the use of different fuels and electricity by households. The methodology used to do so is described in section 3.1. The primary intention was to include information on animal traction, too, as it
is an important source of mechanical drive. However, it was not possible to find data of sufficient quality and detail to make it worth including. A distinction of traction for agricultural purposes, such as tilling and pumping, for transport in the productive sectors, and for transport in the household sector, would have been the minimum requirement.

3.1. Constructing a novel two-dimensional measure of energy poverty and distribution

3.1.1. Estimating basic energy needs for the average household

As a first step to the construction of the new measure the basic energy needs of an average sized household are estimated and then combined with corrections for the scale effects for differing household size. To determine the energy requirements for a normatively defined set of basic needs, engineering type calculations are made, based on assumptions regarding the types of energy used, and the sizes, efficiencies and intensities of use for end-use energy equipment. In this way the energy needs corresponding to a vector of energy services are determined, rather than just a single average value. In this sense, this is a more robust measure, as it is able to better capture the multi-dimensionality and diversity of the poor. In addition, the approach has the added advantage that in theory it allows for distinguishing between the basic energy needs of rural and urban households and those residing in different climatic regions or different socio-cultural groups.

Table 3.1 lists the main energy services that are in demand in households and some engineering estimates for their direct energy requirement. Depending on what one considers as the basic minimum in terms of energy services that a household needs, one can then use Table 3.1 to calculate the minimum energy requirements to meet these basic needs in terms of either useful or end-use energy. It should be noted that the power requirements in Table 3.1 do not refer to the installed power of the equipment, but to the averaged power required to deliver the specific energy services. Following in the tradition of Goldemberg, the unit of power (energy per unit time) in watt (watt = Joules per second) is used to measure energy needs per person. By using the unit watt, the average power consumed by a person during any given time interval is measured.

In order to estimate basic energy needs, we start by calculating the end-use energy requirements for specific energy services. For instance, assume an electric light bulb with an installed power of 40W is used on average for 5 hours per day. Therefore, this light bulb consumes 200Wh per day (5h x 40W). The averaged power requirements for lighting with an electric light bulb is calculated by dividing the energy requirement by the time span in which the energy is consumed: 200Wh / 24h = 8W. Another example, for the case of preparation of a daily meal for a five-member household using fuel wood an energy requirement of about 34 MJ is assumed. That refers to an averaged power per day of 34MJ /
Accordingly, the preparation of two meals per day requires 68 MJ per day or 786 watt. These estimates of end-use energy requirements for specific energy services are then converted into useful energy by assuming certain efficiencies of the end-use equipments. The estimates are averages and underlie specific assumptions. Real requirements vary from household to household, depending on several factors like device type, intensity and mode of use, household size, etc.

<table>
<thead>
<tr>
<th>Energy services</th>
<th>Average power per household (in watt)</th>
<th>Useful energy</th>
<th>End-use energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>lighting, one electric bulb (5 h/day, 40W)</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>lighting, 1-2 kerosene lamps</td>
<td>9</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>cooking traditional biomass 1 meal daily</td>
<td>55</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td>cooking kerosene stove 1 meal daily</td>
<td>55</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>cooking LPG stove 1 meal daily</td>
<td>55</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>space cooling 1 room</td>
<td>110</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>warm water (fuel wood; 5l/day)</td>
<td>7</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>warm water (kerosene; 5l/day)</td>
<td>7</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>warm water (electric geyser, 5l/day)</td>
<td>7</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>refrigerator small</td>
<td>15</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>refrigerator large</td>
<td>28</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>washing machine</td>
<td>11</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>various household devices</td>
<td>2</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>radio</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>TV (Black &amp; White / Colour)</td>
<td>11</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>computer</td>
<td>13</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>car (per 10km/day)</td>
<td>66</td>
<td>365</td>
<td></td>
</tr>
<tr>
<td>scooter per 5km/day</td>
<td>13</td>
<td>73</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1. Power requirements of energy services for an average sized 5 member household.


If for electric light bulbs customary conversion factors of about 0.1 to 0.025 had been used, then the obtained useful energy would have been absurdly low compared with the useful energy for cooking. To overcome this problem, we defined “useful energy” to be synonymous with “useful energy for cooking”. For all electric energy services we used only one conversion factor for converting from end-use to useful energy (0.75). Also for kerosene energy services, only one conversion factor was used (0.45), knowing that for lighting the real efficiency would actually be much lower. Thus we have the advantage of not rendering the useful energy for lighting irrelevant, as would have been done by applying the very low conversion factors.
3.1.2. Correcting for household size economies of scale

The energy requirements listed in Table 3.1 refer to those needed per capita for someone residing in an average 5-person household. It has to be pointed out that the efficiencies of some equipment are strongly dependent on the household size. The problem therefore is to compare energy consumption of individuals residing in households of differing sizes. Since cooking energy plays such a dominant role and accounts for about 90% of the total residential energy consumption in India (Natarajan, 1985), the focus is on the scale effect for cooking. One way to estimate the cooking scale effect is to divide the monthly-consumed useful energy for cooking by the total number of meals served at home as reported in the NSS data. Figure 3.1 shows the average per capita energy consumption per person-meal grouped by household size. Following this estimation, a single member household requires about three times more energy for a single person-meal than a household with about six members. Using regression analysis is another way to estimate the scale effect. This approach has the advantage that it enables one to control for the household income effect. This is important, as the per capita income or expenditure also has a significant effect on the per capita energy consumption, apart from household size. Based on NSS data a simple log-log regression was carried out, where the variable useful energy for cooking (ce) was the dependent variable and per capita expenditure (pce) and household size dummy variables (DHSi) were the independent variables:

\[ \ln ce = \alpha_0 + \beta_1 \ln pce + \sum \gamma_i DHS_i \]  

[Eq 3.1]

The regressions, a separate one for each NSS round, show rather low R-squares (0.2-0.35), but significant scale effects, and the average of the three rounds fits well with the results estimated from the calculations based on useful energy per person meal. Additionally, to verify the scale effects obtained with the NSS data, they were crosschecked with household size scale effects reported in other publications (Ironmonger et al., 1995; Huser and Spalinger, 1992; Song et al.; Hughes-Cromewick, 1985; Bensel and Remedios, 1995, Bayrisches Staatsministerium für Wirtschaft, 2006). The comparison illustrates that for household sizes equal or bigger than 4 the curves overlap fairly well. For household sizes 1, 2 and 3 the regression analysis and the average of the reports show a smaller scale effect to those estimated from the calculations based on useful energy per person meal. Adjustments were made based on the equivalence scales estimated from the average of the regression results for different years, in order that the data used is consistent with that used for the rest of the analysis presented in this paper.

Data from the NSS rounds 38, 50 and 55 were used for both approaches. Round 43 did not include information on the number of meals consumed.
Figure 3.1. Estimations of household-scale economics in energy consumption for cooking (scale is relative to that of persons living in an averaged-sized five-member household).

In addition to the household size, other factors also influence the per capita energy requirement. The per capita expenditure was mentioned previously. Another important factor is the household composition. Since young children and elderly people eat less than hardworking adults, less energy is required for cooking for these members. The composition effect has not been studied in depth here, but calculations showed that the average family composition for the different household sizes is more or less alike⁵. A more sophisticated method to analyse the effects of household size and household composition for different regions in India is described in Meenakashi and Ray (2002). They perform a simultaneous estimation of a system of share equations to determine the scale and composition effects on expenditure shares. Their results indicate considerable diversity in the composition and scale effects in consumption expenditure for the different Indian States.

⁵ To describe the household composition the NSS variable total consumer unit, which is the sum of the household members’ individual consumer units, was used. The average total consumer unit divided by household size was for all household sizes around 0.8. The variable consumer unit was only available for Round 55.
3.1.3. Grouping households by the amount of energy they consume

To assess the relationship between poverty and energy four segments or classes of physical energy consumption per capita are defined, depending on the amount of useful energy consumed. Based on the engineering type data from Table 3.1, the following four segments of useful energy consumption are created: < 15, 15 - 30, 30 - 60 and > 60 watt per capita useful energy consumption in an average five member household. Combining these values with the household size scale effects as calculated previously allows to assign individuals residing in households of differing size in the data set to one of these segments. These segments correspond to the kind of energy services that reflect the range typically consumed in Indian households (see Table 3.2). In what follows, it is referred to the segments as Bottom (B), Lower (L), Upper (U) and Top (T).

<table>
<thead>
<tr>
<th>Energy use segments</th>
<th>less than 15 watt/cap Bottom (B)</th>
<th>15 to 30 watt/cap Lower (L)</th>
<th>30 to 60 watt/cap Upper (U)</th>
<th>more than 60 watt/cap Top (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples of energy services:</td>
<td>Up to 1 warm meal per day, a kerosene lamp, possibly a little hot water.</td>
<td>1 to 2 warm meals per day, a few kerosene lamps or one electric bulb, some hot water.</td>
<td>2 warm meals per day, hot water and lighting. Some small electric appliances (radio, TV, telephone) for groups with electricity. Possibly a scooter.</td>
<td>2 or more warm meals per day, hot water, lighting, some space heating and – in case of groups with electricity, possibly some space cooling, as well as other electric appliances. Possibly a scooter or a car.</td>
</tr>
</tbody>
</table>

Table 3.2. Examples of energy services, which may be available for an average-sized five-member household in the given intervals of useful energy.

These segments of useful energy consumption, while somewhat normative, have been constructed and chosen to reflect a progressive improvement in the kinds of energy services that they can afford. Thus, for instance, in the Bottom energy consumption segment, only a level of energy services that might be associated with abject poverty is affordable, while the Top segment consumes energy services that would be associated with a comfortable level of well-being. The typical range of energy services that might be available to those in the different energy consumption segments is shown in Table 3.2. The implicit assumption we make here is that an improvement in the level of well-being of

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6 In general, estimates of physical energy consumption from the sample data are likely to be underestimates. It is also likely that the cut-off values for useful energy intervals constructed from the engineering calculations are underestimates, since in practice the different end-use devices might be left running beyond the time of assumed and the efficiencies of – often not well functioning equipment – might be lower than that of the equipment measured.
a person or household is related to an increased demand for more diversified energy services. The cut-off values for useful energy intervals constructed on the basis of engineering calculations can in principle be fixed differently and refined in order to take into account a more detailed account of available energy services, or differences in amounts of useful energy needs arising from climatic or regional differences or varying tastes and customs.

3.1.4. Grouping households with respect to their access to different energy carriers

Since different energy carriers vary greatly in quality, convenience and utility, not only the amount or quantity, but also the type of energy used is of importance when assessing energy use in relation to poverty. For instance, only households that have access to electricity can enjoy benefits of energy services associated with the use of electrical equipment and appliances. And traditional wood stoves cause much higher levels of indoor air pollution than kerosene or LPG stoves. In the absence of more detailed data on access, for the purpose of the construction of the energy poverty measure, access is defined and measured by using data on utilisation. In addition, it is distinguished between households that incur positive expenditures or have positive consumption of a particular fuel or electricity as those having access and the others as not. Of course, though a lack of access implies non-utilisation, the latter may not be due to lack of access in every case. The rationale behind defining access in this way is that only those households that have the energy source available to them, and the purchasing power (either monetary or in labour time) to buy it, are capable of using it and therefore, can be thought to have real access to it. Such a measure is likely to be a lower bound to the real access enjoyed by a household. However, such a measure is still preferable to one based on official estimates of coverage, which overestimate access by a large margin.

In Figure 3.2 the distribution of households in India according to the type of energy used based on the data from the NSS rounds spanning the period between 1983 and 1999-2000 is presented. The majority of the households (still more than 60% for the most recent year) use a combination of biomass and kerosene or biomass, kerosene and electricity to meet their direct energy needs. The proportion of electricity users grew considerably over this period. About a third of all households use three or more energy carriers (increasing from less than 20% over the last twenty years). In contrast, the number of households dependent on a single energy type for meeting their direct energy needs is very low for all years. The 15 to 20% of “inconsistent” households have been termed thus as the data reported by these households appears inconsistent. There are two questions in the survey that pertain to the type of energy carriers used by the household. If in the first question, which asks for the major source of energy for cooking and lighting respectively, they report the use of a certain energy type, but

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in a subsequent question relating to the quantity and expenditure on that energy type they report no consumption, then data for that household has been excluded.

For the analysis, households are classified into three levels of access. To allow for the fact that households use multiple fuels and that there might be “fuel stacking” (Masera et al., 2000), the levels are defined to reflect improved access to more efficient energy sources, but do not preclude the use of less efficient sources in conjunction. Defined in this way, households that use biomass and kerosene, but no electricity and no LPG are classified as being at the BIO level; households using electricity but no LPG and who may use other fuels are classified as being at the ELEC level; and households using both electricity and LPG and who may use other fuels are classified as being at the LPG level. Only very few households do not fall into any of these levels and are excluded.

3.1.5. The energy access-consumption matrix

Combining the results from the previous sections, a matrix we call the energy access-consumption matrix can be constructed. It has been referred to as the energy access-use matrix in Pachauri and Spreng (2004). This matrix divides the population according to their access to different energy types (section 3.1.4) and the quantities of per capita useful energy they consume (section 3.1.3). The three levels of access to energy combined with the four energy consumption segments produce 12 groups that comprise this matrix (Figure 3.3). In what follows, it is discussed how this matrix can trace the
development of society with respect to a number of poverty-related variables measured at the household level.

![Figure 3.3](image)

**Figure 3.3.** The access-consumption matrix: the development of the size of the twelve groups over 1983-2000 (number of people, rural and urban, within each group). The bold line is the energy poverty line applied in this paper.

### 3.2. Changes in energy poverty and the energy distribution pattern between 1983-2000

The access-consumption matrix does not portray exclusively energy poor households, but in fact, represents all households in India. For illustrative purposes, an energy poverty line is depicted in Figure 3.3. Clearly, other choices of poverty lines are possible and the reader is invited to draw hers/his own poverty line. This line has been chosen so as to separate people having less than sufficient energy for cooking one to two meals a day and very limited lighting from the ones having more than that. This division is able to capture poverty on the level of both functionings and capabilities (Sen, 1999), as reflected by the energy services obtainable. It also takes account of the fact that useful energy from different energy sources provides differing qualities of energy services. For this reason, the energy poverty line does not coincide with a single useful energy consumption
Energy poverty measured by means of this line decreased from more than 75% to less than 40% in India during the period 1983 to 1999-2000 (see also Table 7.1 in the appendix).

Deaton (1996) discusses the relative merits of poverty lines versus welfare measures that take into account both the mean of distributions and its dispersion. The access-consumption matrix measures not only energy poverty in two dimensions, but also combines the advantages of a poverty line-measure with the advantages of a distribution measure. Defining an energy poverty line allows us to count the number of energy poor. However, at the same time the matrix allows one to see the distribution of energy access and consumption for the entire population, at a glance.

Unlike relative divisions such as deciles or quartiles, the divisions in access-consumption matrix are fixed and do not change with a shift in mean values over time. On the access axis the divisions are defined, quite naturally, by the important access-situations encountered in the country being analysed. On the consumption axis, the division boundaries are set normatively, in our analyses at 15, 30 and 60 watt per capita for the useful energy supplied to meet specific energy needs of households. This approach is not without a drawback, as a consumption of 60W is still low compared with for instance the Swiss average of about 700W. With on-going development the largest consumption group (> 60W) will become very large and heterogeneous and thus, describing inadequately future energy distribution. The use of additional consumption groups will become necessary. For a present representation, however, the four groups seem adequate.

Besides analysing the shift, or the net movement of households across the matrix, it is analysed how much the groups differ in terms of other welfare measures, both across the matrix and across time. We will see that the groups differ very much in terms of mean expenditures, and level of literacy across the matrix, but interestingly, the characteristics of households within individual groups hardly change over time. In other words, the groups, solely defined in terms of energy access and consumption, represent fixed levels of well-being.

3.2.1. Shifting shares of people across the access-consumption matrix over time

Figure 3.3 contains information on the change of the size of the groups over the years. The darker shade indicates urban population, the lighter shade the rural. Development is seen here as net movements from one group to another. The horizontal and vertical movements of “members of representative households” between groups are investigated. One has to emphasise, that this

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7 It is possible that the very small numbers of persons at the LPG level in the early years and especially for the B and L segments is to some extent due to misreporting. Household responses to the questions on quantity and expenditure on LPG also appear to be somewhat clustered around values corresponding to about 15 kg. This might be because the general cylinder size in India is 14.2 kg.
description of the dynamics captures the situation at an aggregate level only. Only “net” changes of the groups or “members of representative households”, respectively, are described, and not “real” movements or migrations of people between the groups. Thus, this description captures well the situation for “members of representative households” in each group, but not that at the level of individuals (in contrast, for example, to the shifts of individual households in Bangladesh described in Sen, B. (2003), where an average decrease of poverty goes along with some groups of households escaping from and others descending into poverty).

The general trend is clearly from groups consuming little and having limited access to groups consuming more and having less restricted access to energy, especially a net shift from the group of extreme energy poverty, the upper left group, to the central ones. This overall development affects at the same time both the types of energy carriers employed and the amount consumed.

There are also big differences between the net movement of members of rural and urban households over this period. In general, there are few urban households at the BIO level, and relatively large numbers at the ELEC and LPG level. The number of rural households is very large at the BIO and ELEC level and small at the LPG level. More than half of the urban households and more than a third of the rural household that were extremely energy poor (B consumption segment at the BIO level) in 1983 managed to improve their lot by the year 2000. The number of urban households that achieved a reasonably comfortable energy situation (U and T consumption level at the ELEC and BIO level) by 2000 was by far larger than the number of rural households, many of which only barely managed to move out of energy poverty. The largest shift in the number of rural households is the increase in the two central groups of the matrix.

3.2.2. Changes in per capita expenditure (PCE) across the matrix and across time

The mean PCE, measured in constant 1993-94 Rupees, differs widely across the different groups. Having better access to more efficient energy types (especially to LPG) or being in higher energy consumption segments is positively correlated to mean PCE values. Although the mean PCE value has increased at the all-India level, during the period from 1983 to 2000, there is hardly any change, both within the access levels or the consumption segments (see Figure 3.4). A slight decrease in the mean PCE for those at the ELEC level can be noted. The absence of change within the access levels and consumption segments seen in combination with the overall increase of the PCE mean value and the big change in the size of the groups (see Figure 3.3) implies that the dynamics with respect to PCE stems from households switching from one group to another and not from changes in average

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8 The large increase in the earliest years for the highest use segment may be explained by the very small size of this group in these early years.
expenditure levels within each group. The lack of any change for groups at the BIO level in combination with the trend of increasing mean for the whole of India suggests that those living in households that have higher PCE shift to higher access levels. The increasing mean for the whole of India combined with the lack of change or slight decrease in the mean PCE for the other two access level implies that within these groups the percentage of relatively less well-off households has risen and that access to better energy sources has become increasingly available to even relatively less well-off households.

It has to be noted that within the groups the spread of PCE is considerable. In part, this might be due to the fact that there have been no corrections made to this variable to account for economies of scale in household size. In addition, it is due to the inclusion of non-commercial energy in household energy consumption, which leads to a far less pronounced correlation of PCE and energy consumption than if only commercial energy is taken into consideration. This is also reflected in Table 3.3, where the within-group percentage of people living below the official monetary poverty line is indicated. The numbers for the earliest round (38) and the most recent round (55) are presented in the table. In general, the energy poor groups are also poor in monetary terms and there has been a slight decline in the share of money poor people for each group over the period from 1983 to 2000. The only exception being, those in the L, U and T consumption segments for the LPG access level, but this is due to the fact that there were practically no people in these groups in 1983.

Figure 3.4. Mean value of the total monthly per capita expenditure in constant 1993-94 Rupees per month (left: access levels, right: consumption segments).
### Table 3.3. Percentage of people below the monetary poverty line of per capita Rs. 219/month (rural) and 272/month (urban), respectively (real values, base year 1993/94). See for comparison Table 7.1 in the appendix, which compares the changes of the energy and economic poverty groups between 1983 and 2000.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Year</th>
<th>Bottom Segment</th>
<th>Lower Segment</th>
<th>Upper Segment</th>
<th>Top Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO</td>
<td>1983</td>
<td>69.6</td>
<td>54.8</td>
<td>36.7</td>
<td>28.7</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>57.2</td>
<td>45.1</td>
<td>26.4</td>
<td>12.7</td>
</tr>
<tr>
<td>ELEC</td>
<td>1983</td>
<td>44.8</td>
<td>27.9</td>
<td>10.8</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>36.1</td>
<td>28.1</td>
<td>9.9</td>
<td>2.1</td>
</tr>
<tr>
<td>LPG</td>
<td>1983</td>
<td>8.6</td>
<td>2.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>2.2</td>
<td>3.1</td>
<td>0.7</td>
<td>0.1</td>
</tr>
</tbody>
</table>

3.2.3. **Changes in illiteracy and other indicators of well-being**

As is the case with the PCE discussed above, the groups widely differ in the percentages of illiterate people for all the years as well (Figure 3.5). The development of the percentage of illiterate people in the groups shows that although for India as a whole illiteracy is decreasing, it is increasing in the groups at the ELEC and LPG levels. This again suggests that these more efficient energy sources become available also to households that, being illiterate, tend to have lower levels of well-being. This trend is even more pronounced if due attention is paid to the change in size of these groups (see Figure 3.3). For the consumption segments, there is no trend that illiteracy in better-off segments increases, but it does not decrease either, as is evident for the whole of India. There does seem to be a tendency for it to decrease in the Bottom energy consumption segment. In general, within access levels and consumption segments, the percentage of illiterates changes only slightly over the years. This indicates that the dynamics of this variable again stems predominantly from households shifting between groups and not from within group changes, which is similar to the picture that emerges from analysing the trends in development of mean per capita expenditure across access-consumption groups.

In order not to be repetitive, we do not present the analogous data for other indicators of living conditions like the availability of tap water and flush toilets (for tap water, see Figure 7.1 in the appendix). These indicators also differ considerably from group to group in the energy access-consumption matrix but hardly change over time within individual groups.
3.3. Conclusion

One method of measuring energy poverty is based on engineering type calculations that can either be used for setting a normative poverty line or can serve as an illustration of what energy service a certain amount of useful energy may provide, in the average. Information of this type, coupled with that on the access of households to different energy sources is then combined to develop the energy access-consumption matrix. This two-dimensional energy based poverty measure complements monetary poverty indicators in three ways:

- The two dimensions of the matrix are not synonymous with Sen’s functioning vector and capability space, but they are constructed in the spirit of his approach. The amount of energy consumed is similar to the functioning vector, the energy access to the capability space, respectively. Even if one does not have the money to use any electricity, to have access to it gives one the possibility to some day use it and with it perhaps the hope for a better life.

- Including non-commercial energy avoids the mistake of disregarding well-being accrued from self-production and barter economy. This is often neglected by income based measures alone.

- Describing development as the net movement of households from one situation, i.e. from one of the 12 groups in the access-consumption matrix, to another, affords a novel quantitative perspective. The fact that socio-economic variables, like literacy, remain in the average more or less constant within each group over the examined period from 1983 to 2000 shows that the movement between the groups has significance beyond energy itself. However, as Table 3.3 shows, energy poverty is not to be equated with monetary poverty in general.

Applying the access-consumption matrix to the data furnished by the NSSO for the years 1983 through 2000 shows a rapidly developing sub-continent. For instance, the proportion of people living
in desperately energy poor households having access to only biomass and kerosene and using barely enough of it to cook a full meal a day (top left cell of the matrix shown in Figure 3.3) decreased from 38% to 14% of the population, whereas the proportion of people living in households having access to electricity and possibly LPG and using more than is necessary to cook two full meals a day (all four cells near the bottom right of the matrix together) increased from 3.5% to 35%.

Figure 3.3 reveals not only that the number of energy poor is rapidly deceasing, but suggests also that inequality in the distribution of energy consumption and access might have increased. In 2000 the very energy poor, (the top left-hand group) were not quite half of what they were in 1983, (about 124 million people in 2000), whereas the numbers in the three relatively well-off groups in terms of energy (T segment at the ELEC level and the U and T segments at the LPG level), grew from 3 million in 1983 to 160 million people in 2000. However, a comparison of the Gini-Index based on energy consumption for the different NSS rounds does not provide evidence for an increase in inequality (see section 5). Moreover, the inequality within India has to be seen in the context of global inequality. The direct consumption of useful energy in industrialised countries is far off the scale of the Indian access-consumption matrix.9

There are large differences apparent in general levels of well-being of persons, as reflected in the examined indicators, especially across different access levels. In general, access to higher-quality energy sources is clearly associated with much higher expenditure levels and improved living standards. A similar observation holds for the consumption segments, but only from the mid-eighties or early nineties onward. Prior to this, the differences in well-being of persons belonging to different consumption segments were less pronounced.

The general picture of development drawn by the variables assessed above shows that improvements in access to higher quality energy sources is taking place at a slightly faster pace than changes in other socio-infrastructure characteristics of households. Generally, the development of these variables indicates that the dynamics can be approximated by the net movement of households from one group to another. By defining the matrix according to access and consumption groups, we allow for the fact that development can be viewed as having continuous and discrete aspects simultaneously.

It is important to be cautious in espousing energy poverty alleviation as an effective means of improving overall poverty and improving the well-being of the worst off population groups. However, investments in the provision of clean and efficient energy to the poorest to meet their basic needs often does lead to large improvements in their well-being. Additionally, evidence provided here points to the

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9 In Swiss households, for instance, the direct consumption of useful energy amounts in the average to roughly 700 watt/capita. Considering that three quarters of it is required for heating purposes, the remaining average of 175 watt/capita still far exceeds values for most Indian households. See Spreng (2005) on inter and intra country energy equity issues.
fact that in India energy poverty, as defined by the two-dimensional access-consumption matrix, is declining at a faster rate than other indicators of well-being improve, such as literacy and per capita expenditures. This seems to suggest that the provision and use of energy services may be an important driver of overall development. In particular, the provision of better energy services is clearly associated with significant economic and social benefits for those who are most deprived. This association and attempts at estimating some of these benefits have been highlighted in recent studies for the Philippines (UNDP/WB, 2002), India (Barnes et al., 2002), and Peru (World Bank, 1999). Yet, the provision of energy, by itself, cannot improve well-being in every case, and it is clearly important that other concerted actions and direct policies and measures be implemented to improve the lives of the poor through the spread of literacy, healthcare, employment and other income generating options.

While a significant reduction in energy poverty in India is evident from this analysis, energy poverty is still widely prevalent and particularly so in rural areas of the country. Between 1983 and 2000, whereas the number of people in the Bottom energy consumption segment did decline, there was only a 5% reduction in the total number of people in the Bottom and Lower consumption segments taken together (from 545 million to 516 million). Improving the well-being of these sections of the population will require significant additional efforts and large investments in infrastructure expansion in the next years. Ensuring that this is done in a sustainable and efficient way will be a major challenge to India’s policy makers, planners and economic players.
4. Energy poverty in relation to other poverty dimensions

The purpose of this section is to analyse the relation between energy poverty and other poverty dimensions and to study how energy indicators can be used as a reflection of the general level of human well-being. This is analysed by comparing three energy measures with conventional poverty dimension measures. By exploring the accuracy and reliability of energy poverty indicators for measuring (general) poverty, it can be shown that the use of energy indicators is not restricted to environmental and economical issues, but is significant for social issues as well.

Section outline

Subsection 4.1 describes the energy measures and the compared poverty dimensions and explains the methods employed for the comparison. First, simple correlations between the energy measures and the other poverty measures are estimated. Next, energy use deciles are formed and their socio-economic characteristics described. The results of the comparison are presented in subsection 4.2 and discussed in subsection 4.3.

Data source

For assessing the explanatory power of energy based poverty measures, the four rounds of the NSS data described in subsection 2.4 are employed. Since in the NSS data monetary expenditures and physical quantities are surveyed, it is possible to include non-commercial energy in the analysis. However, the data quality on dung use is very poor. Although the use of dung for cooking in India has decreased steadily over the last years, about 30% of the households still indicate some dung use and 8% indicate that dung is still their main cooking fuel (round 55). Since energy for cooking forms a large amount of the energy consumed by households, where the main cooking fuel is specified with dung, the total quantity of energy used is expected to be under-reported. Consequently, any analysis of the relationship between the amount of energy used and other poverty measures would be biased. Therefore, household observations were omitted where dung was listed as the main cooking fuel. Dung is not used as a fuel in all regions. More than 75% of all dung users are located in the states Uttar Pradesh, Bihar, and Punjab, whereas in other states the percentage of dung users is small. Thus, omitting the households with dung as a main cooking fuel will likely introduce a small geographic bias.
4.1. Assessing the explanatory power of energy-based poverty indicators

4.1.1. Available poverty measures

The goal of the analysis is to compare energy measures with other poverty measures, in order to assess their relation and to study how energy indicators can be used as proxy indicators of well-being and poverty. Poverty measures available in the NSS data are total household expenditure, education level of the head of the household, calorie intake, source of drinking water, sanitation type, house condition, dwelling area size, dwelling construction type and land possession. Of course, this selection does not cover the entire poverty spectrum, as many important dimensions like health, political freedom, hope, and the like are missing.

The three energy measures that are used for the comparison are primary, useful, and access-adjusted useful energy (all per capita). The energy quantities collected in the NSS data refer to the end-use level. By assuming certain efficiencies of the energy supply chain and end-use equipment, primary and useful energy quantities were derived, respectively (see section 3.1).

The access-adjusted useful energy measure

An access-adjusted energy use measure was constructed to include an energy measure that takes the quantity as well as the type of energy used into account, analogously to the access-consumption matrix. The matrix itself is not applicable because it is a two-dimensional measure, and correlations cannot be estimated nor deciles formed. Therefore, the two-dimensional measure is transformed into a one-dimensional one by giving up the access axis, but compensating for this by weighting the household's energy use according to its accessible energy sources. Similarly to the access-consumption matrix, three access categories are distinguished:

- households with access to biomass and kerosene
- households with access to electricity and other fuels, but not to LPG
- households with access to LPG and other fuels, as well as electricity.

Access is defined as the households' ability to consume a certain fuel. Therefore, a household has access to a certain fuel when the survey data indicates some use of this fuel. The Indian "energy ladder" puts these three categories in order. Since no scientifically reasonable basis for weighting factors can be found, largely arbitrary but logical factors are applied. For households of the biomass and kerosene group, the original energy quantities are employed. The amount of useful energy consumed is multiplied by a factor of two for households of the electricity group and by a factor of three for households of the LPG group. Obviously, this approach is rather crude. Therefore, other weighting factors will be applied to check the robustness of the original weighting factors.
4.1.2. Method

Correlation analysis

A good indicator is characterised by a close relationship between the indicator and the represented dimension. Therefore, to quantify the closeness of the relationship between the three energy measures and the listed poverty measures, their correlation coefficients ($R^2$) are estimated. For continuous variables, the Pearson's correlation coefficient is calculated. Nominal variables are initially ordered according to an increasing state of development, and then the Spearman's Rank correlation coefficients are estimated. Since data from different NSS rounds are available, they can be tested if the relationship is stable over time. However, not all variables are available in all rounds.

In general, correlation can be understood as the relationship between characteristics, events, or states. It is noted, however, the correlation coefficient does not describe the relationship between the variables $x$ and $y$ but rather the linear relationship between the variables $x$ and $y$ and the variables that are linked with $x$ and $y$ (Sponsel, 2004). Therefore, what a correlation finally means is unclear, because the space of variables in which the calculation is done is mostly unknown. Since correlation coefficients are difficult to interpret, an alternative analysis is added to describe the relationship between the energy and poverty measures.

Decile analysis

To this end, decile groups are formed and characterised for each of the three energy measures. The same poverty measures used in the correlation analysis are employed to describe the characteristics (calorie intake, education, etc.). If an energy measure is supposed to be a good basis for proxy well-being and poverty indicators, then clearly pronounced differences between the deciles should be revealed, with those in higher deciles showing higher levels of development and those in lower deciles being relatively worse-off.

Additionally, the energy measures are compared with expenditure, the most commonly used indicator of poverty. If one of the energy measures shows high correlation coefficients, and its deciles clearly illustrate distinct and reasonable differences between the bottom and top deciles, then this energy measure has significance for well-being and poverty measurements.
Table 4.1. Overview of the results of the correlation analysis ($R^2$). The correlations of the three energy measures and the expenditure within the NSS data on available poverty measures are depicted. All energy and expenditure measures are per capita.
4.2. Results of the explanatory power assessment

4.2.1. Correlation analysis

Table 4.1 gives an overview of the results of the correlation analysis. In the data set, not all poverty dimension variables were included in all NSS rounds. Round 50 is almost complete, except for the food variables. The food variables calorie and protein intake are solely available in round 55. Table 4.1 reveals significantly differing correlation coefficients for the compared energy measures. Whereas primary energy has very low $R^2$'s, access-adjusted useful energy has a strong correlation with most of the analysed poverty dimension measures. In general, the access-adjusted useful energy measure has a stronger correlation than useful energy, which has a stronger correlation than primary energy. In fact, adjusted useful energy correlates as well as expenditure with the compared poverty measures. With infrastructure variables like latrine type, dwelling structure, house condition, and access to drinking water, the adjusted energy measure correlates well. On the other hand, all energy measures correlate poorly with area size, land owned, and calorie intake. A look at the differences between the rounds reveals increasing correlation coefficients over time. While early in round 38, all coefficients are rather low, rounds 50 and 55 show much better correlations.

![Figure 4.1. Comparison of the correlations of the three energy measures and expenditure with a range of poverty dimensions. The access-adjusted energy measure has a stronger correlation with most poverty measures than do useful and primary energy. Based on NSS data round 50, except food variables round 55.](image-url)
To check the robustness of the results of the access-adjusted energy measure, alternate weighting factors were tested. It turns out that the correlation coefficients are not sensitive to the applied weighting factors, and the bias caused by applying arbitrary weights is not serious. However, the comparison of useful energy and access-adjusted useful energy reveals that a weighting of the energy quantities according to the accessible energy carriers has a significant impact on the correlation. This finding brings out the importance of considering both quantity and type of energy used by a household.

4.2.2. Decile analysis

Figure 4.2. Selected household characteristics of the access-adjusted energy and expenditure deciles. The education level, type of latrine, and the source of drinking water are described. Data from NSS rounds 50 and 55 (education).
An analysis of the characteristics of the deciles reveals that the access-adjusted useful energy deciles have similar characteristics to the expenditure deciles for the following variables: education level, latrine type and drinking water (Figure 4.2). The column charts on the left (adj. useful energy) are very similar to the charts on the right side (expenditure). The variables calorie intake, house condition, and construction type also show analogous results. Higher adjusted energy and expenditure deciles show characteristics of higher development: they have higher education, better sanitation facilities, and greater access to tap water, their houses are in better condition, and they have a higher daily calorie intake. The two other energy measures also show differences between the higher and lower deciles, but they are slightly less pronounced than for the adjusted energy measure. The differences between the energy deciles are generally more pronounced between the higher deciles. Between the three-bottom deciles, there are just small differences, particularly in the energy deciles. This may be caused by the small difference in energy use between these bottom groups.

The characteristics of access-adjusted useful energy and expenditure deciles look similar, but they are not equal. For instance, for the variables latrine type and source of drinking water the difference between the highest and the lowest decile is more distinct in the access-adjusted energy deciles. The difference in food intake is more pronounced between the expenditure deciles.

Figure 4.3 describes the average per capita daily calorie intake of the deciles. The energy deciles show small increases in calorie intake with increasing energy quantities. In particular, the five bottom deciles have about the same average calorie intake. The average intake is somewhat higher only in the two to three highest deciles. The standard deviation of the decile means is considerable for all energy measures, but the same holds true for the expenditure deciles.

![Figure 4.3. Average daily calorie intake per consumption decile.](image)
Discrepancy with food intake

At first glance, the weak correlations between food intake and expenditure and energy use is somewhat surprising, particularly in regard to the fact that a large amount of energy is used for cooking. Whereas minimal literature exists connecting energy use and calorie intake, quite substantial work has been done to describe the relation between household expenditure and calorie demand. For instance, Abdulai and Aubert (2004) found a strong, significant and positive relationship between household expenditure and calorie intake. However, estimated food–income (expenditure) elasticities seem to be highly controversial. In the literature elasticity estimates vary between less than 0.05 to more than 1 and depend on income and food item group (Bouis, 1994). The limited relationship is reflected in Figure 4.4. A considerable proportion of people with a deficiency in calorie intake are neither energy- nor expenditure-poor.

Figure 4.4. Outcomes of different poverty indicators. Different sets of people are identified and the poverty rate varies. For energy, the poverty line proposed in Figure 3.3 was applied. For calorie intake, a minimum requirement of 2400 kcal per consumer unit was assumed (NSSO, 1997; Ghosh and Pal, 2003) and for expenditure, the official poverty line was applied (Government of India, 1993), data NSS.

Although average per capita expenditure and energy use have steadily increased from 1972 to 2000, the NSSO reports a simultaneous decrease in average per capita calorie intake in rural and urban India (NSSO, 1997). One reason for this may be due to a change in dietary patterns. Traditionally, cereals were the main source of calories, but the NSSO describes a decline in percentage of total intake of calories from cereals in higher income groups. It seems that households tend to add other food items like vegetables, fruits, milk products, fish and meat to cereals with increasing income. Therefore, a higher income results only in a slight increase in cereal intake, respectively calorie intake, but leads to
a diversification in the diet\textsuperscript{10}. Another reason for the change in the dietary pattern may be caused by deficits in the cereal production, leading to increased cereal prices and lower consumption quantities (Ghosh and Pal, 2003). Furthermore, the dietary pattern may change due to a penetration of urban lifestyle in rural areas linked with a reduction in the biological requirement. However, the decline in average calorie intake seems to be closely related to the fall of cereal consumption.

### 4.3. Usefulness and limitations of energy-based indicators for measuring poverty

The energy poverty measure based on access-adjusted useful energy correlates reasonably well with most of the other poverty measures considered. The correlation is about as good as the correlation between expenditure-based measures and the same poverty measures. Moreover, the adjusted energy use deciles show distinct differences between the bottom and top deciles. These findings suggest that access-adjusted useful energy is a practical base for a proxy indicator of well-being and poverty.

Primary and useful energy measures are less valuable, since they have a weaker correlation and show smaller pronounced differences between the top and bottom deciles. In particular, primary energy shows very low correlation coefficients when compared to other poverty measures. Apparently, it is more promising to approximate energy services with the proximal level of useful energy than with primary energy, because depending on the energy source and the equipment used, the efficiency of transformation from primary into useful energy can vary greatly.

However, this analysis is restricted to a limited set of poverty dimensions. Hence, the appropriateness of energy-based poverty indicators was only tested for this limited spectrum of poverty dimensions and the explanatory power is only tested in respect to this set. No conclusions can be drawn for the appropriateness of approximating health, (political) freedom, happiness, social integration, or other important poverty dimensions.

Furthermore, even though energy measures like access-adjusted useful energy seem to be practical and reliable poverty indicators, they are subject to similar limitations as income- or expenditure-based indicators. Generally, more than one indicator is needed to describe all important aspects of a situation. Although energy development is closely related to measures that focus on basic human needs such as clean water, shelter, and education, a single energy-based indicator cannot grasp the multidimensionality of poverty. Energy is a factor in fulfilling each of these needs. However, by measuring energy poverty, they are not completely captured. Therefore, while access-adjusted useful

\textsuperscript{10} For instance, the NSSO reports an increase of fat intake in higher income groups (NSSO, 1997).
energy correlates fairly well with most of the analysed poverty dimensions, it is only a rough approximation for poverty.

In fact, the various poverty dimension groups overlap only partly (Figure 4.4). Consequently, the "poor" are a very heterogeneous group with divergent socio-economic characteristics. While some people suffer multiple constraints, others are only poor in relation to one poverty dimension. This also clarifies why the choice of the poverty indicator is crucial to the outcome of a poverty assessment. For instance, although expenditure and access-adjusted useful energy correlate similarly with the other poverty measures, their deciles show comparable characteristics, and the estimated poverty rate is similar, they identify different people as poor. Only about half of the energy-poor people are also expenditure-poor (Figure 4.4). In other words, no one-dimensional poverty indicator is a comprehensive measure of poverty, but the energy poverty indicator performs as well as any.

The utility of an indicator depends on the context and the purpose of the use to which it is put (Goldblatt et al., 2000). Hence, the point of its application determines whether it might be appropriate to employ a single indicator to measure a complex multidimensional social construct such as poverty. When we attempt to obtain a regional and detailed view to assess the vulnerability, nature, and scale of poverty in a certain community for the purpose of structuring an alleviation program, a single indicator cannot satisfy the requirements. In such cases it is necessary to use a comprehensive set of poverty indicators that can portray the specific situation in this particular community. On the other hand, when we are interested in a quick general overview of system behaviour and development or if we want to compare different regions, a single indicator is often more suitable. Thus, for the purpose of basic orientation indicators, the use of energy indicators such as the access-consumption matrix as a proxy indicator of poverty is adequate.
5. Energy indicators for tracking sustainability in developing countries

Although human activities and most sustainability issues are closely related to energy consumption, up to now the use of energy indicators has mainly been limited to environmental and economic issues. However, in section 4 we have shown that energy indicators are also reliable measures of social issues as poverty and thus, energy indicators qualify for measuring relevant topics in all three sustainability dimensions. This section discusses the idea of using the energy system as a framework for providing a small set of energy-based lead indicators for sustainable development, which can be consistently projected forward in time. We suggest such a set, employ for illustration the suggested energy indicators to describe the development of India over the past twenty years, and offer a possible projection into the year 2025. An energy system-based lead indicator set can be used to develop consistent and coherent future indicator estimates to track sustainability, a clear advantage over existing indicator sets.

Section outline

Subsection 5.1 explains the motivation for finding a set of lead-indicators for measuring sustainable development. Subsection 5.2 presents the energy framework and the derived set of lead indicators. Subsection 5.3 describes issues related to the measuring of the energy-based lead indicators and illustrates their performance in the context of India. This subsection also discusses the use of the lead indicators for understanding the likely evolution of a system over time.

5.1. Challenges of measuring sustainable development

While sustainable development, in theory at least, is a common goal for nations, communities, and firms, its quantification remains difficult. Sustainable development is not a fixed condition, nor is there a final “sustainable state”. On the contrary, sustainable development is inherently a dynamic process (Mog, 2004). Future generations, with greater knowledge, more sophisticated technology, and different needs, will define sustainable development in their own way and set other development goals. In addition, sustainable development also depends on a society’s worldviews and values (Meadows, 1998). These define which issues are regarded as important, which questions are asked, and which goals should be pursued.

Despite numerous difficulties in defining sustainable development, its measurement is indispensable to the operationalisation of the concept. The comparison between an indicator and its targets is a prerequisite for evaluating development in reference to sustainability (Scheller, 1999). Moreover, the
measurement aids in clarifying the meaning of sustainable development (Hardi and Barg, 1997). Indicators facilitate orientation in a complex world by condensing large amounts of information into a recognisable pattern (Bossel, 1999). Many approaches for measuring sustainable development have led to very detailed frameworks, from which long lists of indicators have been derived. For instance, the original UN CSD indicator set from the United Nations Department for Policy Coordination and Sustainable Development comprises over 130 indicators (UN CSD, 1996). Such large indicator sets have the advantage of covering most sustainable development issues and providing detailed insights. However, due to the high numbers of indicators, these sets are complex, difficult to interpret, and cannot provide a concise general overview of system behaviour. Therefore, they are not useful for decision-making purposes, because without any aggregation, such sets do not provide a measure of progress (Hardi and Barg, 1997). For decision-making purposes, less complex frameworks with small sets of a few lead indicators, sometimes called flagship indicators, have more promise. Charles Vest, former President of MIT, commenting on past successes and the work ahead in the area of sustainability research, said the following: "We need, I believe, to develop better metrics of sustainability that can be tracked over time, metrics that can be tracked by companies, by universities, for regions or for nations" (Vest, 2005).

Since human activities are closely linked to energy use, the energy system is a good candidate for providing a small, manageable list of interlinked lead indicators, with the ability to track sustainability. Most important sustainability issues relate to the production and use of energy. In this section we will show that using the energy system as a framework offers the advantages of consistency and coherence. Most importantly, it is possible to calculate future energy flows, demand and distribution with common energy-economic models. From these calculated future properties of the energy system, consistent estimates of the linked energy-based lead indicators can be derived. Thereby, the energy models are not more reliable in predicting a single future indicator than economic or environmental models, but unlike these other models they have a strong link to most of the important sustainability issues in all three sustainability spheres. Thus, for assessing the sustainability of the scenarios, the entire energy system is extrapolated, relationships between the sustainability dimensions are considered, and consistent estimates are generated. This contrasts with other approaches, where single indicators are not physically interconnected and must be extrapolated independently, making consistency questionable.

Through the possibility of developing consistent future indicator estimates, the energy framework qualifies particularly well for assessing the sustainability of different development paths. Spreng proposed that there may be an upper as well as a lower sustainable energy use boundary (Spreng, 2005). The lower boundary is given by the minimum energy a household requires to meet its basic needs. The upper boundary is given by the CO2 carrying-capacity of the atmosphere and can be translated into a global average direct plus indirect household energy use, assuming fossil fuels will
remain a non-negligible part of the energy mix for the next generation. The world average can be translated into national averages, making further the assumption that a sustainable world is also a world not inequitable by orders of magnitude in respect of CO2 emissions per capita.

Although the relationship between energy and human development is increasingly recognised, as highlighted by the IEA’s energy development index (IEA, 2004), the use of energy indicators has previously been limited to environmental and economic issues. For instance, they are employed to measure negative effects on the ecosystem (climate change, air pollution) or describe resource stock changes and economic activities. This may satisfy the demand for measuring sustainable development in already “developed” countries, where the sustainability discussion is focused on environmental topics. However, the situation is different in developing countries, where socio-economic issues like poverty alleviation and fulfilment of basic needs take priority. Consequently, the inclusion of a poverty indicator is indispensable in a set of indicators for measuring sustainability in developing countries. But there exists a close relationship between standard of living and energy use. In the previous section 4 we have shown that some aspects of energy consumption can be used to derive reliable indicators of poverty. For instance, the energy access-consumption matrix as a proxy indicator of poverty seems adequate in the context of orientation indices on the national level. Consequently, the energy system provides reliable indicator estimates for all the main sustainability areas, and we argue that the energy framework is useful for tracking sustainability on fairly aggregate levels.

5.2. Energy-based sustainability indicators

How should one choose the best possible set of sustainable development indicators? Although a number of researchers have formulated some guidelines, e.g. the Bellagio Principles (Hardi and Zdan, 1997), there is no standardised or commonly accepted methodology. However, some steps are usually mentioned. First, it is often recommended to formulate one’s own vision of sustainability and to identify the major issues that are relevant in the context of sustainable development. Next, a framework is constructed that addresses these issues (Meadows, 1998; Bossel, 1999). Such frameworks organise and link an entire sustainable development information system.

5.2.1. The energy framework

The proposed indicator set is based on a pragmatic notion of sustainability. To assure sustainability it is essential to give equal consideration and weight to economic, social, and environmental aspects. This means that a course of action for economic development that disregards environmental and social aspects is likely to be unsustainable, as are courses of action that focus only on social or environmental aspects while disregarding the economy. This idea assumes a special meaning in developing countries,
where sustainable development is a tightrope walk: fast development may not only help the economy but also alleviate poverty, and thus be needed urgently. However, it may contribute to worsening environmental public health-threatening conditions. Slow development could mean that poverty remains at an unacceptably high level, but it may have the advantage of tending to positive technology and business solutions adaptable to the local environmental conditions and rooted in local society. Sustainability depends not only on the speed of development but also on its direction. For example, one direction could be working towards improvement in education and public health without accumulating debt or overburdening companies and households with taxes. Another direction might be increasing public access to infrastructure while still charging enough for the accessed services. Thus, equity is considered to be an important criterion for whether or not the walk is on the tightrope.

The framework proposed here, i.e. the energy system, allows the selection of a small set of indicators that can be consistently projected and enables the tracking of sustainability. The key idea of the energy system framework is to see the world as flows of energy where every activity within the anthroposphere and the environment is linked by energy flows. Moreover, the two systems are interlinked by energy flows, as the energy people use is derived from energy resources in nature and finally results in heat in the environment. In addition, no means of harnessing or applying energy is completely free of adverse environmental impacts. Therefore, Ehrlich calls energy the ultimate resource and, at the same time, the ultimate pollutant (Ehrlich et al., 1970). Energy is not consumed but converted into different energy forms at various levels of the energy supply chain.

The energy framework also distinguishes fuel types and economic sectors. The outlined framework is nothing new, but the idea to use it as a framework for linking a set of sustainable development indicators is new. Although it appears rather crude, it has some specific advantages. First, since most of the commonly cited sustainability issues have links to energy use, they can be represented in the energy system. Thus, the selected energy-based indicator set can cover most relevant sustainability issues. This contrasts with economic or environmental models, where not all sustainability spheres can be described adequately. Even though, economic models may cover well economic and to a lesser extend also social issues, they are hardly useful for describing environmental issues like climate change. Second, the energy framework is based purely on physical units. This simplifies the formal modelling of the framework; interdependences and interactions between components or the selected indicators can be modelled and consistent future estimates can be developed. Moreover, the comparison of different demand and distribution scenarios enables the evaluation of different development paths and reveals possible trade-offs between sustainability goals (e.g. between intensified economic growth and the stabilisation of GHG emissions). On the other hand, the confinement to physical units also has some shortcomings. Some important social values like community integrity, identity, freedom, happiness, security, gender equality and self-respect are non-physical and therefore cannot be described within an energy-based framework. Moreover, also some
relevant environmental issues such as biodiversity are not measurable with energy indicators. However, the ambition here is not to cover and measure everything with energy indicators, but to map a small set of selected issues of paramount importance.

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**Figure 5.1. The energy system and the related sustainability dimensions.**

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**5.2.2. Energy-based indicators**

The list of energy indicators in use is nearly inexhaustible, e.g. IAEA (2005), EEA (2006) or DTI (2006). The question arises, which energy indicators are strongly linked to one or the other important sustainability topic and should be used within the small set of lead indicators. Since the selected
indicators are meant to form a small set of indicators, the set will be neither exhaustive nor exclusive. In addition, because social dimensions are difficult to measure with physical units like energy, they are bound to be under-represented in the set. Nevertheless, the aim is for these few indicators to cover the most important sustainability dimensions, which would allow a general evaluation of the development process, knowing that probably each person would choose a different set, according to his or her preferences. Moreover, the set presented here serves mainly for illustrative purposes, showing how the framework is applied. In this set, energy resources, economic activity, energy efficiency, climate change, air pollution, poverty and equity will be covered, with the specific circumstances in India taken into account (Figure 5.1).

Energy resource conservation

The basis of the energy system is built by the natural energy resource stock. In the very long run a sustainable energy system will by a large degree base on renewable energy sources. However, most of today's energy is consumed from finite fossil fuels. Careful use is required to ensure that future generations still have access to these energy sources or alternatively, that equivalent substitutes are developed. As an indicator of resource conservation, we propose the ratio of primary renewable energy to total primary energy used. This indicator would be misleading, if the availability of the renewable resources would be at risk. In India of today this is not the case. Within this paper it is assumed that in India the biomass, predominately fuel wood, is collected sustainably, as generally branches and twigs are collected from the ground, but no trees are chopped (Ravindranath and Hall, 1995). This contrasts the unsustainable combustion of the biomass in traditional inefficient cooking-stoves, an issues, which will be discussed in the paragraph on air pollution.

Economic activity and efficiency

There is a strong relationship between energy use and economic activity. In economic theory, energy is often included as a third input factor in the production function, in addition to capital and labour, and is therefore seen as one of the key drivers of economic growth. In India for instance, energy shortages are characterised as a major obstacle to economic growth (Asafu-Adjaye, 2000). However, the relationship between energy use and economic growth is reciprocal; higher development also induces higher energy use (Shyamal and Bhattacharya, 2004). Therefore, the input of total primary energy into the economy is used as indicator of its activity and performance.

The energy intensity of the economy, defined as the ratio of total energy consumption to economic output (GDP), is also considered. It indicates how efficiently the limited energy resources are employed for the production of goods and services. Differentiating the energy use of the economic sectors (transport, service, industry, agriculture) and their sector-specific energy intensities could enhance the indicator. This would allow avoiding that a very energy intensive, but very energy
efficient economy could be considered less efficient than a very energy inefficient service oriented economy. However, that is not done at this point.

Climate change

The greatest ecological risk facing the world today is probably climate change, caused by anthropogenic emissions of greenhouse gases (GHG). The lion’s share of anthropogenic greenhouse gas emissions stems from the combustion of fossil fuels. In India, more than 30% of the energy used is still renewable biomass (TERI, 2003). Generally, biomass is considered CO₂ neutral if the biomass is harvested sustainably, as is the case in India. Forest cover has remained constant since the 1980s (Ravindranath and Hall, 1995). However, a large part of this biomass is burnt in inefficient cooking stoves that divert substantial quantities of fuel carbon into products of incomplete combustion, which are far more potent greenhouse gases than CO₂ (Smith et al., 2000). Therefore, emissions from fossil and biomass fuels are included and the three most important greenhouse gases – CO₂, CH₄, and N₂O – are considered. The CO₂ equivalent emissions of these GHG are summed as an indicator of climate change.

Regional, local, and indoor air pollution

Another environmental problem related to combustion of fuels is local air pollution. Emitted NOₓ, SOₓ, VOC, and particulate matter are responsible for surface ozone and acid rain, and they also cause health damage and harvest losses. Unlike climate change, these are local environmental problems. In addition, the combustion technologies used significantly affect the amount and composition of released emissions. Consequently, for a measurement of local air pollution, the quantity of fuels consumed is not a sufficiently reliable indicator. Due to the complexity of this issue, a measure of regional air pollution is not included. However, an extensive emission inventory of India has already been compiled (Garg and Shukla, 2002). From it, we take the SOₓ and NOₓ emissions caused by fuel combustion as indicators of local air pollution.

While in developed countries indoor air pollution is largely a matter of tobacco smoke, in developing countries it is mainly caused by emissions from the indoor combustion of solid fuels like coal, charcoal, and biomass (wood, crop residues and dung). The use of these combustibles as energy sources for cooking and heating may lead to extremely high indoor concentrations of pollutants (Smith, 2000; Holdren and Smith, 2000; WHO, 2006). Indoor air pollution is one of the burdens of disease in developing countries, with an attributable mortality rate of about two million yearly (Ezzati et al., 2002). The exposure to pollutants is determined by the quantity of burnt fuel, the stove and ventilation system, inhabitants’ behaviour, and the location of the kitchen. However, this information is not available on a scale representative of the entire country. Nevertheless, the number of people living in households that rely on solid fuels for cooking can be used as an indicator of the number of people experiencing serious exposure.
Poverty and equity

As mentioned, in developing countries poverty alleviation has the greatest importance and must be taken into account when measuring sustainability. The elimination of poverty is associated with fulfilling the basic needs of individuals at some minimum level. Of course, for this to occur, a well-running economy is a prerequisite, and measures like the GDP/capita are useful indicators for the average wealth in a country. Wealth is not well-being, and one often gets a clearer picture when one is not just looking at averages but studying the distributions and identifying the poor households. For that reason, the economic performance of a country is not suitable for assessing poverty. However, this study looks at energy-based poverty measures, which can be linked to the energy system. A common way to estimate energy poverty is to apply the affordability of fuels and electricity, i.e. the budget share a household spends on fuels and electricity (IAEA et al., 2005). For instance, the Government of the United Kingdom defines a fuel-poor household as one which needs to spend more than 10% of its income on all fuel use (DTI, 2002). However, since poor households in developing countries generally rely on cheap but inferior biomass, such a measure would underestimate the extent of energy poverty. Therefore, the energy access-consumption matrix is applied as an indicator of poverty (Figure 3.3). The matrix separates the households into three different access categories and distinguishes four energy consumption categories. The cut-offs are not arbitrary; the segments correspond to the kind of energy services that reflect the range typically consumed in Indian households. According to the matrix, household members in the boxes on the left side of the poverty line are considered as poor.

Equity is closely related to poverty and well-being. The definition of equity applied herein does not take gender, generation or racial equity into account but does simply account for the equity in respect to energy consumption. If the energy use pattern of a household describes its well-being, then the distribution of energy use within a population can be applied as a measure of some sort of consumption or also income equity. To describe the distribution of energy use, the Gini-Index of access-adjusted useful energy is estimated (see section 4.1.1).

5.3. Tracking sustainable development

5.3.1. Performance of indicators for sustainable development in India

First, energy statistics and the proposed indicators are employed to describe the development of India between 1983 and 2000 (Table 5.1). The indicators show that the Indian economy grew quickly, especially in the late 1990s. Energy efficiency increased as well. However, the increase was not large enough to satisfy the growing energy demand, which led to a declining ratio of renewable to total primary energy. The increased demand for energy, in particular for fossil fuels, led to a considerable increase in emissions of GHG and other air pollutants. Although the share of people relying on inferior...
fuels for cooking has steadily declined from about 90% to 75%, the absolute number of people without access to clean energy sources for cooking has increased from 595 to 690 million. On the other hand, the percentage of people below the energy poverty line decreased from 1983 to 2000 by 50%, but the inequality between the wealthy and the poor remained at a high level.

<table>
<thead>
<tr>
<th>Sustainability criteria</th>
<th>Indicator</th>
<th>83/84</th>
<th>88/89</th>
<th>93/94</th>
<th>99/2000</th>
<th>2025 scenario</th>
<th>Tendency</th>
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<tr>
<td>Economic activity</td>
<td>Total primary energy consumption [MMT]</td>
<td>275.3</td>
<td>333.1</td>
<td>395.8</td>
<td>485.7</td>
<td>1135.8</td>
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<td>Efficiency</td>
<td>Energy intensity</td>
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<td>18.47</td>
<td>19.74</td>
<td>23.64</td>
<td>69.72</td>
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<td>Energy resource stock</td>
<td>Ratio of renewable and total energy resources used</td>
<td>0.49</td>
<td>0.42</td>
<td>0.40</td>
<td>0.36</td>
<td>0.14</td>
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<tr>
<td>Climate change</td>
<td>Sum of released CO2 equivalents due to energy use [MMT]</td>
<td>545</td>
<td>760</td>
<td>865</td>
<td>1075</td>
<td>3550</td>
<td></td>
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<tr>
<td>Local and regional air pollution</td>
<td>Fuel based emissions of SOx and NOx [MT]</td>
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<td>4.51/3.45</td>
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<td></td>
<td></td>
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<tr>
<td>Indoor air pollution</td>
<td>Number of people relying on solid fuels for cooking (million)</td>
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<td>625</td>
<td>622</td>
<td>690</td>
<td>585</td>
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<td>Poverty</td>
<td>Access-usage matrix poverty rate</td>
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<td>60.4</td>
<td>47.2</td>
<td>34.1</td>
<td>23.6</td>
<td></td>
</tr>
<tr>
<td>Equity</td>
<td>Gini-index of access-adjusted useful energy</td>
<td>0.4</td>
<td>0.485</td>
<td>0.49</td>
<td>0.49</td>
<td>0.49</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.1. The development of the indicators from 1983 to 2000 in India and a possible future scenario. Tendency arrows: the bright arrow indicates sustainable development and the dark arrow unsustainable development. The values for local air pollution are for the years 1990 and 1995, respectively; no values were available for the years 83/84 and 99/00. (Calculations based on data sources: a* (OECD/IAE, 2002), b* (GoI, 2005), c* (TERI, 2003), d* (Garg and Shukla, 2002), e* (NSS data), f* (Sundar and Deb, 2004).

Second, one set of consistent future indicator estimates is derived from an energy-economic model (Table 5.1, scenario 2025). For this purpose, energy demand data is employed from a model of infrastructure services in India in 2025 by Sundar and Deb (2004), which assumes average annual GDP growth of 8.5% and average annual population growth of 1.2%. Based on this growth path, the model derives the future energy demand for different economic sectors and fuel types. In addition, the model includes some assumptions of the number of households with access to commercial energy sources like electricity and LPG, but not on the distribution of the amount of energy consumed in the households. However, as the model results are a business-as-usual scenario, it is assumed that the level of inequality remains constant, as it was in the previous decade.
5.3.2. Assessing the system evolution

An important function of sustainability indicators is to highlight trades-offs. Here, two conflicting goals are stressed. First, the observed economic growth is based on increasing input of fossil fuels, which intensifies the pressure on the environment (increasing air pollution and GHG emissions) and augments the import dependency. Second, a considerable part of the population benefits little from the economic improvements and remains poor. As a consequence, the gap between the well-off and the poor is not reduced and the inequality remains at a high level.

To assess sustainability, it would be necessary to choose several development scenarios and calculate their respective indicator sets. Since every scenario is thus characterised by a particular and consistent set of indicators, it is possible to compare them, highlight trade-offs and differences, and assess the sustainability of one scenario versus another. The small number of indicators in the set simplifies the aggregate evaluation and helps to identify relatively sustainable scenarios.

The possibility of using an energy-economic model for tracking sustainability increases the benefit of such models. However, the models employed should provide information on all indicator-relevant variables. Although an assessment of relative sustainability is not done here, we have shown that the proposed energy indicator set can be consistently projected into the future by applying an energy-economic model.
6. Geography of electrification

According to Sen's capability framework (e.g. Sen, 1993, 1997), energy carriers can be understood as commodities or input factors that frame an individual's capability set and thus enable his functioning in society. In particular, electricity expands one's set of capabilities as it provides lighting, motive power and access to mass media and telecommunications, and permits cooling of rooms and the preservation of edibles. As seen in the previous sections, effective access is probably more important than consumed electricity quantity. Generally, indicators of well-being such as income, education or access to clean water increase with access to electricity, whereas the absence of any electricity use is often associated with poverty (IEA, 2002; Pachauri et al., 2004). Consequently, the relationship between household electricity consumption and poverty is bi-directional. On the one hand, access to electricity can contribute to poverty alleviation; on the other hand, lack of access is a sign of poverty.

Although electrification is an important development goal, a large share of the rural population in developing countries still lacks access to electricity. One observes remarkable regional differences in electrification, with areas in which the rate of electrified households is lower than in others. The aim of this section is to investigate the causes of the spatial disparities in electrification rates in India. To this end, factors that affect household access to electricity are analysed, and particular attention is given to the effects of geographic factors upon the village electrification process. If geographic factors indeed influence the village electrification process, then there would be a causal relationship between the geographic endowment of a region and its level of electrification. This could explain why certain states have more difficulty completing village electrification, and a determination of the barriers to electricity use may lead to improved household access and more reasonable tariffs.

Section outline

Subsection 6.1 provides some background on the current state of electrification in India, includes some theoretical considerations on poor areas and presents the applied analysis framework. In sections 6.2 and 6.3 two separate models for village and household electrification are introduced and discussed. Subsection 6.4 concludes with some general lessons that emerge from this analysis and a summary of key findings.
6.1. Background and analysis framework

6.1.1. Electrification of India

In developing countries there are still about 1.5 - 2 billion people who lack access to electricity, and 450 million of these individuals are in India alone. Despite the striking increase in power generation capabilities, India has been unable to keep up with its domestic demand for electricity. Besides the shortfall in power generation capability, India's transmission and distribution (T&D) infrastructure is inadequate to meet future demand. Moreover, due to high T&D losses, non-rational tariffs, and the fact that farmers are commonly provided with free electricity for irrigation pump-sets, the financial situation of state-owned utilities, the State Electricity Boards (SEB), dramatically worsened from the late 1980s to the 1990s. The importance that the utilities attribute to turning themselves around financially leads to their focusing on paying customers, who essentially are urban and industrial, while neglecting rural supply and electrification (Balasubramaniam and Shukla, 2003). In light of these disparities, new policies were introduced to restructure and reform the electricity sector: These include the Electricity Regulatory Commissions Act (1998), designed to promote investment friendliness and provide transparency in tariff-setting, and the Electricity Act (2003), which serves as a basis for a liberalised electricity market. By implementing these measures, the government aims to complete village electrification by 2007 and household electrification by 2012.

![village electrification in Indian states](image)

*Figure 6.1. The electrification rate, or share of electrified villages, in the 16 big states from 1970 – 2000. Data taken from CMIE (1995, 1999, 2002).*
Originally, India was demarcated into five electrical regions for planning, development and operation of the power system. For over three decades, the generation and transmission planning continued with regional self-sufficiency as an objective criterion, and consequently the inter-regional links were planned only for marginal exchange of power (CERC, 2005). The transmission links between India’s five regional electricity grids are still very limited, although Power Grid\textsuperscript{11} started to construct and operate regional system coordination centres to improve grid coordination and facilitate bulk power trading between the SEBs (ADB, 2000). Figure 6.1 shows the village electrification rate in the 16 big states from 1970 - 2000. The states Kerala, Tamil Nadu, Haryana and Punjab already had a high level of electrified villages in the early 1970s and completed all village electrification before 1980. The other states seem to have a similar rate of electrification and differ merely in their initial levels. However, in the states Orissa, Uttar Pradesh, West Bengal, Bihar and Assam, the village electrification process began to stagnate in the 1990s before being completed.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure6.2.png}
\caption{Percentage of electrified rural households per district. Calculations based on NSS data, round 55 (year 1999-2000).}
\end{figure}

\begin{table}
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Electrification Rate} & \textbf{Percentage} \\
\hline
Less than 10% & 0 - 10\% \\
11 - 25\% & 11 - 25\% \\
26 - 40\% & 26 - 40\% \\
41 - 55\% & 41 - 55\% \\
56 - 70\% & 56 - 70\% \\
71 - 85\% & 71 - 85\% \\
86 - 100\% & 86 - 100\% \\
No data & No data \\
\hline
\end{tabular}
\end{table}

\textsuperscript{11} The Power Grid Corporation is the central transmission utility of India with the mission to establish and operate regional and national power grids to facilitate transfer of electric power within and across the regions.
Today, 85% of Indian villages are electrified (Srivastava and Rehman, 2006). However, fewer than 60% of households actually consume electricity. In this way, one observes large spatial differences in electrification rate. This difference in village electrification rates among the states is illustrated in Figure 6.1. Moreover, there is a large difference between rural and urban areas. Calculations based on NSS data show that about 81.5% of urban households are electrified, whereas in rural areas this rate is only 46.2% (NSS data for 2000). Even within rural households there is a remarkable spatial heterogeneity in electrification rates, with some areas having a higher share of households without access to electricity than others (Figure 6.2). Electrification rates are particularly low in the eastern and north-eastern regions.

6.1.2. Poor areas, geography and electrification

Lack of access to electricity is generally related to energy poverty. Consequently, a spatial heterogeneity in access to electricity leads to spatial differences in energy poverty. In economic theory, two lines of explanations for regional differences in income poverty and poor areas are discussed (Crump, 1997). Researchers who employ an individualistic model assume that people are highly mobile and attribute no causal significance to spatial inequalities in resource endowments (geographic capital), although differences in geographic endowment may function as a sorting mechanism that leads to spatial poverty concentration (Henninger, 1998). Causes of poverty are identified at the individual level, and poor areas are described as consequences of personal decisions. On the other hand, researchers who use structural explanations suggest a causal link between the geographic endowment of a region and the general level of well-being of the people living in that area. It is assumed that local factors like land-use type, climate, infrastructure and access to services influence the marginal returns on investments. Because of limited mobility, structural differences in terms of natural resource endowment tend to persist and intensify between regions (Ravaillon, 1996). Each of the two theoretical models has shortcomings in explaining the spatial clustering of the poor, with a combination of individual and structural factors often identified as the cause of poverty and its spatial concentration12 (Miller, 1996). The degree to which individual or structural factors cause poverty has implications for developing a strategy to improve the situation of the poor (Henninger, 1998).

Are individual or infrastructural and geographic factors causing the regional differences in household electrification illustrated in Figure 6.2? Unlike income, the use of electricity traditionally requires a grid infrastructure. If a village is not electrified (that is, the village is not connected to a regional power grid), then no household within that village is able to consume electricity, irrespective of its

12 Here, structural factors include geographic endowment and infrastructure.
income or status. Even though the accessibility of electricity generally does not depend upon the availability of local resources, geographic factors are likely to influence the construction of the grid infrastructure and thus are relevant for explaining regional differences in village electrification rate. For instance, Chaurey reports that, within a given district, the electrification of a village may take place solely on account of its physical location (Chaurey et al., 2004). Also, certain land-use types may complicate the erection of the grid infrastructure, thus increasing costs and making the village’s connection financially unattractive. In this way, geographic endowment acts as a sorting mechanism by influencing the decision process as to which villages get electrified before others.

Although village electrification is traditionally a prerequisite for household access, there is a large gap between the share of electrified villages per state and the share of electrified households (Figure 6.3). The rate of village and household electrification is particularly low in the states of Assam, Bihar, Orissa, Uttar Pradesh and West Bengal. But even in states in which all the villages are officially connected to the power grid, large shares of the rural households do not use electricity. Moreover, in electrified villages, the proportion of households that actually consume electricity often varies considerably. Obviously, village electrification is an essential prerequisite for household electricity access, but it is not enough to guarantee it (Srivastava and Rehman, 2006). For there to be the possibility of electricity access, a grid not only has to reach a village, but it must also reach the neighbourhood and the street where the household resides.

![Figure 6.3. Comparison of village and household electrification rates per state. Both correlate well with per capita expenditure. Calculations based on NSS data, round 55 (year 1999-2000).](image)

13 Of course, this is only true disregarding stand-alone systems, which up to now have not been very widespread.
According to the literature on fuel switching, households climb up the rungs of the “energy ladder” by switching to or adding more convenient and more efficient energy sources in relation to their rising household income, assuming that the possibility of access is presented (Hosier and Dowd, 1987; Masera et al., 2000). Accordingly, income (expenditure), education, household size and fuel price are commonly the most significant factors for explaining the energy source choice of households, cf. UNDP/WB, 2003a; Heltberg, 2004. Generally, it is assumed that natural endowment has no effect on the utility of electricity use and thus does not influence the household’s decision whether to use electricity.

6.1.3. Analysis framework

Having observed the significance of household characteristics for household fuel choice, the dependence on grid infrastructure and the influence of geographic endowment on infrastructure erection, we see that a mix of individual, infrastructural, and geographical factors seems to cause the observed spatial disparities in electrification. We drew a distinction between the electrification of villages and the electrification of households, as the former is a prerequisite for the latter. Our hypothesis is that the electrification of villages is influenced by geographic endowment, whereas the use of electricity in electrified villages depends on household characteristics, the attributes of the electricity supply, and community electrification, but not on geographic factors themselves. The degree to which these factors cause the low electrification rates in certain regions has implications for developing a strategy to improve the situation of the people who lack access to electricity.

In order to take into account both village and household electrification, our analysis is based on a village electrification model as well as a household electrification model. Herein, village electrification is defined as the connection of a village to a regional power grid and is the traditional prerequisite for household electrification. Household electrification is defined as the connection of a household to its local community grid. In our study, the availability of data had a strong influence on the choice and the specification of the models. When setting out to do this research, we hoped to make use of the Census of India data, which is an immense household-level data set containing information on each and every household including its precise geographic location (village name). This would have afforded the construction of geographic variables that refer to single villages and their inhabitants and identify the decisive factors for village and household electrification. Unfortunately, the Census of India data seems to be inaccessible to researchers.

For this reason it was decided to make use of the NSS data set for the household electrification model. These data contain a large amount of information on households’ characteristics and their energy

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14 Aggregated Census of India data is available, but not at the household level.
consumption. However, this does not permit the localisation of the villages in which the households exist, and thus it is not possible for us to link the households with precise geographic variables. The NSS data only allow for the identification of the district containing a household. Therefore, the household data are combined with aggregated geographic district-level variables. Then, to estimate the factors affecting the household’s choice for using electricity, a discrete choice model is employed. Because the NSS data do not contain information on villages, they are not appropriate for the analysis of village electrification. Instead, we decided to use state level panel data that contain information on the share of electrified villages. The employed village electrification model is a panel data model that allows for the analysis of the effect of geographic endowment of the states on the process of village electrification, and is expressed in the rate of electrified villages. This approach is not without drawbacks, however, as it does not permit the identification of the factors that are relevant for the connection of single villages, and the high level of aggregation may blur effects of geographical variations within states.

Despite village electrification being a prerequisite for household electrification, no physical linkage between the two models was made. However, the NSS data allow for the construction of a proxy measure of community electrification, which is used in the household access model. This measure indicates whether the village in which a household resides is electrified as well as how comprehensively the village is electrified. Despite the drawbacks outlined above, the household and the village model together allow for an assessment of the factors influencing access to electricity and an explanation of the regional disparities in the electrification rate.

6.2. Village electrification

6.2.1. Model specification

The village electrification model is outlined first. What primarily concerns us is whether geographic endowment influences the process of village electrification. The principal actors in this process are the State Electricity Boards. They are responsible for power generation, transmission and distribution, and they own the intrastate lines. In the proposed model, it is assumed that the rate of electrified villages of a state (ER) – that is, the rate of electrified villages to the total number of villages in the state – depends mainly on the SEB’s built grid infrastructure (SEB), and, to a lesser extent, on the state’s general development and structure (S), and geographic endowment (Geo):

\[ ER = f(\text{SEB, } S, \text{ Geo}) \]  

[Eq. 6.1]

The SEB built infrastructure is represented by the variables length of installed T&D lines per state area and the T&D losses. Every connection of a village to the regional power grid requires the erection of additional grid infrastructure. Generally, the easily-accessible villages (those close to the
power plants) are connected first, while the remote villages are connected later\textsuperscript{15}. T&D losses are an indicator of the condition of grid infrastructure and show how well an SEB can maintain its grid\textsuperscript{16}. The T&D losses cause a loss of earnings and lessen the available electricity quantity, thus potentially resulting in fewer households being supplied. Initially, the variables *per capita available electricity, installed capacity* and *length of the railway net* were also considered in the model but were dropped later due to high correlation with other variables in the model or because they were insignificant (in the case of the railway).

The state development and structure vector (S) considers the per capita state domestic product (SDP) and the shares of the three main economic sectors at the SDP. Rural village electrification might have a higher priority in states that depend on the agriculture sector, and it is assumed that wealthier states can more easily afford to connect remote and less financially-attractive villages. In addition, the per capita SDP correlates highly with per capita available electricity ($p=0.92$) and thus corresponds well with electricity supply.

The geographic endowment (Geo) of the states is described by the variables *state area, the number of villages per state area, the share of agriculture area* and *the difference in altitude within the state*. Larger areas with a higher number of villages require longer transmission lines for the interconnection and thus cause higher costs. Therefore, it is assumed that these variables have a negative effect on the village electrification process. On the other hand, a high share of agricultural area might have a positive effect on electrification process when the modernisation of the agriculture sector (irrigation and crop processing) goes along with rural electrification. Some argue that agriculture electrification as opposed to village electrification was the main driver for rural electrification. For instance, according to Bhattacharyya, the energisation of the irrigation pump sets was for a long time a principal aim of rural electrification. Consequently, the level of electrification was not measured as a percentage of electrified households but in the extension of electricity lines to a particular area expressed by the percentage of electrified villages (Bhattacharyya, 2006). Mountains may form physical barriers and hamper the erection of power grids. The variable share of mountain area itself was not applicable, because in most of the states this land-use type exists only to a marginal extent. Therefore, the *variable altitude difference within a state* is used as a proxy variable. This measure correlates well with share of mountain area but is distributed more evenly among the states.

\textsuperscript{15} The connection of remote villages may require a proportionately greater number of additional transmission lines and thus the effect of new build transmission lines on village electrification might decline. To capture this effect, we tried to include the variable *squared length of transmission lines per area* in the model. However, due to multi-collinearity, this was not feasible.

\textsuperscript{16} The poor condition of grid infrastructure is not the only reason for high T&D losses in India: theft is very common, but there were not adequate data available to consider it in the model. However, electricity theft seems to be more prevalent in urban than rural areas.
Within this work it is assumed that the considered land-use types do not change over the observed time span. Thus, the geographic variables are treated as constants. To capture any common tendency of growing over time, a linear time trend is included in the model. It is likely that a region has a higher electrification rate if its adjacent regions have high a rate of electrification. A variogram analysis, which measures the difference of a characteristic between two locations in relation to their distance, shows some spatial correlation at the district level, and it is likely that such a correlation also exists on the state level. While the neighbourhood relationships between the states are not modelled explicitly, we will nevertheless allow for mutual correlation between the states, as described below.

6.2.2. Econometric method

The problem of village electrification shows some kind of censoring, since additional built power lines do not lead to a higher rate of electrified villages once all the villages are electrified. One way to deal with a censoring problem is to employ Tobit or Logit models. These approaches were not chosen here for two reasons. First, although there are a couple of observations with an electrification rate of around 0.99, there are only a few observations where all villages are electrified (~7%). Second, the data show high serial correlation, which cannot be dealt with using straightforward Tobit and Logit models. Instead, an arcsin-sinus-root transformation \((\text{arcsin}(\sqrt{ER}))\) was applied to improve the normality of the dependent variable (Mosteller and Tukey, 1977; Stahel, 2002). For the same reason, the logarithmic value of the variable length of the T&D lines per state area was employed. The model to estimate is therefore of the form:

\[
TER_i = a_0 + \beta_1 lntr_i + \beta_2 \text{area}_i + \beta_3 \text{vpa}_i + \beta_4 sa_i + \beta_5 ss_i + \beta_6 \text{area}_i + \beta_7 \text{vpa}_i + \beta_8 \text{sal}_i + \beta_9 \text{fd}_i + \epsilon_i \tag{Eq. 6.2}
\]

where \(TER_i\) is the arcsin-sinus-root transformed rate of village electrification, subscripts \(i\) and \(t\) denote the state and year, and \(\epsilon_i\) is an iid error term.

The above statistical model is estimated for a balanced panel data set consisting of 16 states over 29 years (464 observations). The repeated observations of a same state allow the use of panel data models that can account for unobserved heterogeneity across states. However, the number of states is considerably smaller than the number of periods (N<T). Such a data set, sometimes called time-series-cross-section data (TSCS), is an unusual case for widely used panel data specifications such as fixed effects and random effects models, in which T, the number of periods, is small relative to N, the number of units (Greene, 2003; Wooldridge, 2003). When the sample period is relatively short, one can assume that the individual effects remain constant. However, in long panel data these effects might change over time, resulting in the serial correlation of errors. The significant test statistics from
an autocorrelation test in panel data indicate the presence of serial correlation in the data (Wooldridge, 2002).

<table>
<thead>
<tr>
<th>variable</th>
<th>definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TER</td>
<td>arcsin-sinus-root transformed rate of village electrification</td>
</tr>
<tr>
<td>lntr</td>
<td>natural logarithmic transformed length of the transmission lines per state area</td>
</tr>
<tr>
<td>l</td>
<td>T&amp;D losses in percentage of production</td>
</tr>
<tr>
<td>pcsdp</td>
<td>per capita state domestic product (SDP)</td>
</tr>
<tr>
<td>sa</td>
<td>share of SDP generated in the agriculture sector</td>
</tr>
<tr>
<td>ss</td>
<td>share of SDP generated in the service sector</td>
</tr>
<tr>
<td>area</td>
<td>area of the state</td>
</tr>
<tr>
<td>vpa</td>
<td>number of villages per state area (village density)</td>
</tr>
<tr>
<td>aa</td>
<td>share of agriculture area</td>
</tr>
<tr>
<td>alti</td>
<td>difference in altitude within a state</td>
</tr>
<tr>
<td>t</td>
<td>linear time trend</td>
</tr>
</tbody>
</table>

Table 6.1. Variable definitions

For the above reasons, it was decided to pool the data across different states and use a heteroscedastic model with autoregressive errors that considers contemporaneous correlation between the cross-sections, as was proposed first by Parks (1967) and then discussed by Kmenta (1986). The Parks-Kmenta approach is attractive when \( N < T \), or when the within-variation of many explanatory variables is very low (Farsi et al., 2007). Both conditions hold here as \( T \) is significantly larger than \( N \) and the employed geographic variables are assumed to be time-constant. In the Parks-Kmenta model the cross-sectional heteroscedasticity captures the unobserved heterogeneity across states, while the serial correlation is modelled through an autoregressive error structure. Geographic entities like regions or states are generally not mutually independent of each other but show contemporaneous correlation\(^{17}\). When this correlation is taken into account, the model may be termed a cross-sectionally-correlated and first-order autoregressive model. The particular characterisation of this model is:

\[
E(\varepsilon_{it}^2) = \sigma_{ii} \quad \text{(heteroscedasticity)}
\]

\[
E(\varepsilon_{it}\varepsilon_{ij}) = \sigma_{ij} \quad \text{(contemporaneously correlation)}
\]

\[
\varepsilon_{it} = \rho \varepsilon_{it-1} + \mu_{it} \quad \text{(autoregressive errors)}
\]

A likelihood ratio test indicates the use of state-specific first-order autocorrelation parameters \( \rho_i \). The Parks-Kmenta method consists of two sequential feasible generalized least squares (FGLS)

\(^{17}\) A likelihood ratio test provides evidence for a correlation between the states (cross-sections).
transformations. First, autocorrelation is removed and then the contemporaneous correlation of errors is eliminated. In this way, the correction for the contemporaneous correlation automatically corrects for any cross-sectional heteroscedasticity.

Beck and Katz argue that the estimated standard errors in the Parks-Kmenta model may be underestimated (Beck and Katz, 1995). Therefore, the model has also been estimated using an OLS model with panel specific first-order autoregressive errors and panel corrected standard errors (PCSE) as proposed by Beck and Katz for TSCS data. This approach assumes that the disturbances are heteroscedastic and contemporaneously correlated across panels, too. However, it is usually less efficient than the Parks-Kmenta model.

6.2.3. Data

The employed state level panel data covers yearly data for the 16 big Indian states over the years 1970–1999. The yearly data on electrified villages and the SEB indicators are taken from the Energy statistic books from the Centre for Monitoring Indian Economy (CMIE, 1995, 1999, 2002). The data on the state domestic product relies on work of the Economic and Political Weekly Research Foundation (EPWRF, 2003) and the information on the number of villages per state is taken from the Census 1991 (Census of India, 1991). Although the village numbers seem to change slightly over time when compared with the results of other surveys, we decided to consider them constant over time.18 The state level geographic variables were generated in a GIS.

<table>
<thead>
<tr>
<th>variable</th>
<th>mean</th>
<th>std. dev.</th>
<th>minimum</th>
<th>maximum</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>rate of electrified villages</td>
<td>0.692</td>
<td>0.299</td>
<td>0.025</td>
<td>1</td>
<td>464</td>
</tr>
<tr>
<td>T&amp;D lines per area [km/1000km2]</td>
<td>1999.08</td>
<td>1562.73</td>
<td>90.28</td>
<td>6757.04</td>
<td>464</td>
</tr>
<tr>
<td>losses [% of production]</td>
<td>0.210</td>
<td>0.063</td>
<td>0.047</td>
<td>0.58</td>
<td>464</td>
</tr>
<tr>
<td>pc SDP in 1000 Rs.</td>
<td>0.182</td>
<td>0.082</td>
<td>0.060</td>
<td>0.487</td>
<td>464</td>
</tr>
<tr>
<td>share of agricultural sector</td>
<td>0.425</td>
<td>0.109</td>
<td>0.161</td>
<td>0.656</td>
<td>464</td>
</tr>
<tr>
<td>share of service sector</td>
<td>0.347</td>
<td>0.071</td>
<td>0.200</td>
<td>0.521</td>
<td>464</td>
</tr>
<tr>
<td>share of industry sector</td>
<td>0.228</td>
<td>0.062</td>
<td>0.067</td>
<td>0.397</td>
<td>464</td>
</tr>
<tr>
<td>area [Mio. km2]</td>
<td>0.157</td>
<td>0.105</td>
<td>0.032</td>
<td>0.391</td>
<td>16</td>
</tr>
<tr>
<td>villages per km2 (</td>
<td>0.241</td>
<td>0.134</td>
<td>0.043</td>
<td>0.507</td>
<td>16</td>
</tr>
<tr>
<td>share agriculture area</td>
<td>0.608</td>
<td>0.180</td>
<td>0.229</td>
<td>0.903</td>
<td>16</td>
</tr>
<tr>
<td>difference altitude [1000m]</td>
<td>1.956</td>
<td>1.179</td>
<td>0.875</td>
<td>5.675</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 6.2. Descriptive statistics of the parameters used in the village electrification analysis. (SDP in constant prices, base year 1981)

18 This restriction allows avoiding decreasing electrification rates when the number of villages is “increasing,” particularly with regard to the possibility that the actual number of villages is not increasing, but merely the number noted in the official statistic.
6.2.4. Results of the village electrification analysis

The estimation results for the two village electrification models are given in Table 6.3. The coefficients of both SEB variables are significant and show the expected direction signs: electrification increases with additional installed power lines but is constrained by T&D losses. The per capita SDP coefficient also has the expected positive sign and is significant. As expected, the OLS model with panel corrected standard errors (PCSE) shows larger standard errors than the Parks-Kmenta model; the variables T&D losses and per capita SDP are no longer significant. However, all other variables, including the geographic variables, stay significant and show the same direction signs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parks-Kmenta estimate</th>
<th>se</th>
<th>OLS PCSE estimate</th>
<th>se</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln trans. lines/area</td>
<td>0.103</td>
<td>0.008 ***</td>
<td>0.117</td>
<td>0.020 ***</td>
</tr>
<tr>
<td>losses</td>
<td>-0.022</td>
<td>0.012 *</td>
<td>-0.024</td>
<td>0.027 -</td>
</tr>
<tr>
<td>pc. SDP</td>
<td>0.166</td>
<td>0.066 **</td>
<td>-0.045</td>
<td>0.150 -</td>
</tr>
<tr>
<td>share agriculture</td>
<td>-0.145</td>
<td>0.029 ***</td>
<td>-0.178</td>
<td>0.075 **</td>
</tr>
<tr>
<td>share service</td>
<td>-0.025</td>
<td>0.045 -</td>
<td>-0.065</td>
<td>0.113 -</td>
</tr>
<tr>
<td>area</td>
<td>-0.567</td>
<td>0.091 ***</td>
<td>-0.856</td>
<td>0.212 ***</td>
</tr>
<tr>
<td>village density</td>
<td>-1.032</td>
<td>0.058 ***</td>
<td>-1.186</td>
<td>0.128 ***</td>
</tr>
<tr>
<td>share agriculture area</td>
<td>0.394</td>
<td>0.078 ***</td>
<td>0.550</td>
<td>0.214 ***</td>
</tr>
<tr>
<td>difference altitude</td>
<td>0.058</td>
<td>0.010 ***</td>
<td>0.041</td>
<td>0.023 *</td>
</tr>
<tr>
<td>time trend</td>
<td>0.018</td>
<td>0.001 ***</td>
<td>0.024</td>
<td>0.002 ***</td>
</tr>
<tr>
<td>intercept</td>
<td>0.012</td>
<td>0.055 -</td>
<td>-0.073</td>
<td>0.159 -</td>
</tr>
</tbody>
</table>

Table 6.3. Regression results of the village electrification models. *** , ** and * refer to 1%, 5% and 10% levels of significance, respectively.

Economic structure also shows a significant effect on village electrification, but the nature of the effect is somewhat different than expected. First, there seems to be no difference between the service and industrial sectors. Although the coefficient share service sector is slightly negative, this is not significant. The share of agriculture, however, shows a significant and negative effect. Consequently, village electrification seems to be lower in states with an SDP depending heavily on agriculture. On the other hand, the model shows a significant and positive effect for the share of agricultural area, demonstrating that agriculture electrification is an important driver for rural electrification. This means that the level of village electrification is higher in regions with large agricultural areas where electricity is used for irrigation and crop processing. Therefore, village electrification is higher in states that, despite having large agricultural areas, have modern economies that do not depend on agriculture.

The variable difference in altitude was employed as a proxy variable for mountainous areas, as it was assumed that mountains form physical barriers that hamper village electrification. The coefficient difference in altitude is significant but, in contrast to expectations, has a positive sign. Perhaps
difference in altitude is a bad proxy variable for mountainous areas, or the unexpected direction sign is due to the high level of regional aggregation

The coefficients of the variables state area and number of villages per area are both highly significant and show the expected negative sign, indicating a constraining effect on the electrification process. An additional descriptive analysis reveals that those five states that have the lowest electrification rates by far (Bihar, Orissa, Assam, West Bengal and Uttar Pradesh) show the highest number of villages per area. Moreover, a look at the village composition of these states indicates that these states also have a high proportion of small villages (Figure 6.4 and 6.5). Two of the other states with a high proportion of small villages, Madhya Pradesh and Rajasthan, could not electrify all their villages yet either. Obviously, it is more difficult and less economically attractive to connect many small villages with few paying customers than to connect only a few larger villages with lots of potential customers. In addition, the unfavourable village structure may have aggravated the financial misery of these SEBs. The constraining effect of state area is smaller and thus less relevant than village structure for explaining the regional differences in village electrification.

![villages per 10 km²](image)

**Figure 6.4. Village density in the larger Indian states. Calculations based on data from Census of India (1991).**

19 The direction signs and significance levels do not change if the model is estimated without this variable but, because the coefficient was significant, the variable was not removed from the model.
6.3. Household electrification

6.3.1. Model specification

In the second model the focus is on the electrification of households. As the focus here is on access, the factors that determine a rural household’s choice whether to use electricity are analysed without taking the consumed electricity quantity into account. In the proposed binary choice model it is assumed that the choice of the households is based on the utility of the alternatives of using or not using electricity. The restricted utility \( U \) can be represented by the function:

\[
U = f(H, E, C, L) \tag{6.3}
\]

where \( H \) is a vector of household characteristics, \( E \) refers to a vector describing the attributes of the electricity supply, \( C \) refers to a vector of the community electrification and \( L \) refers to a vector of geographic location variables. The vector of household characteristics (\( H \)) considers the variables of per capita expenditure, household size, education levels of husband and wife, age and sex of the head of the household, access to liquefied petroleum gas (LPG), and information on employment type category and social group affiliation. The attributes of electricity supply (\( E \)) are described using the electricity tariff, the percentage of forced outages as a measure of the supply quality, and the supply of the alternative fuel kerosene. Low supply quality may be an important factor for not using electricity. For instance, Alam reports that, despite the growing importance of electricity, its supply is the most erratic among all major energy sources (Alam et al., 1998). Because the variable \textit{percentage of forced outages} refers only to outages of fossil power plants, the variable \textit{share of fossil production} was considered in the model to control for the relevance of the fossil production. Unfortunately,
information on costs of connection and internal wiring was not available and could therefore not be
included. To facilitate electricity access for the poor, the SEBs offer initial electricity units at a
reduced tariff. This subsidised, non-cost-effective electricity tariff is the tariff considered in the
model. Other policies including the “Bright Home Programme,” the national policy scheme to
facilitate household electricity access (Kutir Jyoty), are not taken into account.

As access to electricity requires the availability of grid infrastructure, it is necessary to control for
whether or not a household can effectively choose to use electricity. Because this information is not
directly recorded in the NSS data set, a proxy was created. As a grid has not only to reach a village but
the neighbourhood and the street where the household exists as well, it follows that the likelihood that
access possibility is given is higher the better the electrification is within the village. For this reason,
the vector community electrification (C) is employed to control for the potential access possibility.
This vector considers two variables: the availability of other infrastructure, expressed by the length of
the railroad and highway net per district area, and the share of neighbouring households from the same
sample village that are using electricity. For instance, if none of the neighbouring households is
using electricity, then the village is probably not electrified and it is unlikely that the household has
potential access. On the other hand, the greater the number of neighbouring households using
electricity, the more comprehensively the community is electrified and the higher the likelihood that
access possibility is given.

In order to test whether the geographic endowment indeed has no direct effect on household choice,
some geographical variables were included in the analysis as well; they include average yearly
rainfall, temperature, altitude and shares of land-use types, all variables aggregated at the district
level. Additionally, state dummies were considered in the model to capture other regional effects that
are not caused by geographic factors (L). To avoid multi-collinearity between the explanatory
variables, some states had to be grouped into mini-regions.

---

20 Average tariff for 1 kW rural (50kWh/mth) in Paises/kWh.
21 Households below the poverty line are eligible for a single point connection. The central government bears the
entire cost of service connection and internal wiring. Only about 550,000 households have participated in the
programme (REC, 2006).
22 The employed NSS data is structured into first sample units (FSU), usually a village or a city block each
containing 12 household observations. Although the NSS data does not permit the identification of the exact
localisation of the FSU, it is possible to identify which households belong to the same FSU and to calculate for
every household observation the share of electrified neighbouring households in the FSU. In other studies, e.g.
Heltberg (2004), a community is considered to be electrified if one of the households in the sample unit is
electrified and not electrified otherwise. We think it is more appropriate to describe the community
electrification as something continuous rather than with a dummy variable, particularly when the proxy variable
is based on a small sample of 12 observations.
23 As mentioned in section 6.1.3, the NSS data do not allow a further spatial disaggregation.
6.3.2. Econometric method

In the proposed binary choice model it is assumed that the choice of household $i$ is based on utility, which can be expressed as follows:

$$U_{i0} = H_i \lambda_0 + E_i \gamma_0 + C_i \rho_0 + L_i \delta_0 + \varepsilon_{i0} \quad \text{[Eq. 6.4]}$$
$$U_{i1} = H_i \lambda_1 + E_i \gamma_1 + C_i \rho_1 + L_i \delta_1 + \varepsilon_{i1} \quad \text{[Eq. 6.5]}$$

where $U_1$ is the utility due to using electricity, $U_0$ the utility due to not using electricity, $H, E, C$ and $L$ are the vectors of the explaining variables and $\lambda, \gamma, \rho$ and $\delta$ the corresponding vectors of coefficients and $\varepsilon_i$ the stochastic part, capturing the uncertainty. Following the model, a household $i$ does choose to use electricity if the utility of using it ($U_1$) is larger than the utility of not using it ($U_0$). In random utility models, the net utility for individual $i$ is described by a latent variable $y_i^*$. The decision rule is therefore:

$$y_i^* = U_{i1} - U_{i0} \begin{cases} > 0 & \rightarrow \text{choose 1} \\ \leq 0 & \rightarrow \text{choose 0} \end{cases} \quad \text{[Eq. 6.6]}$$

$$= X_i \beta + u_i \quad \text{with } u_i = \varepsilon_{i1} - \varepsilon_{i0} \quad \text{[Eq. 6.7]}$$

where $X$ is the vector of all the explanatory variables of the vectors $H, E, C$ and $L$, $\beta$ is the corresponding vector of coefficients and $u_i$ the stochastic part. In order to estimate the vector of coefficients, a Probit model is employed. As the net utility itself is not observable but the choice $Y$, in Probit models the probability of choosing electricity is defined as:

$$Pr(Y_i = 1 \mid X_i) = Pr(y_i^* > 0 \mid X_i) = F(X_i \beta) \quad \text{[Eq. 6.8]}$$

where $F$ is the cumulative normal distribution function and $Y$ is the observed household choice. As an alternative, a Logit model is estimated and the results compared. To avoid heteroscedasticity, robust standard errors are employed.

6.3.3. Data

The analysis of household electrification depends mainly on NSS unit-level budget survey data (round 55, year 1999/2000). The employed rural sub-sample of the 16 big Indian states contains almost 60,000 household observations and, being this large, is representative of the rural population as a whole. The state-level information on electricity tariffs, forced outages, energy mix and number of kerosene dealers is taken out of the Energy statistic book by the Centre for Monitoring Indian Economy (CMIE, 2002). The data are complemented by geographic district-level variables generated.

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24 Some states created after 1999 are included within these 16 big states; Uttar Pradesh includes Uttaranchal, Madhya Pradesh includes Chattisgarh and Bihar includes Jharkhand, respectively.
in a GIS. The employed geographic variables describe average values for each of the 428 districts of the 16 states considered. Table 6.4 and Table 6.5 show the descriptive statistics. The estimates are unweighted and thus do not describe the rural population but the applied sample.

<table>
<thead>
<tr>
<th>variables</th>
<th>mean</th>
<th>std. dev.</th>
<th>minimum</th>
<th>maximum</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>user electricity</td>
<td>0.49</td>
<td>0.50</td>
<td>0</td>
<td>1</td>
<td>59543</td>
</tr>
<tr>
<td>per capita expenditure [Rs./month]</td>
<td>331.94</td>
<td>249.93</td>
<td>25.8</td>
<td>16376.4</td>
<td>59543</td>
</tr>
<tr>
<td>household size</td>
<td>5.34</td>
<td>2.78</td>
<td>1</td>
<td>36</td>
<td>59543</td>
</tr>
<tr>
<td>share of electrified neighbours</td>
<td>48.73</td>
<td>36.14</td>
<td>0</td>
<td>100</td>
<td>59543</td>
</tr>
<tr>
<td>transport infrastructure length /area [km/100km²]</td>
<td>4.57</td>
<td>2.88</td>
<td>0</td>
<td>15.41</td>
<td>428</td>
</tr>
</tbody>
</table>

Table 6.4. Descriptive statistics for variables. *monthly expenditure, real values with base year 1993/94.

<table>
<thead>
<tr>
<th>dummy variables</th>
<th>1 if, 0 otherwise</th>
<th>Frequency [%]</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>household variables</td>
<td></td>
<td></td>
<td>59543</td>
</tr>
<tr>
<td>husband illiterate</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>husband primary education</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>husband secondary or higher education</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wife illiterate</td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wife primary education</td>
<td>0.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wife secondary or higher education</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>no wife in household</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>no husband in household</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>age head &lt; 30 years</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>age head &gt; 50 years</td>
<td>0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>household with Access to LPG</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>social group code is tribe</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>social group code is caste</td>
<td>0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>self-employed</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>self-employed in agriculture sector</td>
<td>0.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6.5. Descriptives for dummy variables.

Table 6.5: Descriptives for dummy variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>wage labourer</td>
<td>0.07</td>
</tr>
<tr>
<td>wage agriculture labourer</td>
<td>0.29</td>
</tr>
<tr>
<td>other employment type</td>
<td>0.11</td>
</tr>
<tr>
<td>district level variables</td>
<td>428</td>
</tr>
<tr>
<td>average temperature &lt; 25°C</td>
<td>0.10</td>
</tr>
<tr>
<td>average temperature &gt; 27.5°C</td>
<td>0.09</td>
</tr>
<tr>
<td>average yearly rainfall &lt; 650mm</td>
<td>0.23</td>
</tr>
<tr>
<td>average yearly rainfall &gt; 1650mm</td>
<td>0.12</td>
</tr>
<tr>
<td>average altitude &lt; 75m</td>
<td>0.13</td>
</tr>
<tr>
<td>average altitude &gt; 400m</td>
<td>0.25</td>
</tr>
</tbody>
</table>

6.3.4. Results of the household electrification analysis

The estimation results of the household choice model are given in Table 6.6. The R² proves satisfying for such a large and heterogeneous cross-section sample, and the coefficients show the expected direction signs. All household variables are highly significant, apart from the employment type self-employed. The marginal probability effects at the mean (MPE) are shown in the last row of Table 6.6. The MPE measures the marginal change in the probability of observing electricity use in the household given a marginal change in the explaining variable. For the logarithmic variables of expenditure and household size, reported numbers can be interpreted directly as a change in percentage points. For instance, an increase in expenditure by one percent corresponds to an increase in logarithmic expenditure by 0.01.

A comparison of the MPE reveals a high correlation between household educational level and household electricity decisions. The probability of electricity use increases considerably as the education levels of the husband and wife in a household rise. On the other hand, the probability is lower in households in which the head is widowed, single or young, and in smaller households. Generally, a close relationship between access to electricity and access to LPG is observed. Only about 6-7% of LPG users have no access to electricity (year 2000). This relationship is reproduced in the high MPE of the variable access to LPG. Although this close relationship is observed, the reason for its existence is not quite clear. Some possible explanations for the electricity – LPG nexus are given in the UN/WB study (2003) and in Barnes et al. (2005). For instance, in the UN/WB study it is stated that "areas that are in some sense more "modern" (for example large as opposed to small

---

25 Estimations based on a Logit model show very similar results, see Table 7.2 in the appendix for comparison.

26 Because the effect is not clear, the model has also been estimated without this variable. The estimated coefficients hardly changed.
towns and places with better infrastructure) get connected first to the electricity grid”, whereby the availability of an LPG market can be considered a sign of better infrastructure.

<table>
<thead>
<tr>
<th>variables</th>
<th>coefficient</th>
<th>robust std.err.</th>
<th>sign level</th>
<th>MPE at mean dy/dx</th>
</tr>
</thead>
<tbody>
<tr>
<td>in pc expenditure</td>
<td>0.734</td>
<td>0.021</td>
<td>***</td>
<td>0.292</td>
</tr>
<tr>
<td>in household size</td>
<td>0.572</td>
<td>0.016</td>
<td>***</td>
<td>0.228</td>
</tr>
<tr>
<td>husband illiterate</td>
<td>-0.215</td>
<td>0.018</td>
<td>***</td>
<td>-0.085</td>
</tr>
<tr>
<td>husband education sec./ higher</td>
<td>0.190</td>
<td>0.021</td>
<td>***</td>
<td>0.076</td>
</tr>
<tr>
<td>no husband</td>
<td>-0.106</td>
<td>0.031</td>
<td>***</td>
<td>-0.042</td>
</tr>
<tr>
<td>wife illiterate</td>
<td>-0.152</td>
<td>0.021</td>
<td>***</td>
<td>-0.060</td>
</tr>
<tr>
<td>wife education sec./ higher</td>
<td>0.089</td>
<td>0.029</td>
<td>***</td>
<td>0.036</td>
</tr>
<tr>
<td>no wife</td>
<td>-0.165</td>
<td>0.032</td>
<td>***</td>
<td>-0.065</td>
</tr>
<tr>
<td>age group young</td>
<td>-0.065</td>
<td>0.025</td>
<td>***</td>
<td>-0.026</td>
</tr>
<tr>
<td>age group old</td>
<td>0.148</td>
<td>0.015</td>
<td>***</td>
<td>0.059</td>
</tr>
<tr>
<td>user LPG</td>
<td>0.528</td>
<td>0.042</td>
<td>***</td>
<td>0.206</td>
</tr>
<tr>
<td>tribe</td>
<td>-0.157</td>
<td>0.025</td>
<td>***</td>
<td>-0.062</td>
</tr>
<tr>
<td>caste</td>
<td>-0.145</td>
<td>0.019</td>
<td>***</td>
<td>-0.057</td>
</tr>
<tr>
<td>self employed</td>
<td>-0.023</td>
<td>0.022</td>
<td>-</td>
<td>-0.009</td>
</tr>
<tr>
<td>labour</td>
<td>-0.239</td>
<td>0.029</td>
<td>***</td>
<td>-0.093</td>
</tr>
<tr>
<td>labour in agriculture sector</td>
<td>-0.396</td>
<td>0.020</td>
<td>***</td>
<td>-0.155</td>
</tr>
<tr>
<td>other employment type</td>
<td>0.111</td>
<td>0.026</td>
<td>***</td>
<td>0.044</td>
</tr>
<tr>
<td>neighbourhood electrification</td>
<td>0.026</td>
<td>0.0003</td>
<td>***</td>
<td>0.010</td>
</tr>
<tr>
<td>transport infrastructure</td>
<td>0.012</td>
<td>0.003</td>
<td>***</td>
<td>0.005</td>
</tr>
<tr>
<td>minimum electricity tariff</td>
<td>-0.001</td>
<td>0.0003</td>
<td>***</td>
<td>-0.0005</td>
</tr>
<tr>
<td>kerosene dealers/pop</td>
<td>0.051</td>
<td>0.007</td>
<td>***</td>
<td>0.020</td>
</tr>
<tr>
<td>% outages</td>
<td>-0.033</td>
<td>0.001</td>
<td>***</td>
<td>-0.013</td>
</tr>
<tr>
<td>share fossil production</td>
<td>0.011</td>
<td>0.001</td>
<td>***</td>
<td>0.004</td>
</tr>
<tr>
<td>average temperature &lt; 25°C</td>
<td>0.035</td>
<td>0.033</td>
<td>-</td>
<td>0.014</td>
</tr>
<tr>
<td>average temperature &gt; 27.5°C</td>
<td>0.044</td>
<td>0.036</td>
<td>-</td>
<td>0.017</td>
</tr>
<tr>
<td>average yearly rainfall &lt; 650mm</td>
<td>0.021</td>
<td>0.025</td>
<td>-</td>
<td>0.008</td>
</tr>
<tr>
<td>average yearly rainfall &gt; 1650mm</td>
<td>0.026</td>
<td>0.040</td>
<td>-</td>
<td>-0.010</td>
</tr>
<tr>
<td>average altitude &lt; 75m</td>
<td>-0.036</td>
<td>0.028</td>
<td>-</td>
<td>-0.014</td>
</tr>
<tr>
<td>average altitude &gt; 400m</td>
<td>-0.005</td>
<td>0.022</td>
<td>-</td>
<td>-0.002</td>
</tr>
<tr>
<td>share forest area</td>
<td>0.0001</td>
<td>0.001</td>
<td>-</td>
<td>0.00004</td>
</tr>
<tr>
<td>share mountain area</td>
<td>-0.001</td>
<td>0.002</td>
<td>-</td>
<td>-0.0005</td>
</tr>
<tr>
<td>share irrigated crop area</td>
<td>-0.0005</td>
<td>0.0004</td>
<td>-</td>
<td>-0.0002</td>
</tr>
<tr>
<td>share grazing area</td>
<td>0.001</td>
<td>0.001</td>
<td>-</td>
<td>0.0003</td>
</tr>
<tr>
<td>share unproductive area</td>
<td>-0.001</td>
<td>0.002</td>
<td>-</td>
<td>-0.001</td>
</tr>
<tr>
<td>share water area</td>
<td>-0.001</td>
<td>0.003</td>
<td>-</td>
<td>-0.0003</td>
</tr>
<tr>
<td>share other area</td>
<td>-0.005</td>
<td>0.001</td>
<td>***</td>
<td>-0.002</td>
</tr>
<tr>
<td>state dummies</td>
<td>-6.480</td>
<td>0.158</td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

n=59543  
R2: 0.4787  
Log pseudolikelihood = -21504.657

Table 6.6. Results of the Probit model for household electrification. Omitted categories include education: primary education of man and woman; employment type: self-employed agriculture; land-use type: non-irrigated crop area. *** refers to a 1% level of significance.
Although economically poor areas largely coincide with those with low household electrification rates, the causal relationship between the two appears to be weak. That is, per capita expenditure shows only a relatively small effect on a household’s decision to have electricity. A rise in expenditure of 1% increases the probability of electricity use by only 0.29%. The effect would possibly be larger if the access cost for connection and internal wiring were included in the model, or if electricity consumption were less subsidised. Furthermore, the effect could be quite different for households far away from the population mean which include, for instance, the poorest segment. However, this seems not to be the case in that an estimation of the MPE for lower income groups does not show larger effects. Figure 6.6 illustrates relative deviations from the mean MPE for different population subgroups. It shows that the MPE is even smaller in lower income groups. For the first expenditure decile (p10) the MPE is about 12% lower than at mean expenditure. The MPE is smaller for the highest decile as well (7% smaller).

Moreover, the subsidised electricity tariff shows only a small effect (MPE: -0.0005). This means that a reduction in the mean tariff by 10Rs. (-7.5%) would result in an increase in probability by 0.5%. Figure 6.6 shows that the MPE of the tariff is not sensitive to the level of tariff. The deviation from the mean effect is only marginal for higher and lower tariffs. The quality of the supply seems to be more

27 In the model, all households within one state pay the same electricity tariff and enjoy the same supply quality. Therefore, for the state level variables, only 16 different values were available for the statistical analysis. In an additional estimation, the option robust cluster was applied, which allows for correcting the standard errors for intragroup correlation in STATA. The significance level of the coefficients, however, did not change.
relevant than the electricity price; a decrease of 1% in outages increases the probability by about 1.3%. The availability of kerosene does not show a negative effect on electricity use. This demonstrates the fact that kerosene is often used as a complementary fuel to compensate for the erratic electricity supply rather than as an alternative energy source. Furthermore, kerosene is also used for cooking, a use for which electricity is not available as a substitute.

The social groups’ scheduled castes and tribes, and in particular the employment type groups’ labour and labour in agriculture, use significantly less electricity. For instance, the probability of electricity use is 15.5% lower in households in which the head is working in agricultural labour as opposed to being self-employed in agriculture. It is unclear whether these people value the benefit of electricity less or if they suffer some sort of access discrimination. These lower social groups generally live in poorer and thus potentially less-electrified neighbourhoods. Therefore, it might be more difficult for them to obtain a household connection even if they were able to afford it. On the other hand, if farm land were made accessible to electricity for irrigation, then the farm of the land-owning, self-employed agricultural worker most probably would have access as well. In any case, community electrification proves to be a crucial factor for household access. It was assumed that a higher share of electrified neighbours signifies a better access situation and a higher likelihood that the household gets connected itself. The estimations confirm this hypothesis: the coefficient share of electrified neighbours is clearly positive and highly significant. Density of highway and railroad infrastructure, the other applied proxy variable for community electrification, is less relevant despite being highly significant. On the other hand, as expected, none of the geographic variables is significant except for share of other area. This variable stands for a mix of different minor land-use types which are found only in certain states, and thus the effect is difficult to interpret. Nevertheless, the hypothesis that the coefficients of geographic factors are zero cannot be rejected, and we therefore conclude that geographic factors have no direct effect on the utility of electricity.

6.4. Conclusion

This research set out to combine conventional household- and village-level data with a GIS in order to identify geographic factors which could potentially effect electrification rates and cause regional disparities in access. While this approach offers great potential for gaining new insights, the necessary conditions were not yet fully available to exploit its entire potential. The Census of India is not made accessible for public research and therefore more highly aggregated data had to be used. The NSS and SEB data employed as an alternative permit linking geographic data only to the district and state levels respectively. Despite these limitations, the presented analysis allows for an explanation of the observed regional disparities in electrification according to a combination of factors influencing household electrification and grid availability. Areas experiencing the lowest electrification rates are
such as a result of poor household characteristics and low local grid availability. In this way, some geographic variables are relevant for grid availability but not for household access. A region’s having a high proportion of agricultural area correlates positively with village electrification, which demonstrates the importance of agriculture electrification as a driver for rural electrification. On the other hand, an unfavourable village structure and a large state area constrain the village electrification process. In particular, areas with small but numerous villages seem to have lower village electrification rates. Thus, this analysis provides some evidence for a causal relationship between the man-made geographic endowment of a state and its level of village electrification. However, geographic factors influence only the speed of the erection of regional infrastructure and act temporally as a sorting mechanism; they seem not to affect electrification inside the villages, as they do not change the utility of electricity use.

Even though economically poor areas largely coincide with areas with low household electrification, an analysis of household choice has shown that expenditure has an attenuated effect. Indeed, an increase in expenditure alone would hardly improve low household access rates, although a higher household expenditure in a region might increase the incentive for the utilities to expand grid infrastructure to that area. In any case, the village electrification model provided some evidence for a positive effect of income (per capita SDP) on village electrification at the state level. Other factors besides expenditure, in particular community electrification and education of household members, are probably more relevant for household electrification. Furthermore, the model suggests that electrification is better extended by improving supply quality rather than subsidising consumption by a non-cost-effective tariff. The influence of the present electricity tariffs on the household decision to use electricity is small, and the undifferentiated subsidies benefit those who are already connected to the grid rather than those who are still seeking a connection. The high negative MPE of the social groups’ tribe and caste, as well as the employment type groups’ labour and labour in agriculture, could be a sign of large intra-village differences in community electrification. As these social groups probably live in poorer and therefore less-electrified neighbourhoods, they might suffer from some sort of access discrimination. Unfortunately, access to electricity still seems hardly a given in the hamlets surrounding the outskirts of villages, even those in regions noted for their high village electrification rates.
7. Appendix

<table>
<thead>
<tr>
<th>year of survey</th>
<th>83/84</th>
<th>88/89</th>
<th>93/94</th>
<th>99/00</th>
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<tr>
<td>expenditure and energy poor</td>
<td>61.33</td>
<td>51.74</td>
<td>30.4</td>
<td>20.38</td>
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<td>only energy poor</td>
<td>14.61</td>
<td>12.54</td>
<td>20.95</td>
<td>17.92</td>
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<td>only expenditure poor</td>
<td>10.48</td>
<td>15.12</td>
<td>11.83</td>
<td>12.63</td>
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<td>neither energy nor expenditure poor</td>
<td>13.58</td>
<td>20.6</td>
<td>36.82</td>
<td>49.07</td>
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</table>

Table 7.1. Development and changes of the poverty groups in percentages of people of the Indian population.

Figure 7.1. Percentage of people living in households with access to tap water (left: access levels, right: user segments).
<table>
<thead>
<tr>
<th>variables</th>
<th>coefficient</th>
<th>robust std.err.</th>
<th>sign. level</th>
<th>MPE at mean dy/dx</th>
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</thead>
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<tr>
<td>In pc expenditure</td>
<td>1.335</td>
<td>0.037</td>
<td>***</td>
<td>0.332</td>
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<tr>
<td>In household size</td>
<td>1.038</td>
<td>0.029</td>
<td>***</td>
<td>0.259</td>
</tr>
<tr>
<td>husband illiterate</td>
<td>-0.388</td>
<td>0.032</td>
<td>***</td>
<td>-0.096</td>
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<td>husband education sec./ higher</td>
<td>0.345</td>
<td>0.037</td>
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<td>0.086</td>
</tr>
<tr>
<td>no husband</td>
<td>-0.176</td>
<td>0.055</td>
<td>***</td>
<td>-0.043</td>
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<tr>
<td>wife illiterate</td>
<td>-0.262</td>
<td>0.037</td>
<td>***</td>
<td>-0.065</td>
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<tr>
<td>wife education sec./ higher</td>
<td>0.154</td>
<td>0.051</td>
<td>***</td>
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<tr>
<td>no wife</td>
<td>-0.297</td>
<td>0.058</td>
<td>***</td>
<td>-0.073</td>
</tr>
<tr>
<td>age group young</td>
<td>-0.119</td>
<td>0.044</td>
<td>***</td>
<td>-0.029</td>
</tr>
<tr>
<td>age group old</td>
<td>0.260</td>
<td>0.028</td>
<td>***</td>
<td>0.065</td>
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<tr>
<td>user LPG</td>
<td>1.072</td>
<td>0.075</td>
<td>***</td>
<td>0.255</td>
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<tr>
<td>tribe</td>
<td>-0.273</td>
<td>0.044</td>
<td>***</td>
<td>-0.067</td>
</tr>
<tr>
<td>caste</td>
<td>-0.263</td>
<td>0.033</td>
<td>***</td>
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<td>self employed</td>
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<td>labour</td>
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<td>0.052</td>
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<td>labour in agriculture sector</td>
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<td>0.035</td>
<td>***</td>
<td>-0.174</td>
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<td>other employment type</td>
<td>0.203</td>
<td>0.046</td>
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<td>neighbourhood electrification</td>
<td>0.048</td>
<td>0.0005</td>
<td>***</td>
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<tr>
<td>transport infrastructure</td>
<td>0.023</td>
<td>0.006</td>
<td>***</td>
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</tr>
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<td>minimum electricity tariff</td>
<td>-0.002</td>
<td>0.0006</td>
<td>***</td>
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<td>kerosene dealers/pop</td>
<td>0.093</td>
<td>0.013</td>
<td>***</td>
<td>0.023</td>
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<td>% outages</td>
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<td>average temperature &lt; 25°C</td>
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<td>0.059</td>
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<td>average temperature &gt; 27.5°C</td>
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<td>share forest area</td>
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<td>-0.0007</td>
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<td>share irrigated crop area</td>
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<td>0.0008</td>
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<tr>
<td>share grazing area</td>
<td>0.001</td>
<td>0.002</td>
<td>-</td>
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<td>share unproductive area</td>
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<td>0.003</td>
<td>-</td>
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<tr>
<td>share water area</td>
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<tr>
<td>share other area</td>
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<td>0.002</td>
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<td></td>
<td></td>
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<td>const.</td>
<td>-11.763</td>
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</table>

n=59543                               R2: 0.4794
Log pseudolikelihood = -21474.287

Table 7.2. Results of the Logit model for household electrification. Omitted categories: education: primary education of man and spouse; employment type: self-employed agriculture; land-use type: non-irrigated crop area. *** refers to 1% level of significance.
8. References


UNDP/WB (2003a). Household energy use in developing countries. a multi country study. Energy Sector Management Assistance Program (ESMAP) of the UNDP and World Bank, Washington DC.


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Curriculum Vitae

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