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Measuring Multidimensional Energy Poverty

The Case of India

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Abstract

According to the capability approach developed by Sen (1993), access to basic energy services enables capabilities such as good health, education and balanced nourishment, that further increases overall well-being. Deprivation of energy services leads to energy poverty and reduced well-being. There are millions of people without access to clean cooking facilities and electricity in the world today, a majority of them are located in developing countries. It is crucial to tackle these problems, reduce energy poverty and advance sustainable development. In order to do so, good measures of energy poverty are needed to identify the energy poor and develop targeted and relevant policies and solutions.

Thus, the aim of the thesis is to measure basic energy deprivations, by using an adapted energy poverty index. Energy poverty is evaluated based on the dimensions of access to clean cooking fuels, access to electricity and access to the most basic energy services. The novelty of the measure is to combine these three dimensions into a composite index using the methodology of the *Multidimensional Energy Poverty Index,* developed by Nussbaumer, Bazilian & Modi (2011). A multidimensional deprivation score is used to evaluate energy poverty across the three dimensions.

The measure is applied to study energy poverty in India. The results indicate that there are great differences in the level of access that the various Indian states have to certain basic energy services. The extent of deprivation is greatest in the dimension of access to clean cooking facilities. Rural and lower income groups tend to have more energy poverty than urban groups and higher income groups, respectively. Thus, these are certain groups that policymakers should prioritize. Continued analysis of energy poverty in India and other regions is useful for making spatial and temporal comparisons to monitor progress and provide recommendations for reducing energy poverty.

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1. Introduction

The year 2016 saw the launch of the United Nations' (UN) Sustainable Development Goals (SDGs). The 17 goals replace the UN's Millennium Development Goals (MDGs), with the aim of tackling poverty, inequality and climate change in the next 15 years. The seventh SDG focuses specifically on providing access to energy for all human beings. Modern energy services are deemed as crucial for economic development and the well-being of humans (International Energy Agency (IEA), 2014). The SDGs, as well as other international initiatives launched in the last decade, highlight the urgency to tackle these issues.

Access to electricity and to clean cooking fuels is essential in reducing energy poverty. Almost one-fifth of the world's population lacks access to electricity, and close to two-fifths is without access to clean cooking facilities[1] (IEA, 2012b). A majority of these people are located in the rural areas in the developing countries. There has been some progress; more than one billion people in developing countries gained access to electricity and clean cooking fuels between 1980 and 2005 (Saghir, 2005). However, major efforts are still needed to eradicate energy poverty (IEA, 2012b).

In India alone, there are close to 300 million people without access to electricity, and about 770 million without access to clean cooking facilities (IEA, 2012b). Rapid economic growth and continued increase in the population, which is already the second-largest in the world, is increasing the demand for energy in India. Despite major progress made in reducing poverty and ensuring access to electricity to many, poverty and deprivation of basic (energy) services in the population still continues to be among the greatest challenges that India is facing today.

The concept of energy poverty is complex and multidimensional, and so far there is no widespread consensus on how to define and measure it. Nonetheless, there is a consensus that the essence of energy poverty is the deprivation of basic energy needs and of access to modern, clean and efficient energy. Specific measures are essential for identifying the energy poor, providing access to clean energy, implementing effective energy policies and monitoring progress.

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[1] Clean cooking facilities are defined as those "which can be used without harm to the health of those in the household and which are more environmentally sustainable and energy efficient than the average biomass cook stove currently used in developing countries" (IEA, 2012a).

The aim of this thesis is to measure basic energy deprivations, using an adapted energy poverty index. Inspired by Pachauri, Mueller, Kemmler, & Spreng (2004), the measure will evaluate energy poverty through the dimensions of access to modern energy sources and ability to meet basic energy needs. However, the novelty of this measure is to combine these dimensions into a multidimensional composite index to evaluate energy poverty, using the methodology of the *Multidimensional Energy Poverty Index* (MEPI) developed by Nussbaumer, Bazilian, & Modi (2011). The measure will be empirically tested using household survey data from India from 2012, adding to the research on energy poverty in India.

The score will be computed state-wise, and it can be expected that there are variations in the achievements of the different Indian states, both in each of the dimensions and in the overall multidimensional score. The methodology allows for analysis of the results in each dimension, as well as within subgroups of the population. It can be expected that scores will deviate significantly between the different sectors (rural and urban), as it is a common understanding that the rural areas are more dependent on biomass fuel and the infrastructure for modern fuels is less developed. Similarly, the correlation between income and energy consumption also leads to the expectations that lower income groups might have higher deprivation than the relatively higher income groups.

The next section presents the background on the link between energy and development, the adverse effects of biomass fuels for individuals and the advantages of modern energy fuels like electricity. An overview of the household energy situation in India is also presented. Section 3 continues with a theoretical background for measuring (energy) poverty, including an attempt to define energy poverty within the capability approach, introduction of different types of indicators and review of literature on energy poverty measurement.

A number of studies measuring energy poverty have been carried out in recent years (Bensch, 2013; Foster, Tre, & Wodon, 2000; Khandker, Barnes, & Samad, 2012; Nussbaumer et al., 2011; Pachauri et al., 2004). The studies have developed different measures for energy poverty and applied them for empirical analysis in developing countries.

The methodology used for the analysis, and a model for measurement of energy poverty in India will be derived in Section 4. Section 5 presents the data from the 68th round of the Indian National Statistical Survey (NSS) used for the analysis. The results of the analysis are presented in Section 6, followed by discussion including sensitivity analysis and suggestions for extended research and improvements in Section 7. Finally, Section 8 concludes the thesis.

2. Background

2.1 The Link Between Energy and Development

Energy in itself is not directly demanded by consumers, but demand is rather created through the services enabled by energy use. Some of the basic services which are enabled by energy use are health and educational services, transport and telecommunications, lighting and heating of spaces and cooking food (IEA, 2012a).

As stated by the World Energy Council and the Food and Agricultural Organization of the UN (1999), "for the poor, the priority is the satisfaction of such basic human needs as jobs, food, health services, education, housing, clean water and sanitation. Energy plays an important role in ensuring delivery of these services" (as quoted in Saghir, 2005). Further on, the Organization for Economic Co-operation and Development (OECD) highlights that access to energy is not the only solution to alleviate poverty, but states that "they [electricity and other modern energy sources] are indispensable to sustainable development" (OECD, 2007).

Access to energy was not formalized as one of the MDGs, but its importance for reaching the goals has been acknowledged. The ninth session of the UN's Commission for Sustainable Development (UN-CSD) concluded that "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 pre-requisite (UN-CSD, 2001)". Goal 7 in the new SDGs formalizes the importance of ensuring energy access as a catalyst for poverty alleviation. Providing access to clean energies that are also renewable would also be contributing to reduction of greenhouse gas (GHG) emissions and global warming.

There is a broad consensus that energy consumption is closely correlated with national growth and income levels. The relationship runs both ways, as energy is a pre-requisite to increase gross domestic product (GDP), while simultaneously demand for energy increases with increase in GDP. Economic growth and income poverty reduction is enabled through improved productivity, reduced costs due to increased energy use efficiency and improved human capital through better living standards.

For instance, small and medium-sized enterprises and businesses can increase productivity through the use of electricity. Electric lighting can allow them to operate for longer hours. (Modi, McDade, Lallement & Saghir, 2006; OECD, 2007; Saghir, 2005). Other uses of electricity are in machines that can increase productivity and quality, such as water pumps, machines for food processing and other manufacturing services (Modi et al., 2006). Energy is also found to be important for the improvement of productivity of agricultural crops, which can increase direct consumption or increase revenues.

Further on, electricity is shown to have strong educational benefits for children, as it allows them to study even when it gets dark (OECD, 2007; Saghir, 2005). Hospitals and health clinics can benefit greatly from using electricity for refrigeration of medicines, sterilization of instruments, water supply and purification and sanitation (OECD, 2007; Saghir, 2005). Modern energy services can also be important to attract people with higher education and skills (e.g. teachers, doctors, nurses) to remote areas and thereby provide better services and opportunities for the locals (Modi et al., 2006; Sustainable Energy for All, 2013).

2.2 Reliance on Biomass Fuels

In the discussion about access to energy services and energy poverty, one of the main concerns is the heavy reliance on traditional biomass fuels[2]. Firstly, it is mostly women and children who are burdened with the task of collecting such fuels – a time consuming activity with an opportunity cost, as women could have spent that time on income-generating activities and the children on studying (IEA, 2015; Saghir, 2005). According to Practical Action (2015), an Indian woman spends on an average just above 30 hours for collecting firewood each month. Secondly, it is mostly the women and children who are exposed to the hazardous indoor air pollution resulting from the use of biomass fuels, such as cooking fumes and particles. Because of the exposure, they acquire serious health problems such as "respiratory diseases, obstetrical problems, blindness and heart disease" (OECD, 2007). This is the fourth leading health risk in developing countries (World Health Organization, 2002 as cited in Saghir, 2005).

According to the OECD (2007) more than 1.3 million people (mostly women and children) die prematurely because of exposure to indoor air pollution, and the Sustainable Energy for All Initiative (2013) estimates that over 800,000 of them are children. Reliance on biomass

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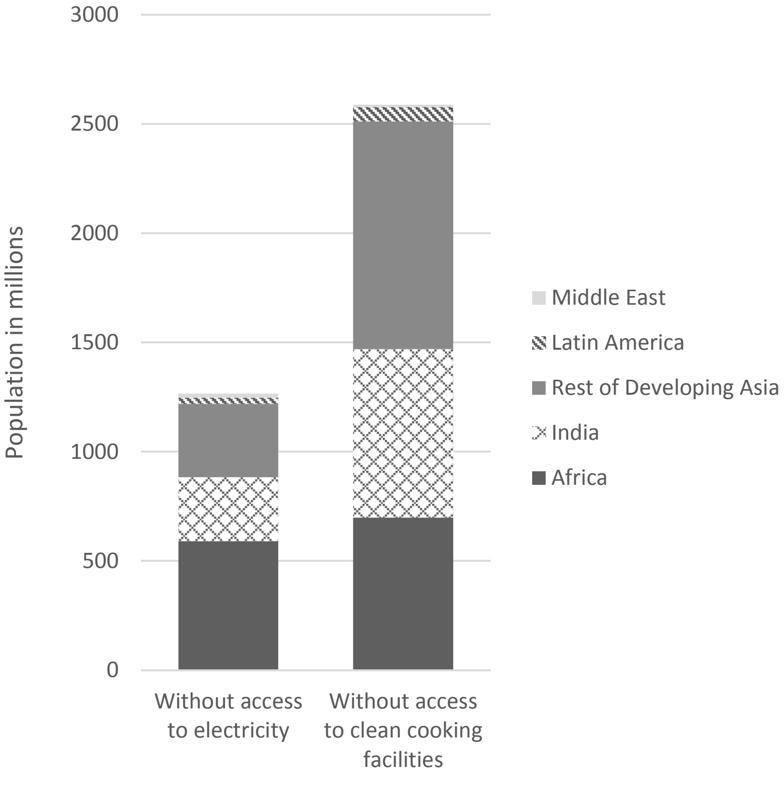
[2] The OECD (2007) defines traditional biomass fuels as fuel wood, charcoal, agricultural waste (crop residue) and animal dung.

fuels is therefore a barrier against poverty alleviation, and it also deepens gender inequality, as women are the ones who are most exposed.

In the world today, nearly 1.3 billion people find themselves without access to electricity and 2.6 billion people lack access to clean cooking facilities (see Figure 1) (IEA, 2012b). Virtually all of these people are living in developing countries[3]. India alone accounts for more than 20 percent of those without access to electricity and 30 percent of those without access to clean cooking facilities as shown in Figure 1 (IEA, 2012b). However, some progress was seen; over the last decade, India has reduced the number of people without access to electricity by around 285 million people (IEA, 2012b). Still, major efforts are needed worldwide as the population and energy demand are expected to grow in the future.

Figure 1: Population in developing countries without access to electricity and to clean cooking facilities (in millions)



Source: Own figure based on statistics from IEA (2012b).

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[3] Only 2 million people of the nearly 1.3 billion people without access to electricity live in developed countries, while all the people without access to clean cooking facilities live in developing countries (IEA, 2012b).

2.3 Advantages of Modern Energy Sources

The IEA (2014) defines energy poverty as the "lack of access to modern energy services such as electricity and clean cooking facilities which does not cause indoor air pollution".

By modern energy sources, we mean broadly those that are not biomass fuels. In particular, the focus is on liquefied petroleum gas (LPG) which is commonly used by households for cooking, kerosene (also used for cooking, to generate electricity at home and as a transport fuel), and electricity. There are also other, less common, modern energy sources such as biogas and renewable sources, but these are still not significant enough in the consumption mix to consider them. Interestingly enough, the most common modern energy sources such as LPG are in fact fossil fuels. The aim to alleviate poverty by increasing the use of such fuels could thus be conflicting with the climate change goals of reducing the use of fossil fuels. This debate has not been adequately addressed in the current research, but the role of renewables in tackling these issues has already been recognized and will become significant in the future.

Electricity has the advantage that it is clean (in terms of indoor air pollution) and also more efficient than biomass fuels. Even though biomass fuels can be obtained "for free" in the nature, the effective cost associated with their consumption is often higher than for consumption of modern fuels. Foster et al. (2000) find that among households in Guatemala, those without access to electricity pay a higher average energy price per unit of efficient energy (more than 2.5 times higher) than those with electricity access. This indicates that access to electricity and clean cooking fuels could allow households to consume higher quantities of energy more efficiently and at a lower cost, while freeing up resources (both in terms of time and money) for other goods and services. It must be noted that this cost is estimated considering the household situation, and that a larger socio-economic cost-benefit analysis has not been included. For instance, the building of a hydropower dam is associated with many costs and externalities such as relocation of local communities, environmental impacts and interference into nature.

As mentioned before, modern energy access has significant educational, health and gender equality benefits. In particular, modern energy access has been proven to have positive effects for the educational opportunities and accomplishments of girls (Modi et al., 2006). Saghir (2005) refer to the results of a study carried out in Nicaragua in 1998. The study showed that the percentage of children in a family that attended school was significantly higher in families that had access to electricity than families who did not. In addition, the results showed that the level of literacy was higher on average for the whole family, in the families that had access to electricity.

Another study done by the Energy Sector Management Assistance Program (ESMAP) of the World Bank in rural India in 1996 found that women that reside in households that had access to electric lighting, read more than the women in households without access to electric lighting. The results showed the same patterns across all income levels, although women in higher income level groups tended to read more and have higher literacy rates than the women in lower income level groups (as cited in Saghir, 2005).

Energy access and energy infrastructure is also thought to attract more educated personnel and enable telecommunications services giving access to educational material, the internet, communications and other equipment such as printers, overhead machines, computers, etc. (Modi et al., 2006; Saghir, 2005).

Additionally, moving to cleaner cooking fuels and electricity can also have an impact on the goal of environmental sustainability. Increased agricultural productivity on land that is already cultivated puts less pressure on ecosystems to be turned into new farmland. This is given the assumption that the market is somehow controlled to avoid overcrowding by new players when profits increase. Biomass use also has severe effects such as deforestation, desertification and soil erosion; pressures which could be reduced through the use of modern energy sources and allowing for more efficient natural resource management (Modi et al., 2006; OECD, 2007; Saghir, 2005). Decreased use of biomass fuels could also lead to a reduction in emissions of GHGs (for instance by avoiding to burn animal dung that releases methane). However, the increased consumption of LPG and kerosene could lead to increase in emissions of GHGs, but depending on their efficiency the net effect might be less GHG emissions. In many developing countries, the issue of providing affordable and reliable electricity access could be solved through developing off-grid solutions that use hydro, solar and wind power, meeting the energy needs of the poor in a sustainable way (Saghir, 2005).

The linkages between energy and development are complex, thus the challenge of energy poverty requires a mosaic of solutions for improvement. For instance, electrification is often a first priority, but traditional connections to the grid is often not the most cost-effective or practical solution to improving energy services. It requires time and infrastructure that developing countries often cannot afford. It could take years to undergo complete electrification in developing countries; an estimate says it would take 250 years in Uganda assuming the rates at which it was happening at the beginning of the new millennium (Department for International Development (DFID) UK, 2002).

Following the above discussion, it is plausible to conclude that access to energy not only has significant impact on welfare and opportunities at the household level, but also at the national and global level. It is crucial for local communities, governments and international institutions to take immediate actions to effectively reduce energy poverty to achieve poverty alleviation, gender equality and other goals in order to ensure overall sustainable development.

2.4 Energy Consumption in India

Rapid economic growth in India, especially since the turn of the millennium, has also led to growth in India's energy demand. Since 2000, India alone is responsible for 10 percent of the increase in global energy demand (IEA, 2015). However, given the large and increasing population, the per capita demand is far below world averages and even below the average of the African continent.

It will be important in the coming years that India addresses energy poverty, as it impacts the millions of people who still lack access to clean cooking fuels and electricity. Simultaneously, it has to be ensured that this happens in a sustainable way, by focusing on renewable and alternative energies. The energy intensity of GDP[4] in India has been decreasing between 1990 and 2013, because of transition towards modern fuels (and away from biomass fuels), higher demand for services and increased efficiency at the end-user stage (IEA, 2015). It is desirable that this trend continues as the growth in the economy and population is continuing in India.

2.4.1 Household Consumption Patterns

The household consumption in India accounted for 8 percent of commercial energy (electricity, kerosene, LPG) and 85 percent of the non-commercial energy (biomass fuel) consumption (Government of India, 2005). Of the total household consumption, more than 70 percent was used for cooking in 2015 (IEA, 2015). As mentioned previously, most of this

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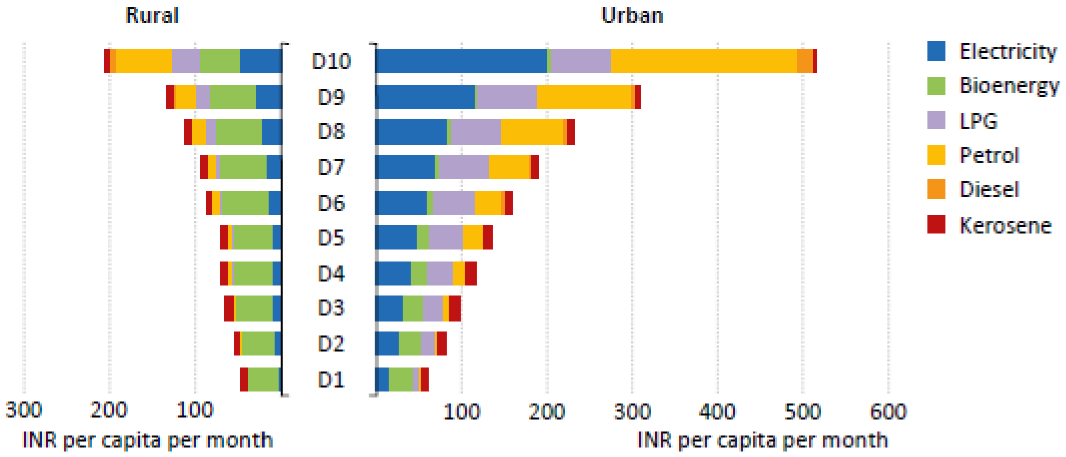
[4] The amount of energy required to produce an additional unit of GDP.

demand is met by consuming biomass fuels, as modern cooking fuels are often not affordable or accessible (IEA, 2015). The modern cooking fuels are predominantly LPG and kerosene, as well as some other forms of gas (e.g. biogas) (Ekholm, Krey, Pachauri & Riahi, 2010). In the urban areas, LPG has become the predominant primary cooking fuel (see Figure 6 in the data description section).

The consumption of electricity in India for cooking is insignificant (see Figure 6), but is necessary for a minimum level of adequate lighting, as well as the use of other household appliances such as refrigerator, air condition, radio and television, telecommunications, etc. (Ekholm et al., 2010).

Energy consumption increases with income levels. However, as a minimum amount of energy is needed to sustain a livelihood, the poorer families spend a much larger share of their household's budget on energy (IEA, 2015; Leach, 1987, as cited in Pachauri et al., 2004). As income levels increase, we see that households also consume different types of fuels. To a greater extent, there seems to be patterns of fuel stacking[5] in rural areas, which can be explained by the availability and access to modern fuels (see Figure 2 below, as published by the IEA, 2015).

Figure 2: Per capita expenditure on energy, by sector and income level



Note: INR = Indian Rupees. D1-D10 are income deciles, by rural and urban areas, where D1 are those with lowest income level and D10 have the highest income level.

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[5] Fuel stacking is when households consume multiple types of fuels or energy sources for the same end-usage, e.g. cooking, instead of switching completely to one type of fuel when given access (through increase in income for instance) (Masera & Saatkamp, 2000).

Source: Figure replicated from the India Energy Outlook by the IEA (2015), based on data from Ministry of Statistics and Programme Implementation (2012)

Rural households continue to consume biomass fuels until the highest income decile, although at a lower level than the lowest income deciles. In urban areas, the switch away from biomass fuels after the fifth income decile is significant (IEA, 2015).

2.4.2 Regional Disparities

Due to the diversity across India, large variations can be found in the energy consumption levels and patterns in the various Indian states. The variations are a result of disparities in geography, resource endowments, climate, demographics, and income levels among other factors. India with a federal political structure, is made up of a total of 29 states[6] and 7 union territories (Government of India, 2016). The political structure allows the states to govern the energy related issues on their own, resulting in great disparities in the access to energy services and the energy consumption levels and patterns (IEA, 2015).

For instance, the annual per capita residential electricity consumption (of those who have electricity access) is 50 kilowatt-hour (kWh) for the North-Eastern state of Bihar, the lowest consumption in the whole country. The average for the whole of India is 200 kWh, while for the capital Delhi it is around 600 kWh (being the only state that has a per capita consumption above the non-OECD average). Indian consumption is far behind both the world average and OECD-levels (IEA, 2015).

2.4.3 Policy Efforts

There have been initiatives to both increase electrification and support transition to modern cooking fuels (mainly kerosene and LPG) and cleaner, more efficient cooking stoves. Both LPG and kerosene are subsidized by the government, but often the subsidies benefit those who are already relatively well-off.

With the aim of providing electricity to all villages with more than 100 inhabitants and free electricity to all below the poverty line, a national rural electrification program – the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) – was introduced in 2005. The results have

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[6] The 29th and newest Indian state was created by the division of the former state of Andhra Pradesh into the two new states of Telangana and Andhra Pradesh on the 2nd of June, 2014 (Times of India, 2014).

been varying and there has been a controversy around the issue of how to define access to electricity (IEA, 2015).

Initiatives aiming to disseminate clean and efficient cooking stoves to the poor, distributed 35 million cooking stoves from the 1980s to the 2000s (IEA, 2015). However, they were not successful owing to social and institutional constraints. One of the main challenges was that subsidies were given to the producers, instead of the end-consumers. The products were being developed without taking into account the demanded social and cultural requirements from the consumers, who reverted back to using traditional cooking stoves (Bhattacharya & Cropper, 2010; IEA, 2015). Attempts were also made to disseminate the use of solar cooking stoves, but faced the same issues as the clean biomass cooking stoves (Bhattacharya & Cropper, 2010). A new initiative was launched in 2009, the National Biomass Cook Stoves Initiative, also aiming to distribute cooking stoves, but this time using the experiences and learnings from the earlier attempts (IEA, 2015).

3. Theoretical Background

3.1 Defining Energy Poverty

3.1.1 The Capability Approach

Although there is a consensus that energy is one of the critical requirements for development, there are varying opinions on the exact definition of the energy poverty-concept.

The capability approach developed by Sen (1993) is often used in relation to definition of poverty. In this approach, a set of capabilities represents “the alternative combination of things a person can do or be – the various ‘functionings’ he or she can achieve” (Sen, 1993). The focus of this approach is on the opportunities (capabilities) that a person is given and the freedom to realize them if he or she wishes to do so. By focusing on the capabilities rather than the functionings, Sen also respects that individuals have different preferences and desires and that as long as everyone is provided with the same set of capabilities, they have the freedom to achieve the same level of well-being. Poverty is accordingly defined as the deprivation of such capabilities. As the focus is on many capabilities, the approach gives a multidimensional view on poverty (Day, Walker & Simcock, 2016).

The capability approach was to some extent developed as an opposition to the traditional welfarist views of using income or resources as a measure of happiness and utility and poverty as a lack thereof. The arguments against the traditional approaches are that they are too narrow to incorporate and measure the full and wide concept of well-being (Day et al., 2016). Sen also discusses that income or resources should not be used as a proxy for capabilities, as different persons might require more resources or income to achieve the same capabilities. An example he uses is that it requires more effort in terms of income or other resources for a disabled person to be mobile compared to a person without disability (Day et al., 2016). However, it has been pointed that out that even Sen has stated that the focus on capabilities (and functionings) does not rule out giving attention to resources in the analysis of well-being. It requires that the user is aware that the resources are simply means and not the ends of well-being and the implications that follow (Robeyns, 2005).

Sen has not defined a set of basic capabilities, and argues that this is contextually dependent and leaves this for others to formalize. However, there is a consensus that a minimum level of well-being is related to attainments or ‘functionings’ such as being in good health, being safe, being nourished, being educated and being socially included among some. Day et al. (2016) call these as the basic capabilities (or functionings if the capabilities are realized). They develop a model in which they conceptualize energy poverty within the capability approach, by dividing the attainment of well-being into different levels and examining the relationship between each of the levels. The basic capabilities (or functionings if realized) are the ultimate stage of the approach. It begins with resources (e.g. different types of fuels), followed by energy supply (e.g. electricity and other forms of energy that can be consumed by the households), energy services (lighting, cooking, heating/cooling, etc.), secondary capabilities (preparing food, reading, accessing the internet, etc.) and finally the basic capabilities as mentioned (Day et al., 2016). By illustrating the development of the different stages of the approach, the authors also attempt to give an overview of which stage the different types of interventions should be directed towards to alleviate (energy) poverty.

One important criticism of the capability approach is that, ironically enough, it is hard to accurately measure capabilities as they are not even always realized. Thus, a need for pragmatism leads to a measurement of the functionings or some other level to be able to operationalize the capability approach.

Other definitions of energy poverty also attempt to use the concept of "capability", however these do not distinguish completely between the capability approach and traditional approaches focusing on the access to resources and services. For instance, The World Bank (2011) defines energy poverty as "whether the households or individuals have enough resources or abilities today to meet their needs". This is further reflected in the Asian Development Bank's definition of energy poverty: "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development" (Reddy, 2000). A similar mixed focus on needs, capabilities and deprivation when defining energy poverty is found in Foster et al. (2000), Pachauri et al. (2004) and Bensch (2013).

3.1.2 Why Focus on Energy Poverty?

Although the thesis will focus on the capability approach, it is useful to look at the resource level and consider microeconomic theory for understanding why energy poverty should be in focus. However, these views are still compatible with the capability approach as long as it is recognized that the resources are some of many inputs or means of well-being and not the ends, as discussed previously.

Commonly, if energy poverty has been measured at all, it has been placed as one of the factors in the well-being function of an individual and measured alongside other indicators such as consumption of food, health services, education and so on. It is formally described in Equation 1,

$$S_i = f\{F, H, Ed, T, C, En\}, \qquad [1]$$

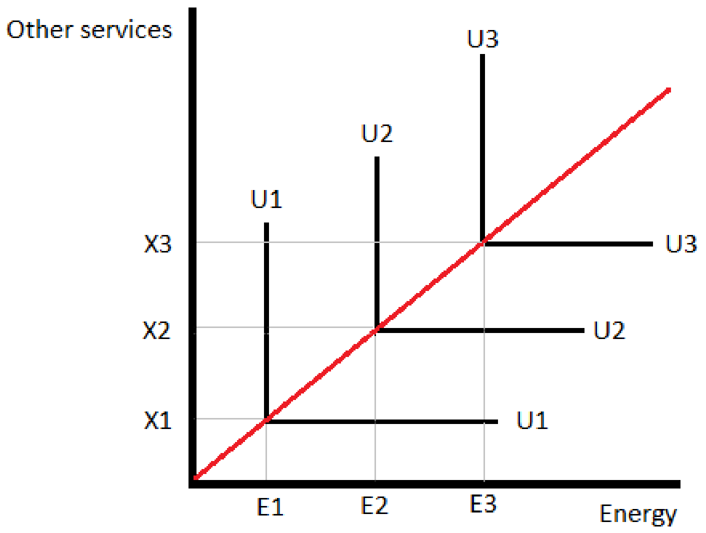
where S is the total well-being of individual *i,* and *F, H, Ed, T, C,* and *En* is the consumption of food, health services, education, transport, telecommunications and energy respectively. However, the aim of this study and other similar research is to highlight the importance of studying energy poverty thoroughly and independently.

The main argument for this is simply that energy holds such an important role in society (as discussed comprehensively in Section 2) that it warrants a study of its own. Thus, even though we know that poverty is multidimensional, it is useful to identify the issues directly related to energy poverty and to identify those who are energy poor. This means identifying the issues around deprivation of energy sources and services and those who are affected by this. Consequently, targeted solutions can be developed to solve these energy-related issues that could otherwise remain unknown.

In addition, we may argue that it is important to study energy poverty because the well-being an individual gains from the consumption of other goods or services is dependent on the simultaneous consumption of energy. There is a complementary relationship between consumption of energy and other types of consumption, as some additional energy is needed for each additional level of other consumption (see Figure 3).

As shown in Figure 3, well-being can only be increased by increasing both the consumption of energy and other services. For instance, to increase utility from U1 to U2, energy consumption has to be increased from E1 to E2 and other consumption from X1 to X2. This relationship explains the importance of studying the access to energy, as consumption of energy is necessary for an individual to be able to enjoy consumption of other basic goods and services and thereby increase their level of well-being. This representation of the relationship between energy consumption and other consumption is perhaps one extreme, and although all other consumption is not entirely dependent on energy consumption it illustrates that energy is to a great extent necessary to enjoy some other basic goods and services. For instance, it is possible to eat some food raw, like vegetables. However, the value of most food increases according to traditional standards when it can be heated (especially food that cannot be eaten unprocessed).

Figure 3: Leontief indifference curves of energy and other services



Source: Own figure based on economic theory on complementary goods.

3.2 Poverty Measures

Poverty measurement is necessary to identify those who are poor, together with the magnitude and intensity of the poverty. Identification of the poor is important in order to implement policy measures to fight poverty and to put it on regional, national and international agendas. Measurement or indicators can facilitate well-informed and targeted decisions. Further on, the measures can be used for comparison between regions and countries, and also to monitor the progress and effectiveness of implemented policies. Indicators can also be important to spread information to the general public and raise awareness around the issue. Additionally, having established measures can facilitate more targeted and tailored data-collection, making analysis even more accurate and informational.

In order to build a poverty measure, the following three steps are required; choosing an indicator for welfare, defining a poverty line and generating an aggregated summary statistic of the distribution of achievements of households or individuals in the population (Haughton & Khandker, 2009).

3.2.1 Poverty Indicators

A concept like energy poverty is elusive and not easily measured with a single indicator. There are many factors like infrastructure, income, household composition or other macroeconomic factors, which could be influencing the incidence of energy poverty. Thus, indicators have to be chosen specifically for the purpose, so that they are useful in decision-making and monitoring processes. Developing indicators to measure the broader concept of (sustainable) development are even more complex.

The indicators which are usually used for poverty measurement can broadly be categorized as three different types: single indicators, composite indices and dashboard indices (Bensch, 2013; Nussbaumer et al., 2011). A single index is simple and easy to understand; the result is one number with an unambiguous result. This could be an energy poverty threshold, equivalent of the income poverty threshold. However, there is no consensus on such an indicator, because the concept of energy poverty is somewhat intangible and hard to measure (Bensch, 2013; Nussbaumer et al., 2011).

A multidimensional approach might be more suitable for intangible and elusive concepts like energy poverty and sustainable development. More factors can be analysed to capture the complex nature of the issues, allowing a more nuanced picture than a single indicator might give. One critique of the multidimensional measures is that when too many measures are involved, it becomes easy to confuse the manifestations of poverty with the causes. Thus, lumping together many dimensions could lead to loss of finding the real causal relationships in the analysis. Furthermore, incorporating multiple dimensions might make it too complicated to handle many and different indicators. It could result in comparison and monitoring becoming inconvenient or insensible (Bensch, 2013; Nussbaumer et al., 2011). This is also known as the “curse of dimensionality” (Bensch, 2013).

To overcome the curse of dimensionality, multiple indicators are often presented either through a dashboard index or a composite index. In the composite index, the different dimensions are grouped together into a single number, to both account for the multidimensionality and simplify the information. An example of a composite index is the *Energy Development Index* (EDI) developed by the IEA, intended to measure energy poverty and progress in a country or region. The EDI is the energy equivalent of the *Human Development Index* (HDI). Four equally-weighted indicators related to access to modern energies and energy services are computed into the EDI (IEA, 2012b). The advantage of the composite index is that it is simple, like the single indicator. However, the simplification process entails some arbitrary assumptions (such as what weights the different indicators should have) and could lead to loss of informational value.

The dash board index avoids this issue by presenting the different indicators alongside each other. It allows for more detail than the composite index, but can give ambiguous results if different indicators have changed in opposite directions. The *Energy Indicators for Sustainable Development* developed by the IAEA is made up of 30 indicators in the social, economic or environmental dimensions. In each case, the user can decide which indicators to use, based on the purpose and feasibility of measurement (IAEA, 2005). This could be dangerous, if users with an agenda pick the indicators as desired to promote their cause. Further on, it also renders it meaningless to do comparisons across time and space if the indicators being measured are not the same. In any case, it is apparent that an index with 30 different indicators is more detailed than a single or composite index. At the same time, the index becomes increasingly complex for each additional indicator that has to be measured. The measurement is also very data intensive if the majority of the indicators are included.

3.3 Literature Review on Energy Poverty Measures

The literature on empirical analysis of energy poverty in developing countries has been slowly increasing in the last decade, but is still not extensive. This section will provide an overview of different measures of energy poverty that have been used for empirical analysis of energy poverty in developing countries. The measures will be evaluated for their usefulness in determining energy poverty. Table 1 summarizes some relevant studies, what measures they use and the main results. Some of the measures from these studies are used as a basis for the methodology in this thesis.

3.3.1 Fuel poverty line

The fuel poverty line derived by Foster et al. (2000) provides a simple and single indicator, based on the income poverty line (the first study presented in Table 1). The critical threshold amount of energy is the average energy consumption of those within a 10 percent range of the income poverty threshold of one US-dollar per day. Despite being a simple measure, the energy poverty line does not provide any new information, as it is based on a metric which is already known. Also, as discussed earlier, energy consumption is not only dependent on income, as some fuels are attained non-commercially.

When the traditional (non-commercial) fuels make up a large part of the energy consumption, other factors affect the amount of consumption more than income. This could be availability of natural resources and labour, to mention some factors (Pachauri et al., 2004).

In addition to calculating the fuel poverty line, Foster et al. (2000) also measure the net price per efficient kWh which accounts for the efficiencies of the fuels, equipment and appliances used for consumption. They find that those who do not have access to electricity pay a higher effective price for their energy consumption because of inefficient fuels and appliances. Also, the occurrence of energy poor is higher for the households without access to electricity (almost half of the group). They consume less energy on an average, in addition to paying the higher effective price.

3.3.2 Budget Share of Energy Expenditure

Another measure which is based on income or expenditure levels measures the budget share of total expenditure spent on energy (Study 2 in Table 1). The poorest groups are found to have larger budget shares of energy expenditure (Leach, 1987, as cited in Pachauri et al., 2004). As with the fuel poverty line calculated by Foster et al. (2000), this measure does not take into account the use of non-commercial fuels, or the efficiencies of fuels and appliances. Also, large budget shares could be caused by high prices or a large household size leading to high consumption (Foster, 2000). Similarly, low budget shares could be caused by high wages, and also because there is a certain point when a person cannot consume more energy (like when you cannot eat more food because you are physically full). Energy consumption can be thought of as increasing monotonically, but non-linearly with income.

Table 1: Overview of Literature Review on Energy Poverty Measures

Study: Indicator	Data used	Main results of study
1. *Foster et al. (2000):* a. Energy/fuel poverty line based on conventional income poverty line **b.** Net price per efficient kWh	Household survey data, Guatemala, 1998-99	• Energy poverty threshold at 2125 kWh per year per household • Higher effective price of efficient energy consumption for those without access to electricity
2. *Leach (1987) in Pachauri et al. (2004):* Budget share of energy expenditure	Unknown	• Larger budget share of energy expenditure for poorest income groups compared to higher income groups • Commonly agreed upon threshold: 10 per cent budget share spent on basic energy services
3. *Khandker et al. (2012)***:** Demand-based income-invariant measure	India Human Development Survey (IDHS), 2005	• Not necessarily a correlation between income poverty and energy poverty • Electrification and more efficient use of biofuels can reduce energy poverty
4. *Nussbaumer et al. (2011):* Multidimensional Energy Poverty Index (MEPI): cooking, lighting, services provided by appliances, entertainment/education, communication	Demographic and Health Surveys (DHS) from selected African countries	• Shows varying levels of energy poverty, and the intensity of energy poverty in the different countries.
5. *Pachauri et al. (2004):* Energy access-consumption matrix: a. Amount of energy consumption b. Access to different types of energy	Indian household expenditure survey (NSS), 1983-2000	• Significant reduction in the level of energy poverty over time • Increased inequality in distribution of energy consumption and access

Source: Own table based on various studies.

3.3.3 Demand-based Income-invariant Measure

The demand-based measure in Khandker et al. (2012) (the third study in Table 1) defines the energy poor as those whose consumption of energy does not vary with income, because of their low income levels. Based on this measure, 57 percent of the rural population in India is considered as energy poor, compared to 22 percent who are income poor. In the urban population, only 28 percent are considered as energy poor versus the 20 percent income poor (Khandker et al., 2012). Further on, electrification (especially in the rural areas) and improving efficiency of traditional biofuels through modern and improved equipment (e.g. biomass stoves) can lead to reduction in energy poverty (Khandker et al., 2012). However, the assumption that energy consumption is income-invariant, even at the lowest income levels, might be unrealistic. Also, this measure encounters the same issue as the other income and expenditure-based measures; that it does not take into account the consumption of traditional biofuels (Bensch, 2013).

3.3.4 The Multidimensional Energy Poverty Index

The *Multidimensional Energy Poverty Index* (MEPI), developed and empirically tested by Nussbaumer et al. (2011), is a composite index (Study 4 in Table 1). It is adapted from the general multidimensional measures for poverty developed by the Oxford Poverty and Human Development Initiative (OPHI) (Alkire and Foster, 2007, 2011; Alkire and Santos, 2010). Five dimensions are examined (as listed in Table 2) through six weighted indicators. The results from each dimension are computed into a single number, representing the combination of energy deprivations of an individual. Energy poverty occurs if that individual’s sum of deprivations is above a certain defined threshold. The authors use the dual cut-off method described in the OPHI-methodology. As mentioned earlier, a multidimensional composite index requires an arbitrary choice of weights for each dimension, which are subject to discussion.

Finally, the MEPI is computed by multiplying the headcount ratio of the energy poor and the average intensity of weighted deprivation of those who are poor. According to the authors, the index can capture increases in energy poverty both in terms of increase in head count ratio (new cases of energy poor) and increased intensity of poverty (persons who become poor in more dimensions). The MEPI is also tested in Bensch (2013) alongside four other metrics and found to perform well, one reason being that it can be used for analysis both on an aggregated, as well as dimensional level.

The MEPI is flexible in terms of the dimensions that can be included. While analysis can be done at dimensional level, it also holds the benefits of the composite indicator by presenting a single number that makes it feasible to perform spatial and temporal comparisons easily. Further on, as mentioned in the previous paragraph, another valuable capability of this index is that it captures poverty both through incidence as well as intensity, an important criteria of a good measure for poverty.

3.3.5 The Energy Access-Consumption Matrix

Pachauri et al. (2004) develop an alternative measure called the *Energy Access-Consumption Matrix*; a two-dimensional index assessing energy poverty based on access to different types of energy and the amount of energy consumption (Study 5 in Table 1).

To measure the achievement of individuals in the energy consumption dimension, the authors have defined a set of minimum energy needs and calculated the corresponding required amount of energy to meet these needs. This amount defines the threshold for deprivation in this dimension. In the energy access dimension, the individuals are determined as having access to one of three levels; access to only biofuels (biofuel level), access to electricity and other fuels, but not LPG (electricity level), and access to both electricity, LPG and other fuels (LPG level). Individuals are grouped according to their achievements in the two dimensions, and a poverty line is drawn to determine the poor. Those who are extremely energy poor are those in the biofuel-level consuming less than 0.36 kWh (kWh) useful energy[7] per capita per day. Those in the biofuel-level consuming between 0.36 kWh and 0.72 kWh are also considered as energy poor, but not as extreme as the previous group. Even the group of people in the electricity-level can be considered as energy poor, if they consume less than 0.36 kWh. Those in the LPG-level are not considered as energy poor, regardless of their amount of energy consumption.

Figure 4 shows that the percentage of the Indian population defined as energy poor, according to this study, was reduced from 75 percent to 40 percent over the 17-year period of analysis. Further on, the share of those who are considered as extremely energy poor has also declined from 38 percent to 14 percent. On the other hand, the distribution of energy consumption and access is less equal in 1999 than in 1983, with a substantial increase in people gaining access

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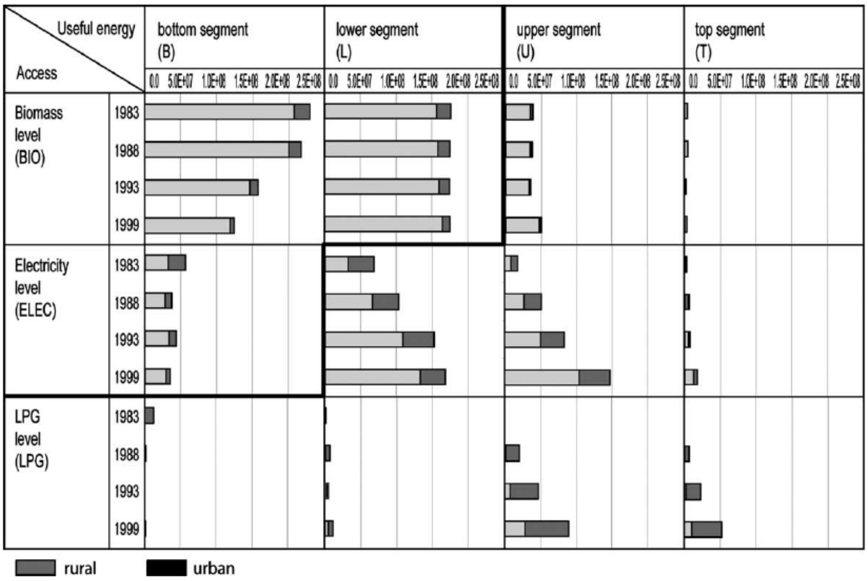
[7] Useful energy is the actual energy that is consumed after taking into the efficiency of the fuel and the appliance being used for consumption. See Table 2 in Section 4.3.

to electricity and LPG and increasing their energy consumption compared to the decrease in the extreme energy poverty (Pachauri et al., 2004).

Figure 4: The Energy Access-Consumption Matrix as presented by Pachauri et al. (2004)



Source: Reproduced from Pachauri et al. (2004)

The index, unlike the others, is not presented as a number, but as a graphical cross section (a matrix) of the Indian population distributed according to their consumption levels. Although this is intuitive for one country, it will be complicated for comparison purposes with other countries. It also becomes complex to do sub-group analysis when there is a large number of categories for a group, such as the states in India for example.

4. Methodology

The methodology used in this thesis is an adapted version of the MEPI developed by Nussbaumer et al. (2011). I follow the same methodology for computing the multidimensional deprivation scores, but have altered the dimensions included in the index to measure deprivation of the most basic energy needs. This is inspired by the *Energy Access-Consumption Matrix* developed by Pachauri et al. (2004). In the following sections, this adapted index will be referred to as MEPI-2.

4.1 Dimensions

It is useful at this point to reflect back on the capability approach. The basic capabilities such as being in good health, being nourished and being educated is what can ultimately lead to well-being according to the approach. However, these capabilities are a function of the many different resources we consume, our physical and mental status, etc. As the aim of this thesis is not to study the capabilities themselves, but rather how energy is contributing (or not contributing) to the well-being of an individual, it is not purposeful to measure well-being at the capability level. Instead, we need to go back to the model proposed by Day et al. (2016) as described in Section 3. By studying energy poverty at the level of energy services, we can establish whether energy is strengthening or weakening the capabilities of a person and more accurately determine where inventions should be directed. For instance, cooking as an energy service allows us to prepare food, that allows us to be nourished. A lack of the possibility for cooking will lead to a weaker capability of being nourished, although it is not a perfect proxy.

Taking inspiration from Pachauri et al. (2004), this thesis aims to study the most basic energy services that contribute to basic capabilities such as being nourished, in good health, sheltered and educated, etc. Following the example of Pachauri et al. (2012), these most basic energy services in India are defined as being able to cook two hot meals, heating some warm water and some hours of lighting daily. Thus, the energy services measured in Nussbaumer et al. (2011) such as access to telecommunications and other electric household appliances are not included, as the intention is to study the most basic services deemed as necessary for survival. However, the indoor air pollution that households are exposed to through the energy services they consume will be measured, as both Pachauri et al. (2004) and Nussbaumer et al. (2011) focus on this aspect of energy as being one of the most impactful on an individual's health capability. The consumption of biomass fuels (or lack of modern fuels) will also be measured, as it has been demonstrated in Section 2 to have a detrimental effect on gender equality, education and employment among a few factors.

These energy services can be divided into different dimensions, as in the MEPI-methodology. Cooking and lighting are two of the dimensions that will still be evaluated in the MEPI-2, with the focus being on modern energy sources. In addition, an individual will also be evaluated on whether he or she has access to the basic energy services of cooking, lighting and heating water, regardless of the type of energy being used. Although modern energies are preferable, this dimension takes into account that biofuels have an important role in household energy consumption in India. Furthermore, it is a fact that modern energy fuels not necessarily give an increased level of well-being, if they are not affordable, reliable or available.

As Pachauri et al. (2004) outline in their paper, a family can be well off in terms of meeting their energy needs mainly through consuming biomass fuels. It is of course desirable that they can meet the same needs with more efficient and modern fuels, but it is not often feasible in reality for a variety of reasons. If the family experiences an increase in income, it is reasonable to assume that they will shift to modern fuels. However, the case is often that affordability, availability and reliability of such fuels in developing countries, especially in rural areas, might still be limited. This is very true for a country like India. The same family that was earlier satisfied through biomass fuels now could have access to modern fuels but cannot consume enough to meet their basic energy needs (Pachauri et al., 2004). Thus, their level of well-being could in fact decrease.

Moreover, there is also evidence showing that even with increased levels of income, households will engage in fuel stacking, rather than switching completely between fuels (Masera & Saatkamp, 2000). Fuel stacking means that households consume new (modern) fuels along with the traditional ones as a base, instead of replacing them completely. Thus, even with higher incomes and access to modern energies, households would still continue to use biofuels, but add the use of for instance electricity, LPG or other modern fuels to the traditional biomass consumption. For instance, households opt for biomass fuels when cooking some traditional foods.

It is therefore interesting and important to measure whether a household or individual consume their minimum level of energy services, regardless of the type of energy source consumed. Households that are not able to meet their energy needs even through biomass fuels, are the households and individuals that should be given the highest priority by policy makers. Further on, it could also identify those who do not meet their energy needs even if they on paper have gained access to modern energies.

After assessing the deprivation in each dimension, the weighted sum of deprivations will be evaluated against a multidimensional poverty cut-off to define those who are (multidimensionally) energy poor. The MEPI-2 (as the MEPI) is then computed as the product of the incidence (headcount ratio) and intensity (average weighted sum of deprivation of those who are multidimensionally poor) of energy poverty.

4.2 Mathematical model

The mathematical outline of the measure is described below as defined by Nussbaumer et al. (2011) for the MEPI.

Assuming a population of *n* being evaluated for energy poverty across *d* variables, the authors define a *n x d* matrix of achievements of *i* individuals for *j* variables, as follows:

$$Y = [y_{ij}] \,, \qquad [2]$$

where $(y_{ij} > 0)$ gives the achievement of individual *i* in variable *j*. Further, Nussbaumer et al. (2011) define each row vector in this matrix as $y_i = (y_{i1}, y_{i2}, \ldots, y_{id})$, that gives the achievement of individual *i* for all the variables, while each column vector $y_j = (y_{1j}, y_{2j}, \ldots, y_{nj})$ gives the achievement of all individuals for the variable *j*. Each variable *j* will have an assigned weight w_j, where the sum of the weights is equal to 1:

$$\sum_{j=1}^{d} w_j = 1 \,. \qquad [3]$$

Nussbaumer et al. (2011) determines a cut-off z_j for each variable that is used to identify whether an individual is deprived in this variable or not based on their achievements. The authors then define a deprivation matrix where $(g_{ij} > 0)$ gives the deprivation of individual *i* for variable *j* as follows:

$$G = [g_{ij}], \qquad [4]$$

$$g_{ij} = w_j \; if \; (y_{ij} < z_j) \,, \qquad [5]$$

$$g_{ij} = 0 \; if \; (y_{ij} \geq z_j) \,. \qquad [6]$$

Finally, Nussbaumer et al. (2011) construct a column vector:

$$c_i = \sum_{j=1}^{d} g_{ij} \,, \qquad [7]$$

where c_i gives the sum of weighted deprivation of person i. A poverty cut-off, k, then gives the poverty line, where $c_i > k$ identifies a person as energy poor across all dimensions. Nussbaumer et al. (2011) have here chosen to use the dual cut-off method described and recommended by Alkire and Foster (2011). This is called dual because a cut-off is first determined for each dimension (z_j), and then the cut-off k determines how many (weighted) dimensions the individual has to be deprived in to be energy poor. Alkire and Foster (2011) also present the union method, i.e. the individual is multidimensionally deprived if he or she is deprived in any one of the dimensions. The authors consider this as “overly inclusive” and that it might exaggerate the poverty numbers. On the other hand, the intersection method requires that an individual is deprived in all dimensions to be poor, and this is considered as too strict and will undervalue poverty.

The modified vector $c(k)$ then includes c_i for those identified as energy poor, and counts zero deprivation for those who are not identified as energy poor. In the last step of constructing the MEPI (and MEPI-2), the authors describe how they compute the head count:

$$H = q/n \,, \qquad [8]$$

where q is the number of energy poor and n is the total population. The average intensity of deprivation of those who are identified as poor is defined as follows:

$$A = \sum_{i=1}^{n} c_i(k)/q \,. \qquad [9]$$

A note of caution at this point is that when Nussbaumer et al. (2011) are referring to their measure of intensity, this is not computed in the same way as the OPHI poverty measure of intensity. In the OPHI measure, intensity is defined as the poverty gap, i.e. the average shortfall from the poverty line (among those who are poor). This measure would not be possible with such categorical variables that are being used in this methodology (either you have access to electricity or you do not), as the average shortfall of a categorical variable cannot be measured. Thus, Nussbaumer et al. (2011) define their measure of intensity as the average sum of weighted deprivation of those who are determined as poor. This essentially means that the intensity measure counts how many dimensions on average the energy poor are deprived in. If those who are already energy poor become poor in additional dimensions the intensity (but not the head count) increases, thus the MEPI score increases.

Finally the MEPI (MEPI-2) is given by multiplying the headcount (*H*) and intensity of energy poverty (*A*):

$$MEPI = H\,x\,A\,. \qquad [10]$$

4.3 Variables

The dimensions and the related indicators and variables are summarized in Table 2.

4.3.1 Cooking and Lighting Dimensions

For cooking and lighting with modern fuels, the variables used are respectively the type of primary cooking fuel and the type of primary lighting fuel. It is easily arguable that these are means-base variables, as they record the actual consumption patterns of the households. As the methodology is placed within the capability approach, the use of these variables for measuring capabilities is reasonably questionable.

As mentioned, the measurement at basic capability level is not suitable or pragmatic for the purpose of identifying the energy contributions to these capabilities. The ideal variables to use for studying the dimensions outlined in this methodology would be for instance the time spent on collecting biomass fuels, the time spent indoor cooking, the type of appliance used for cooking, the hours of reliable and affordable lighting of high quality available and so on. These variables are in the energy service level of the capability approach, allowing analysis of how energy consumption is contributing to overall well-being.

However, the lack of availability of such data results in the use of the types of primary cooking and lighting fuel as a proxy for all of these indicators. Although imperfect, these variables have two main advantages. Firstly, as they are the primary fuels being used, households implicitly reveal that this is the most reliable, affordable and available fuel for them. It allows us to identify whether the primary dependency of a household is on a modern or biomass fuel. Secondly, we can also assume that as a primary fuel, consumption of this fuel must be in such quantities that it significantly (positively or negatively) impacts the lives of the members of the household. The household reveals that they are capable of utilizing this fuel to an end by choosing this as their primary fuel. Because of the important direct effects that that the type of cooking fuel and access to electricity have on individuals' health, education and so on, it can be assumed that these variables provide a good proxy for the ends.

Further on, another important reason why these variables are useful in this analysis is that they give a clear understanding of where the interventions should be directed. To improve the capability of good health for a person from an energy perspective, direct intervention into the type of fuel he or she uses could be necessary as this is one (but clearly not the only) of the underlying means of good health. Thus, it is useful to know and measure who is consuming the "right fuels" and not.

Alternatively, the positive consumption of a fuel could have been used as the proxy for having access to this fuel. However, this would not really indicate whether the consumption (of a modern energy) is high enough to make a significant (positive) impact for the household. Further on, as households also could engage in fuel stacking, it would be more challenging to get unambiguous results using this variable.

Table 2: Dimensions and corresponding variables that will be measured in the MEPI-2

Dimension	Indicator (weight)	Variable	Cut-off (deprived if…)
Cooking without indoor air pollution	Modern cooking fuel (0.5)	Primary cooking fuel	Primary cooking fuel is not LPG, kerosene, natural/biogas or electricity
Lighting with modern energy	Electricity access (0.2)	Primary lighting fuel	Primary lighting fuel is not electricity
Access to basic energy services (all fuel types)	Quantity of individual energy consumption (0.3)	Per capita daily energy consumption	Per capita daily kWh consumption is less than threshold

Source: Adapted from Nussbaumer et al. (2011) and adjusted for dimensions to be used in the MEPI-2.

In the cooking dimension, an individual in a household is considered as deprived if the primary cooking fuel is not one of the modern cooking fuels (LPG, kerosene, biogas, natural gas, electricity). In the lighting dimension, an individual is considered as deprived, if the household they belong to, does not use electricity as the primary source of lighting.

4.3.2 Daily Per Capita Energy Consumption – Defining a Deprivation Threshold

The third and last dimension, having access to the most basic energy services, is measured through the daily per capita consumption of household energy sources. The construction of this variable will be described more closely in the next section. A threshold amount of energy is derived based on a bundle of the most basic energy services, and adjusted for household size scale of economies.

One of the compelling arguments from Sen against the use of consumption of resources as a measure of well-being is that it is means-based rather than ends-based, as discussed previously. The consumption of a certain bundle of resources could, according to his capability approach, result in different levels of well-being for different individuals or households because they could require different amounts or types of resources to realize the same capabilities (as illustrated with the example of the disabled man and the capability of mobility). This is a valid point, and for this dimension we would ideally measure the energy services of hours of lighting and amount of water heated directly. The lack of this comprehensive data of this kind thus results in the use of the consumption variable.

However, the rest of sub-section 4.3.2 explains why this still remains a good proxy for the ability to consume basic energy services, and why it can also be regarded as somewhat ends-based. Although not all differences in households are accounted for, the variable will be adjusted for economies of scale of household size, thus taking into account one of the big differences in households. It could also be adjusted for equivalence scales (to adjust for gender and age, etc.) but this is seen as outside the scope of this study.

Useful Energy Consumption

The estimation of the threshold is complicated by several factors. Firstly, energy consumption can be measured at different stages of the supply chain and the choice of stage affects the outcome. Pachauri et al. (2004) have outlined four stages of energy consumption in the supply chain as described in Table 3.

Table 3: The Four Stages of Energy Consumption

Stage	**Form of energy**	**Examples**
1. Primary energy	In natural form before transformation	Mined coal, extracted gas, collected wood
2. End-use energy	As received by the consumer	LPG in tanks, electricity at delivery point
3. Useful energy	The actual energy from the appliances	Heat from stove, light from lamp
4. Energy services	The services for which energy is required	Transportation, hot shower, telecommunications

Source: Adapted from Pachauri et al. (2004).

Secondly, the amount of energy required is also dependent on which fuel source is used and the type and efficiency of the appliance used to transform the end-use energy into useful energy (from the second to the third stage in Table 3), to mention some factors. It would be most ideal to measure the consumption of energy services rather than of the fuels, but as this might be practically difficult, measurement of useful energy consumption is often the best alternative. However, this also entails making somewhat arbitrary assumptions about the efficiencies of fuels and appliances. Thirdly, adding up amounts of energy from different fuel sources or for different energy services is not straightforward, and could lead to insensible results (e.g. adding up the light radiating from a lamp with heat from a stove) (Pachauri et al., 2004).

Estimating the Threshold

Because of variations in climate, geography, culture, season, etc., the demanded type and quantity of energy services could also differ between different areas. The differences could be increased by variations in types and qualities of appliances used, making it difficult to determine one universal level of minimum needs. The measure of physical needs is therefore somewhat arbitrary and as mentioned before, it should ideally be defined separately for each individual case.

Table 4 gives an overview of different estimates for the minimum required energy consumption. Only the estimates made by the Advisory Board on Energy (1984) (as cited in Pachauri et al., 2004) and Pachauri et al. (2004) are adjusted specifically to India. Bravo et al.

(1979) (as cited in Khandker et al., 2012) have developed their estimate for tropical regions like Bangladesh, which is comparable to India. Foster et al. (2000) use an estimate for Guatemala. It must also be noted that the definitions of what services to include in these estimates vary, so that some of the higher estimates could include services that are not included in the lower ones. For the estimates that have a more universal outlook, there could be higher requirements for e.g. heating, as heating is a greater necessity in most western countries than generally in India. The same useful energy efficiency as given by the Indian Advisory Board on Energy (about 13 percent) is used for the estimates that were reported in other energy stages than useful energy.

The minimum required energy per capita per day varies from 0.36 kWh (which is the lower level energy poverty threshold reported in Pachauri et al., 2004) to 1.59 kWh in Goldemberg (1990). The variations can be explained by the reasons discussed in the previous paragraph; mainly difference in geographic scope of estimation, services included and the stage which energy is reported in and the actual efficiencies to convert the estimates into useful energy. However, we see that the estimates are in the same order of magnitude, making this interval reasonable.

Following the capability approach, I attempt to estimate the minimum amount of energy required to be able to enjoy certain basic energy services. Which services that are deemed as the most necessary must be defined with the context in mind.

Using the same estimation process as Pachauri et al. (2004) for the minimum required quantity of energy, I define the basic energy services for a household in India as being able to cook food, heat some water and some hours of lighting. It must again be emphasized that this is only the most basic energy services, and does not ignore the importance of having electrical household appliances, entertainment, means of telecommunication etc. By estimating the threshold based on the most basic needs, policy makers can target those that do not even have access to the most basic energy services.

Using numbers for India from Pachauri et al. (2004), I get that the useful energy per capita per day (given a five-member household) is 0.648 kWh. This is slightly lower than the upper poverty estimate of 0.72 kWh by Pachauri et al. (2004). The estimate assumes consumption over a 24-hour period, and an end-use efficiency of around 15.5 percent.

Table 4: Overview over estimates of daily per capita energy requirements

Source	**Useful energy requirements (kWh per capita per day)**
1. Goldemberg (1990)	1.59*
2. Advisory Board on Energy, India (1984)	0.792*
3. Pachauri et al. (2004)	0.36 - 0.72
4. Foster et al. (2000)	1.18
5. Bravo et al. (1979)	1.40*
*Efficiency factor: 0.132 as estimated by the Advisory Board on Energy, India (1984)	

Source: Own table based on estimates from Goldemberg (1990), Advisory Board on Energy, India (1984) in Pachauri et al. (2004), Pachauri et al. (2004), Foster et al. (2000), Bravo et al. (1979) in Khandker et al. (2012)

Household Scale Effects

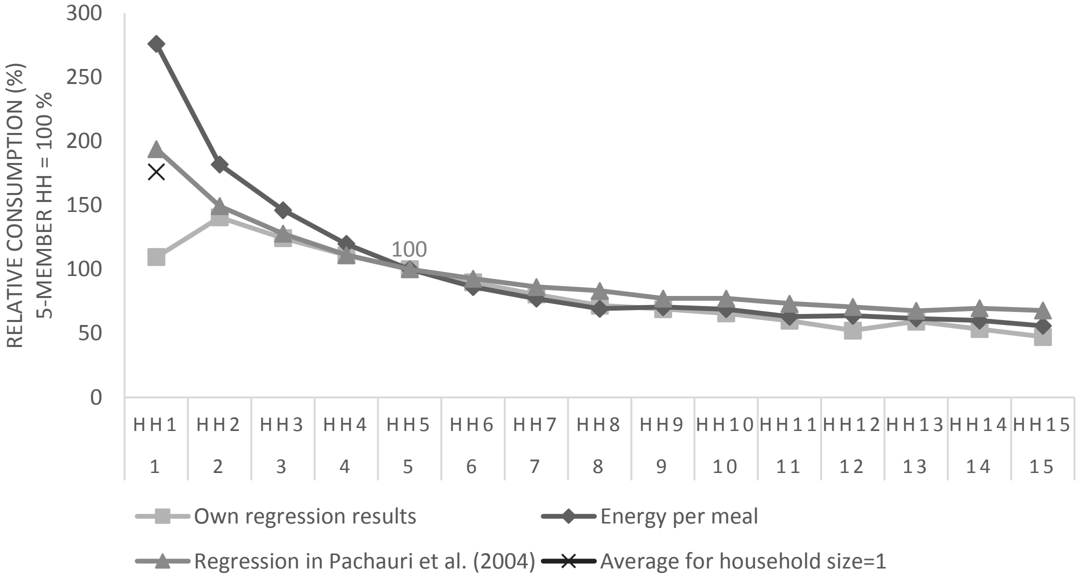
Pachauri et al. (2004) discuss the household scale effects on energy consumption, and argue that the household size will affect the required energy per capita. Their estimates are based on a five-member household, and the authors use various sources to support their claim that there are indeed significant household scale of economies that need to be accounted for. Further on, they estimate the household scale economies with their own data, using two different methods; 1) calculate the required energy per meal cooked at home and 2) regress energy consumption against the household size dummy variables, including monthly per capita expenditure as a control variable. Their calculations match well with the sources.

I follow the same procedure and calculate the energy consumption per meal, as well as doing a regression. The regression is a log-log regression, as described in Pachauri et al. (2004) with per capita daily energy consumption as the dependent variable, and monthly per capita expenditure and household size dummy variables as the independent variables. The regression results are shown in Annex A (Table I) in the appendix. Figure 5 shows the relative consumption of the households, based on the regression, as well as the energy per meal calculation and the regression estimates from Pachauri et al. (2004).

Mostly, the estimates match well with each other, but we see that there are discrepancies for the single-member households. By analysing the data more closely, it seems that this is related to the number of meals that the single-member households actually make at home. The average is about 40 meals cooked per month per capita at home for the single-member households, while it is around 70 meals per month per capita for all other household sizes. It might be reasonable that single individuals eat more out, eat with their friends and family and generally cook less. The regression, however, shows a lower relative consumption for the single-member household than the other estimates. This could again be related to the number of meals, and that these households in fact consume fewer energy services in their homes compared to the other household sizes.

To get a more reasonable estimate for the single-member households, the energy per meal required is estimated by assuming that also these households consume 70 meals per month per capita at home. Then taking the average of this estimate and the estimate from the regression done by Pachauri et al. (2004), results in an estimate closer to Pachauri et al. (2004). It is marked by the “x” in the Figure 5. Finally, this estimate is used for the single-member households, combined with the regression results for the other household sizes to adjust for household scale economies in the energy consumption. Table 5 gives the overview of the threshold limits by household size, with the five-member household being the original estimate, at 0.648 kWh.

Figure 5: Overview of estimates of household scale economies on per capita daily energy consumption.



Source: Own estimates based on NSS-data and Pachauri et al. (2004)

Table 5: Threshold limit of minimum energy requirements, by household size

Household size	**Threshold limit (kWh)**
1	1.140
2	0.910
3	0.805
4	0.719
5	**0.648**
6	0.582
7	0.520
8	0.465
9	0.446
10	0.425
11	0.388
12	0.338
13	0.384
14	0.345
15	0.306

Source: Own calculations based on NSS-data and Pachauri et al. (2004).

4.4 Weights

In the MEPI, cooking is the energy service/dimension that is given the largest weight. Nussbaumer et al. (2011) measures achievements in this dimension through two indicators; access to clean cooking fuels and access to clean cooking facilities.

This relative importance of the cooking dimension is mirrored in Pachauri et al. (2004). Having access to LPG (as a cooking fuel) qualifies to keep a household/individual out of energy poverty, no matter the amount of their energy consumption. Thus, this is seen as the most important dimension when measuring energy poverty. Furthermore, it reflects the severity of the issues that were described in Section 2 related to using biomass fuels and inefficient cooking stoves for cooking. However, because of the availability of data, only one indicator (access to clean cooking fuels) will be used to evaluate this dimension in this thesis.

Further on, the dimension of lighting is also given a relatively high importance in the MEPI, measured through the access to electricity. Also in Pachauri et al. (2004), access to electricity might enable households to come out of energy poverty, given that they are consuming a certain amount of energy. Thus, through the poverty lines they have drawn, Pachauri et al.

(2004) have also assigned invisible weights to the different dimensions. These correspond well with those used in the MEPI.

As shown by Pachauri et al. (2004), there is a threshold amount of consumption (more than 0.72 kWh) where a household is not considered as deprived, regardless of the type of energy consumed (see Figure 4). At lower levels of consumption, the extent of the deprivation is dependent on the level of energy access (i.e. bio-level, electricity-level or LPG-level). Thus, this dimension can be evaluated as being more important than access to electricity, but less important than the having access to clean cooking fuels.

Following this discussion, cooking, lighting and the quantity of consumption are assigned with the weights 0.5, 0.2 and 0.3, respectively. The multidimensional cut-off, *k*, is set to 0.5, meaning that an individual is multidimensionally deprived either if they do not use modern cooking fuels, or if they do not use electricity and a minimum amount of energy (or all three combined). Both the weights and multidimensional cut-off are somewhat arbitrary and the robustness of these parameters will be tested in the sensitivity analysis presented in Section 7.1.

5. Description of Data

5.1 Survey Background and Design

Household consumer expenditure data from the 68th round of the National Sample Survey is used for the analysis (hereby referred to as “NSS-data”). The survey was conducted from July 2011 to June 2012 by the Government of India, represented by the National Sample Survey Office (NSSO). Usually the survey is conducted every five years, but as the round before was conducted during an unusual year (in terms of economic conditions), this round (in 2011-12) was repeated only two years after the previous one. The data is assumed to be nationally representative, as the sample of villages and urban blocks in the survey cover the whole of the Indian Union, with the exception of some inaccessible areas in Nagaland, the Andaman Islands and the Nicobar Islands. There is only data for the former state of Andhra Pradesh, as the survey was conducted before Telangana was established as a separate state. In total, there are 35 states and union territories.

A stratified multi-stage design was used to select the samples to ensure a representative sample from urban and rural sectors and from the different states. The sample strata, or sub-groups, are assigned with weights to be representative of the whole Indian population. The weights ensure the correct representation of sub-groups that are under- or over-represented in the survey. The assigned sample weight is essentially the inverse of the probability of that sample being chosen for the survey. The descriptive statistics, as well as nationally representative results presented in the next section, are weighted figures based on the weights provided by the NSSO.

As summarized in Table 6, a total of 101,662 households have been included in the survey of which 59 percent are rural and 41 percent urban. The households were chosen from a sample of rural villages and urban blocks. In total, the households represent an estimated population of approximately 1.1 billion people[8]. The data used is from the “Central sample” of the survey, meaning the sample that was collected by the central government (as opposed to the “State sample”, which is collected by the state governments).

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[8] This number is estimated using the sampling weights provided in the NSS-data.

Table 6: Number of Households in Survey

NSS 68th round Schedule 1, Type 1	**Rural**	**Urban**	**Total**
Number of households in survey	59,695 (59 %)	41,967 (41 %)	101,662 (100 %)
Estimated population represented	7.92E+08 (71 %)	3.17E+08 (29 %)	1.11E+09 (100 %)

Source: own calculations based on NSS data

5.2 Contents of Survey

The objective of the survey is to measure living standards through estimates such as per capita expenditure, distribution of households over expenditure levels, differences between the rural and urban groups, the states and different socio-economic groups, nutritional intake information and budget shares of different commodity groups, among other things. The survey collects information on the values and quantities of household consumption of various commodities. A detailed item list includes the consumption of food, energy, clothing, educational and medical expenses, durable goods and others items. In addition, there are key demographic data about each household and its individuals, such as age, education, sex, household size, etc.

As the survey is not specifically concerned about energy consumption, only general information on expenditure on household fuels has been collected. For instance, there is no information about access to different sources of energy and related data such as quality, reliability and affordability of access. Neither is there information about the time spent on collection of fuel wood and other biomass. Information on the type of appliances used for energy consumption, duration of their use and purpose of consumption would also be useful for the analysis of energy poverty. However, it is possible to make proxies for some of this information based on the available consumption data, even though it is not a perfect substitute for having a more tailored data set. The data has the advantage that the sample is large and nationally representative, and that the survey procedure and data collection is considered as reliable (Ekholm et al., 2010).

The section on fuels covers consumption in quantity and value of standard fuels used for cooking, heating and lighting, among other energy services (See Figure I in Annex B). These items are reported for a recall period of 30 days (consumption during last 30 days).

Respondents also report on the primary fuel sources used for cooking and for lighting.

5.3 Constructing The Per Capita Daily Energy Consumption Variable

To construct the variable containing the per capita daily energy consumption of each household, the consumption of each fuel that the household consumes are added together. As the variables reporting the total consumption quantity of each fuel for a household are reported in different units, the following steps are executed to get the same unit. First, the energy content per unit of each fuel is found. Then, the numbers are converted to kWh (assuming consumption over a 24-hour period), before applying efficiencies to find the useful energy consumption of each fuel. The efficiencies are based on consumption of the fuels mostly for cooking (and in some cases lighting). As cooking makes up 70 percent of the household energy consumption in India (IEA, 2015), it seems reasonable to apply these efficiencies as Pachauri et al. (2004) also do.

After converting the different fuel consumption variables to the same unit, they are summed to get each household's total energy consumption. This gives the households total energy consumption in kWh reported for the last 30 days. Thus, the total is divided by 30 to get the daily consumption, and further by the household size to get per capita numbers.

Note that there are no responses recorded for the quantity of total consumption for “dung cake”, “gobar gas” or “other fuels”. Consumption of candles and match boxes are excluded, as they do not really contain energy in the same way as e.g. wood or kerosene. Further on, I also exclude the consumption of petrol and diesel, as these are not commonly used for cooking and only 164 and 174 households have reported to consume any quantity of these two fuels, respectively.

5.4 Descriptive Statistics

As described previously, the main variables used for the analysis are per capita daily energy consumption, primary cooking fuel and primary lighting fuel. From the summary statistics in Table 7, we see that the mean of the per capita daily energy consumption in kWhs is around 1 kWh for the rural sector and 1.4 kWh for the urban sector. The means are calculated using the survey sample weights, adjusted for individual level. There is a quite large variation in the per capita daily energy consumption, interestingly enough the variation is larger for the urban sector than the rural. This reflects the large inequalities that can be found especially in the Indian cities, more so as peripheral slum areas are increasing rapidly.

The household size is also included in Table 7, as the variable is used to estimate household size scale economies in the energy consumption. The threshold limit for deprivation in the dimension of sufficient quantity of consumption is adjusted based on the size of the households. We see that for both urban and rural sectors, the mean household size is around five members. The threshold energy deprivation limit for a five-member household is 0.648 kWh (per capita per day), as mentioned previously.

Table 7: Summary statistics

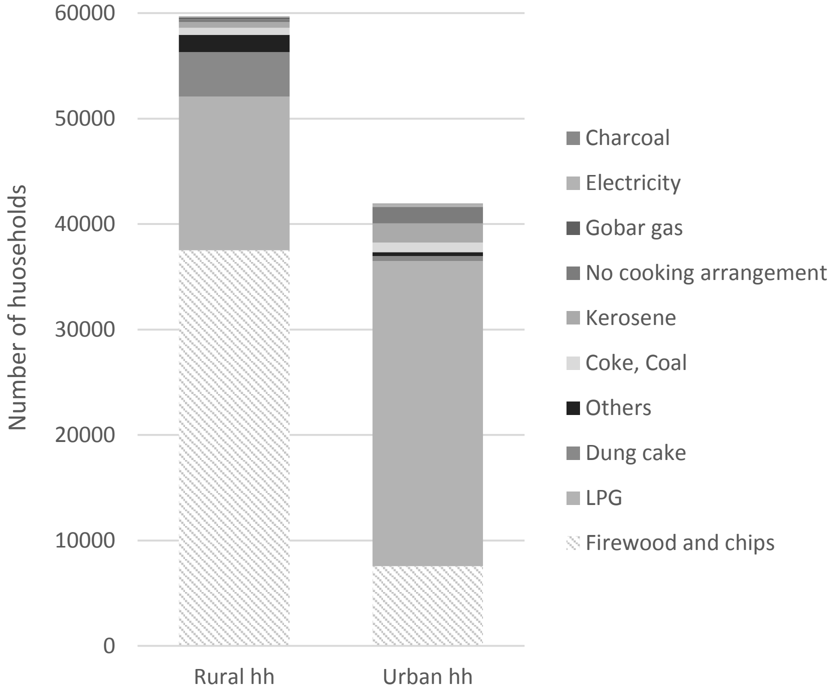
	Rural	**Urban**	**Total**
Per capita daily energy consumption (kWh)	1.009 (0.710)	1.382 (0.873)	1.116 (0.779)
Household size	5.58 (2.337)	5.18 (2.348)	5.47 (2.348)

Note: Table shows means and standard deviation in parenthesis.
Source: Own calculations based on NSS-data.

For the variables primary cooking fuel and primary lighting fuel, the responses are recorded as categorical variables, therefore the data is presented in figures. The distribution of fuels used as respectively primary cooking fuel and primary lighting fuel is shown in Figures 6 and 7. Firewood is the most common fuel used for cooking in rural households in India, while LPG is the most common in urban households. The most common primary lighting fuel is electricity both in rural and urban households. However, a relatively large proportion of the rural households still use kerosene for lighting.

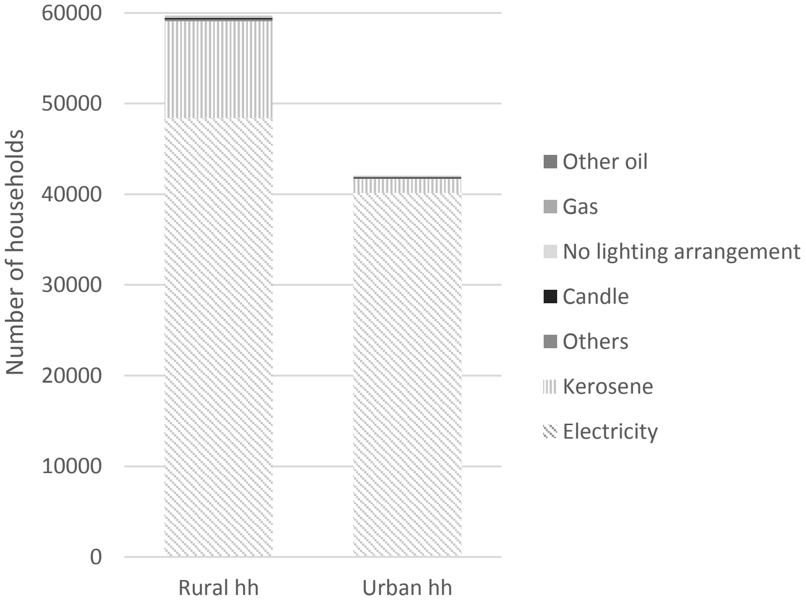
The NSS-data is recorded for households, but the results will be presented using individual averages (computed using the sample weights provided by the NSSO). This makes the results comparable with other energy poverty research.

Figure 6: Distribution of primary source of cooking fuel in Indian households



Source: Own figure based on NSS-data

Figure 7: Distribution of primary source of lighting fuel in Indian households



Source: Own figure based on NSS-data

5.5 Data Treatment

Before executing the analysis, the dataset has been amended as follows. Firstly, all observations where the value of the constructed variable per capita daily energy consumption is zero are excluded. This is because there seems to be some error in the response when there is absolutely no consumption of any of the household energy fuels, and can in any case be considered as outliers. This reduces the dataset by 204 observations. Those observations where there is a missing response for primary cooking or lighting code were also removed. This is because there is a designated code for “no cooking arrangement” or “no lighting arrangement”, respectively, and if the response is missing, this must be due to a recording error. This exclusion reduces the dataset by two (missing cooking code) and five (missing lighting code) observations. Finally, all the observations where the household consists of more than 15 household members are removed, as these observations are considered as outliers. This reduces the dataset further by 171 observations. In total, the dataset was reduced by 382 observations. Thus, the analysis was based on 101,280 observations.

6. Results

The MEPI-2 is estimated for all of the 35 Indian states and Union territories. Figure 8 gives an overview of the scores for the different states. A higher MEPI-2 score shows higher energy poverty. The northern states show higher MEPI-2 scores than the southern states, meaning that there is higher energy poverty in these states. It is especially the north-eastern region that is the most affected by energy poverty. Bihar, being the state with the lowest electricity consumption on average in India, also has the highest MEPI-2 score. In fact, Bihar is the only state to have a score higher than 0.6. Except for Bihar, none of the states face severe energy poverty (higher than 0.7). However, a significant amount of states (mainly in the north-eastern region) face a moderate degree of energy poverty, scoring between 0.2 and 0.4.

A complete overview of the scores can be found in Table III in Annex D in the appendix. The table also gives an overview of the head count ratio, the deprivation intensity, deprivation head count in each of the three dimensions, the HDI score and income poverty ratio for each of the states (if available).

At the national level, the all-India MEPI-2 score is 0.259. The percentage of people that are energy poor are 31 percent and the average deprivation intensity is 0.85. I compare my results with the results from Pachauri et al. (2004), who in their study measured the energy poverty in India at different points in time between 1983 and 1999. The results are found to match well; in Pachauri et al. (2004), they found that the energy poverty had decreased from 75 percent in 1983 to 40 percent in 1999. Thus, the results from this study confirm that there is continued progress in reducing energy poverty.

Further on, if the results are compared with the results from the analysis done by Nussbaumer et al. (2011) on African countries, it is evident that there is much lower energy poverty in India. In fact, most of the African countries that were analysed have a MEPI scored higher than 0.6, and many around 0.8. Although it might be plausible that the energy situation is worse in many African countries than in India, another possible explanation for the big difference is that Nussbaumer et al. (2011) have dimensions on more advanced energy services included in their model. These are the dimensions of services available through the use of household appliances, telecommunication means and entertainment means that were evaluated as not being among the most basic services. Thus, it makes sense that there is less energy poverty in India since the Indian individuals are evaluated based on the most basic energy services, where more efforts have and should be directed. This also illustrates the importance of having consistent models, when comparing results across time and space.

Figure 9 shows the percentage of population with access to each dimension (the inverse of the deprived in each dimension). Note that darker tints in Figure 9 mean higher percentage of access (as opposed to in Figure 8 where darker tints mean a higher MEPI-2 score and higher deprivation). We see the same pattern, with the north-eastern states having least access overall, resulting in the higher MEPI-2 scores. Interestingly, for both access to minimum amount of consumption and to electricity, most states have a high percentage of the population that have access (more than 80 percent).

There is more variation in the access to clean cooking fuels, indicating that this is perhaps the dimension that should be prioritized by policy makers. For example, the southern state of Karnataka has a high percentage of the population with access to both quantity of consumption and access to electricity (more than 80 percent), while the percentage with access to clean cooking fuels is only between 20 and 40 percent. In fact, there are only two states/territories (Pondicherry and Delhi, both of which are cities) that have more than 80 percent of the population with access to clean cooking fuels.

In Figure 10, MEPI-2 is compared for rural and urban sectors by income quintiles (using the variable *monthly per capita expenditure, uniform reform period*). The population is grouped into five “slices” with the 20 percent most affluent in fifth quintile and the 20 percent least affluent in the first quintile. The urban MEPI-2 is much lower than the rural MEPI-2 for all quintiles, which is not surprising. However, the difference between the two sectors is quite significant. For the rural sector, the difference between the MEPI-2 scores for the different quintiles is much more pronounced than for the urban sector. The difference between the rural and urban sectors become less prevalent (but are still significant) in the most affluent quintile.

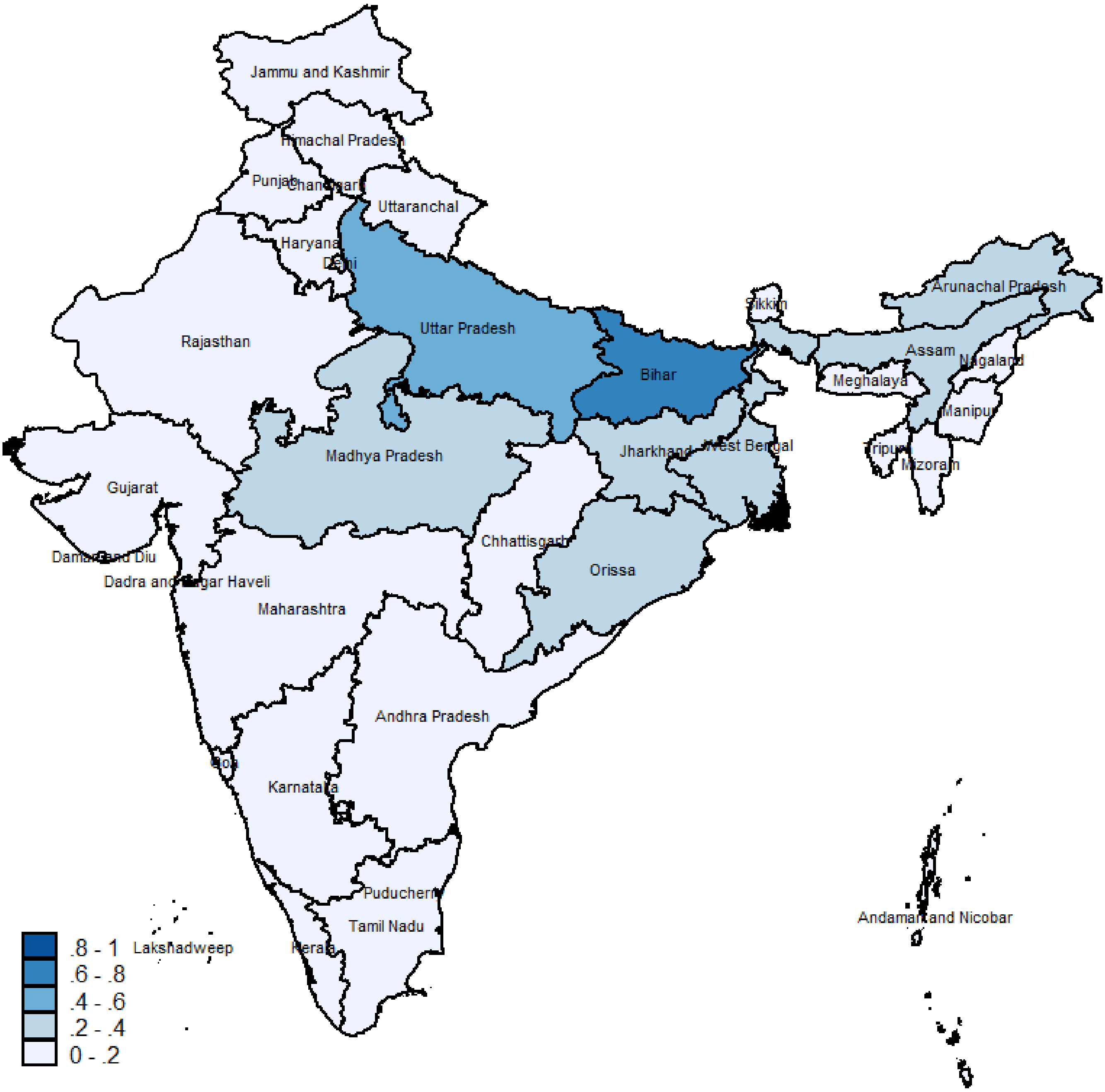
Figure 11 shows the intensity of the deprivation of those who are energy poor plotted against the head count ratio of those who are energy poor. There is a weak positive correlation between the two variables, but it is evident that the interval of the intensity of deprivation is much smaller than for the energy poverty head count. As the intensity of deprivation is only calculated using the weighted sum of deprivation for those who are multidimensionally deprived, it is to be expected that this value is high. The results confirm that for those who are deprived, the average sum of weighted deprivation is above 0.60 for all states, and fluctuating around 0.80 for the majority. It also illustrates that for those states that have a lower MEPI-2 score (due to a lower head count ratio), the intensity of deprivation for those who are deprived is still severely high.

Comparing the MEPI-2 with other welfare measures

The headcount ratios of income poverty and energy poverty are compared in Figure 12. There is to a great extent overlap between the states that are most income poor and most energy poor. However, we see that the degree of severity varies between the two ratios. Bihar has a severely high headcount ratio of energy poverty (higher than 0.8), while the headcount ratio of income poverty is more moderate (just above 0.3). Thus, Figure 12 illustrates that although there is a strong correlation between income and energy poverty, the two cannot be equated.

Finally, Figure 13 shows a plot of the MEPI-2 score against the HDI score for each state. There is a weak negative correlation between the two measures, as expected, but it is not perfectly linear. For some of the states with higher MEPI-2 score, the HDI score is not low as could be expected. The states with the two highest MEPI-2 scores, Uttar Pradesh and Bihar, have a HDI score just below 0.4. Other states with lower MEPI-2 scores have similar HDI-scores, in fact most of the HDI scores are concentrated between 0.4 and 0.6. Thus, it is evident that for some of these states, the HDI score does not reflect the energy poverty situation and it is thus useful to use the MEPI-2 score as a complementary tool for measuring overall well-being and identifying energy related issues that need to be solved.

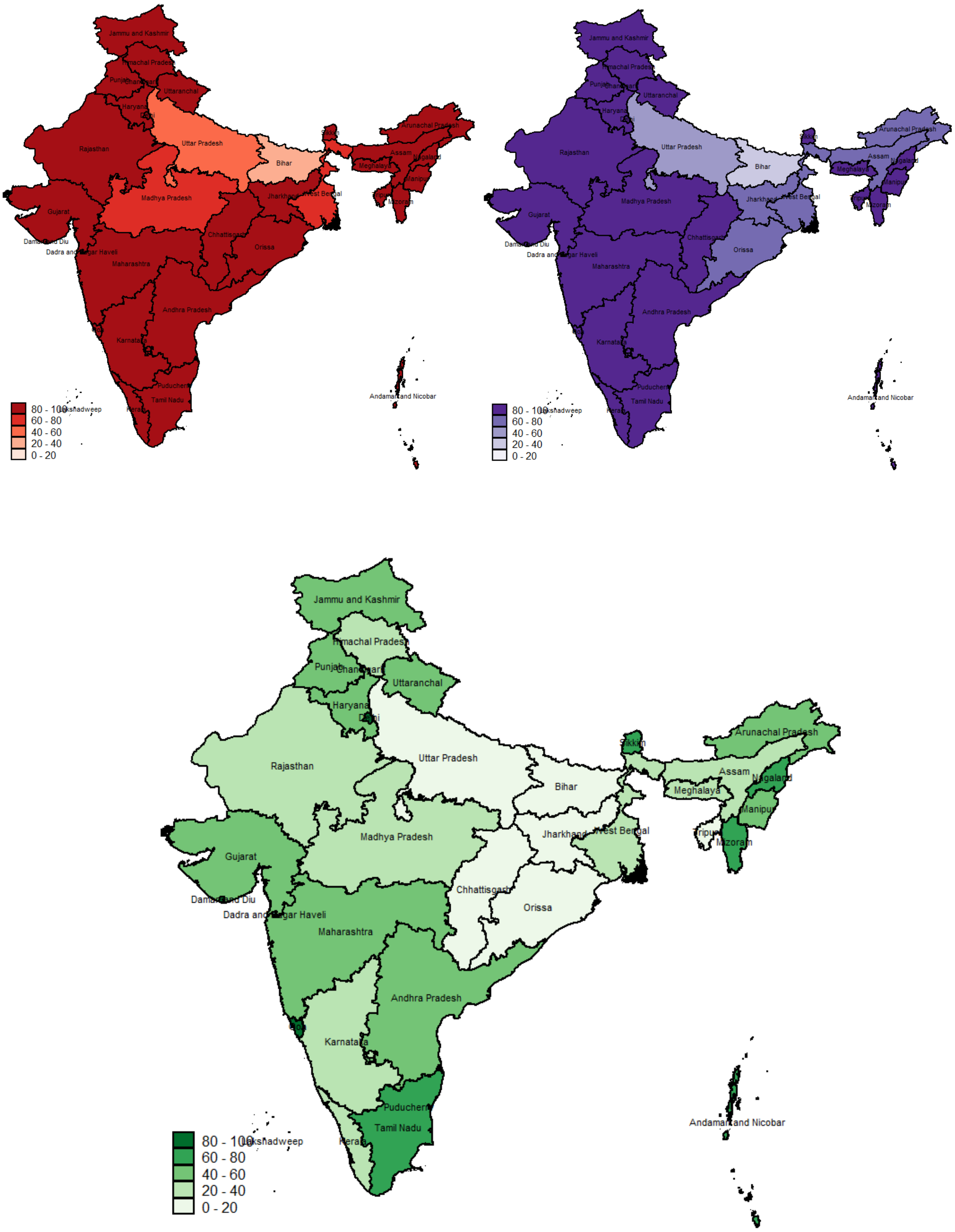
Figure 8: Overview over MEPI-2 scores for the 35 Indian states and union territories.



Note: MEPI-2 is scored between 0 and 1. The states with a higher score (and darker tints in the map) have a higher MEPI-2 score, meaning that there is higher energy poverty in these states.

Source: Visual created by author in Stata

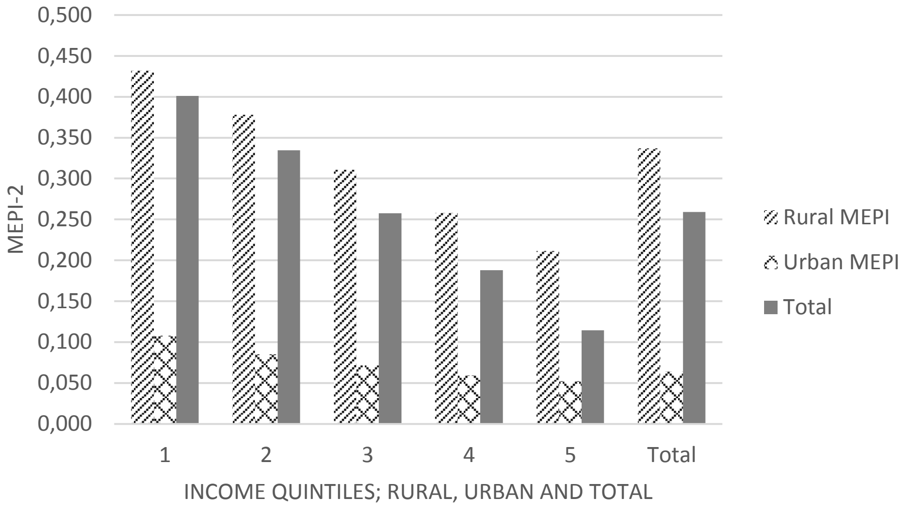
Figure 9: Overview of access to sufficient minimum consumption of energy (top left), access to electricity (top right), access to clean cooking fuels (bottom).



Shows percentage of population with access, darker tint means higher percentage.

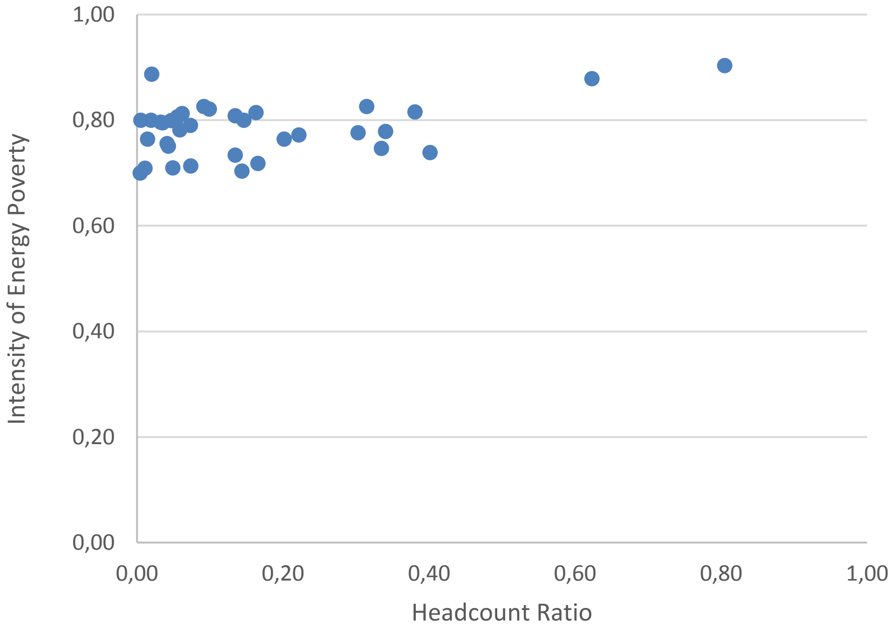
Source: Own estimations based on NSS-data. Visuals created in Stata.

Figure 10: Overview over MEPI-2 scores by rural and urban income quintiles in India



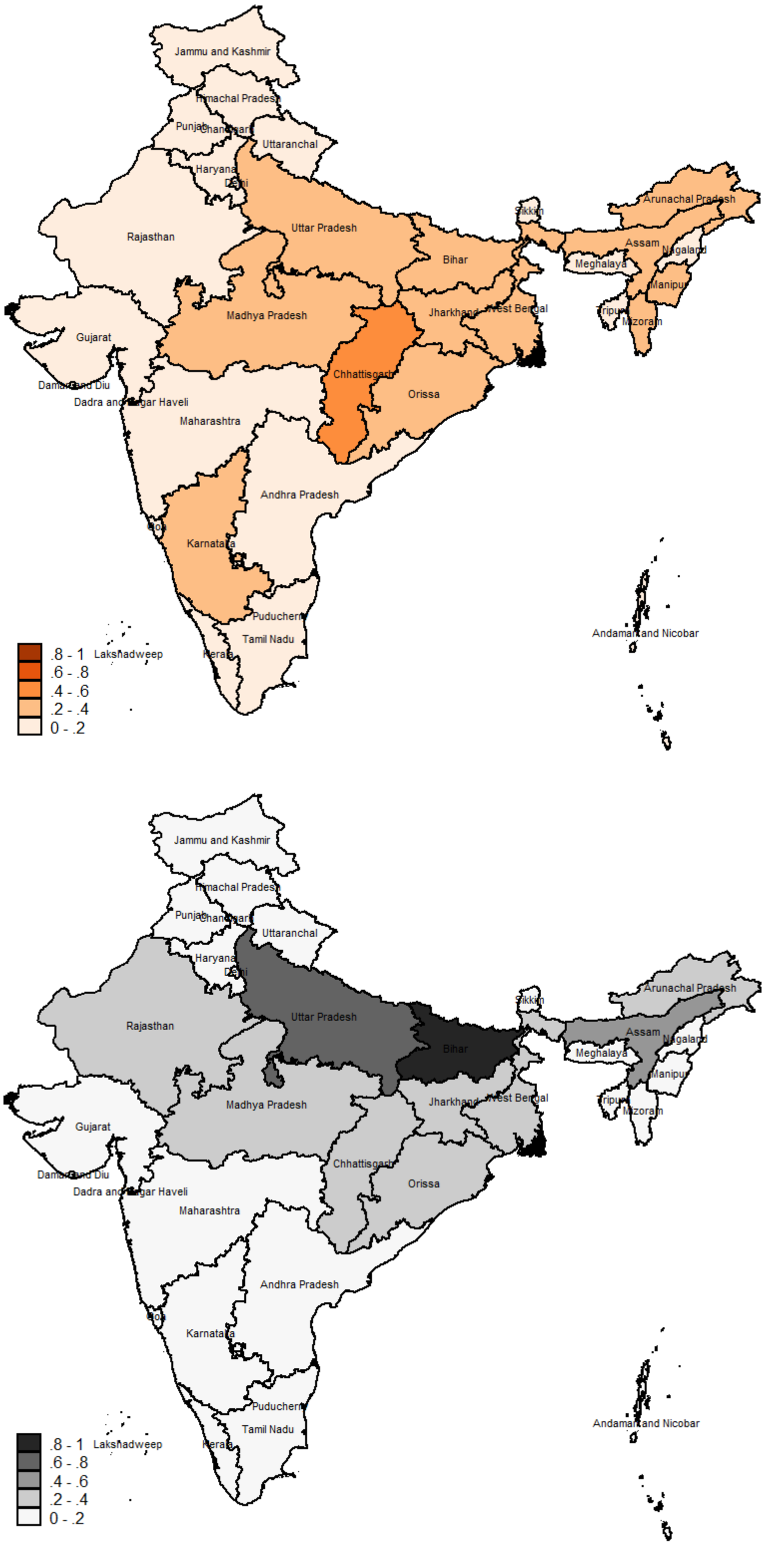
Source: Own estimations based on NSS-data

Figure 11: Scatter-plot of Intensity of Energy Poverty vs. Headcount Ratio of Energy Poverty for Indian states and territories



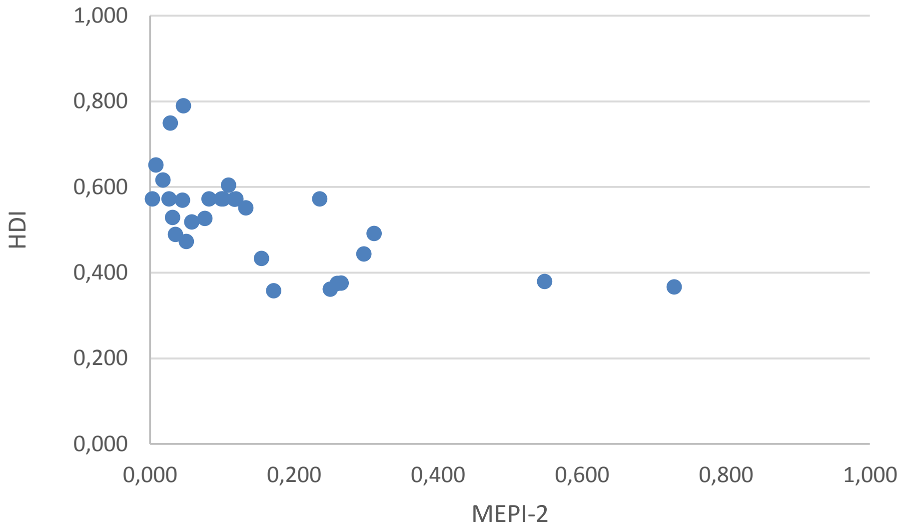
Source: Own estimations based on NSS-data.

Figure 12: Overview over poverty ratio (top) and MEPI-2 headcount ratio (bottom) by state



Source: Own estimations based on NSS-data and poverty headcount: Planning Commission, Government of India (2013). Visuals created in Stata.

Figure 13: Comparison of HDI vs. MEPI-2 for the Indian states and territories



Source: Own estimations of MEPI-2 based on NSS-data, HDI: The Institute of Applied Manpower Research, Planning Commission, Government of India (2011).

7. Discussion

This section presents the sensitivity analysis to test the robustness of the methodology and of the results. Further on, it also gives suggestions for improvement that can be considered in further work with energy poverty measurement using this methodology.

As discussed previously, the data used for the analysis is not ideal. By placing the methodology in the capability approach, it would have been desirable to use actual ends-based data, i.e. measure the actual consumption of energy services. However, due to the lack of data that fulfils this criteria, the consumption of useful energy fuels and of the type of primary energy fuels have been used. Thus, the weaknesses of using this data as a proxy is recognized by the author.

Further on, the issue of weights and the multidimensional cut-off will be discussed below.

7.1 Sensitivity Analysis

7.1.1 Testing the Dimensional Weights – *What if access to clean cooking fuel does not save you?*

Computing a composite index by aggregating the dimensions requires using a somewhat arbitrary set of weights for the dimensions. The weights used for the three dimensions in the MEPI-2 model have been discussed and reasoned. However, as there is always some uncertainty involved, two tests are performed in which the weights are changed to test the robustness of the results.

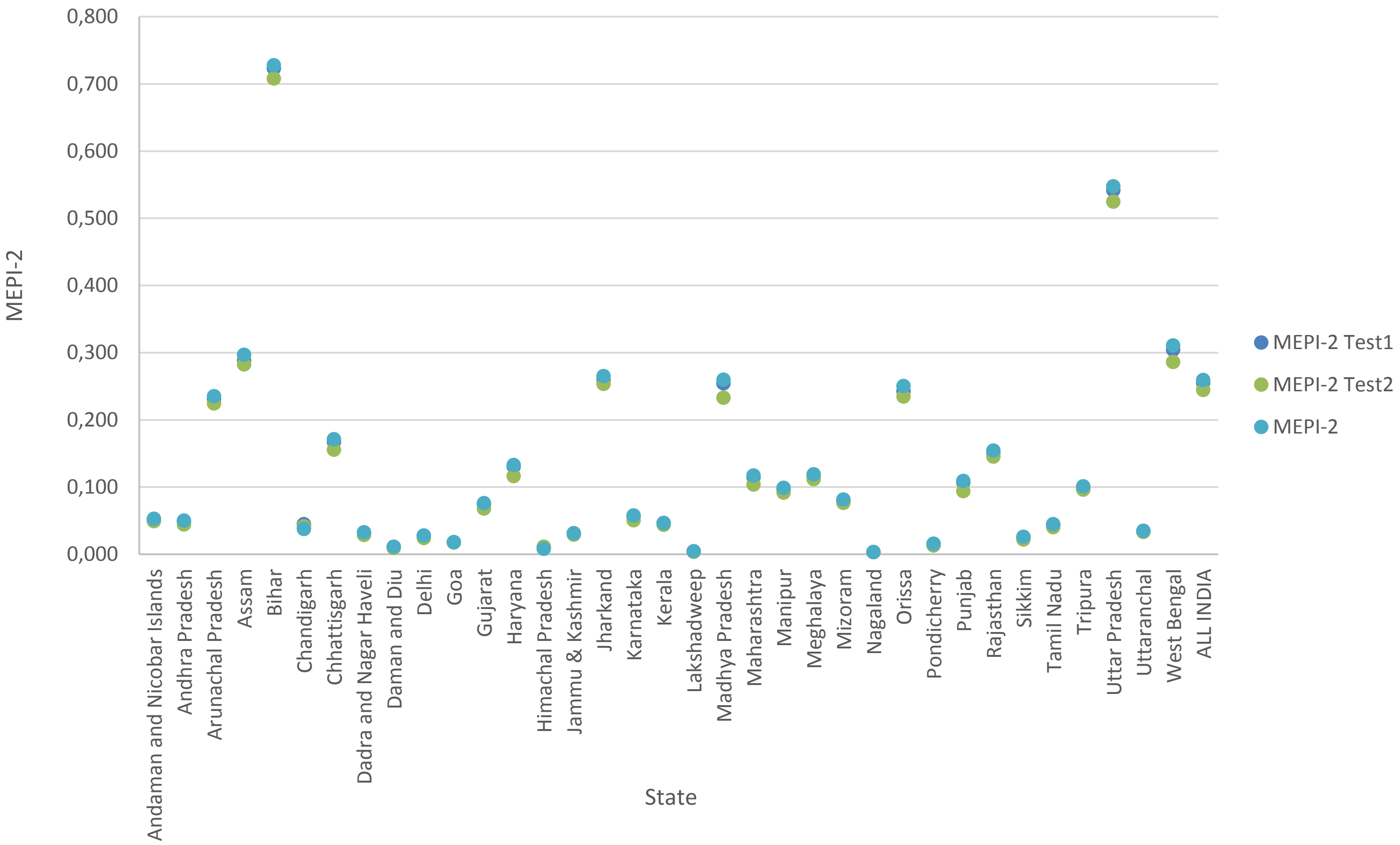
The tests only change the weights and no other parameters of the methodology in order to isolate the effect of the change. This means that the multidimensional cut-off, k, will remain at 0.5 as in the original model. In the original model, k has been set 0.5 because this allows for an individual to remain out of energy poverty if he or she has access to only clean cooking fuels (which has the weight of 0.5), without having access to the other two dimensions. For the testing of the weights, the assumption that having access to clean cooking fuels alone can keep an individual out of poverty is no longer valid. Thus, I reduce the weight of the dimension of cooking below 0.5 and adjust the other two dimensions accordingly.

In the first test, the weight of the cooking dimension is reduced to 0.45. As the sum of the weights have to equal 1, the other two dimensions have to be increased accordingly by a total of 5 percentage-points. The two dimensions are increased with equal amount of percentage-points, so that lighting is increased to 0.225 and quantity of consumption to 0.325. This change of weights entails that an individual that only has access to clean cooking fuel (and not at least one of the other dimensions) will be defined as energy poor. If the individual has access to both of the other two dimensions, he or she will not be defined as energy poor (as earlier). In essence, the measure has become stricter in determination of energy poverty, so the head count can be expected to increase. At the same time, it has been shown that the dimension of cooking fuels is the one where most individuals are deprived on average, so the intensity of deprivation would decrease as the contribution of the cooking fuel dimension to the weighted sum of deprivations is lower. The MEPI-2 scores could change in both directions, if any.

In the second test the weights are changed to be equal; each weight has the value of one-third. As in the first test, having access to clean cooking fuels is no longer enough, a combination of cooking fuels and at least one of the other dimensions or having access to both of the other two dimensions is necessary to remain out of energy poverty. The same effects apply here as in the first test, and it is not possible to determine the direction of change in the MEPI-2 scores.

Figure 14 gives shows the MEPI-2 scores by state for Test 1, Test 2 and the original model. Without exception, the scores do not deviate significantly (at most by about 0.03-0.04). In fact, in some of the states, the scores are in practice the same for the three computations. Further on, in almost all cases, the MEPI-2 score of the original model is the highest and the scores from Test 2 the lowest (with some exceptions).

Figure 14: Overview of MEPI-2 scores with change in dimensional weights



Source: Own figure based on NSS-data

7.1.2 Testing the Multidimensional Cut-off

In the second sensitivity analysis, the multidimensional cut-off has been tested. The cut-off in the original model is 0.5 as mentioned above. In the test, it has been changed to 0.2, 0.3, 0.7 and 0.8. Although it might seem very drastic to change the cut-off using such a large interval, the reason for this is that these alternative cut-offs represent the other possible weighted sum of deprivations that an individual can achieve. Because of the limited number of indicators representing the three dimensions, the different possible combinations of achievements do not allow for a wide variation in the weighted deprived sum. With the weights given in the original model, an individual can have the weighted deprivation of 0 (no deprivation), 0.2 (deprived in lighting), 0.3 (deprived in quantity), 0.5 (deprived in lighting and quantity or cooking), 0.7 (deprived in cooking and lighting), 0.8 (deprived in cooking and quantity) and 1 (deprived in all three dimensions). Thus, it would not be of any value to change the cut-off to for example 0.4 and 0.6, as this would give the same results as k=0.5 as long as an individual cannot attain the sum of 0.4 or 0.6.

Tables 8 and 9 show the results of the Spearman and Kendall Rank Correlation tests respectively, of the ranking of the states by MEPI-2 when cut-off has been changed. In the Spearman Rank Correlation test, the correlation is tested based on the differences between the ranks of the two variables for one observation (in this case, each state). The Kendall Rank Correlation test however, measures the correlation based on the number of concordant and discordant pairs of variables. Concordant pairs occur when the rank of one observation of the variable, x1, is greater than the rank of y1 both when sorting the observations by the x-variable and the y-variable. To put it more simply, concordant pairs are where the ranks of the variables are ordered in the same way and discordant pairs are those with ranks not ordered in the same way. Both the Spearman and Kendall tests are non-parametric tests, meaning that there is no assumption of an underlying distribution. The data fulfils the requirements of both tests of being ordinal or continuous (they are continuous in this case) and monotonic (either a positive or negative correlation, not a mix). The Kendall correlation coefficient, *Tau*, usually results in smaller values than the Spearman correlation coefficient, *Rho*.

From both Tables 8 and 9, the results show that there is a positive correlation between the rankings of the different MEPI-2 outcomes, significant at a 5-percent significance level. In Table 8, the *Rho* is shown as 0.7703 between k = 0.5 and k = 0.3. It is similar between k = 0.5 and k = 0.2, but between k = 0.5 and k = 0.7/k =0.8, it is higher at 0.8541. Interestingly, the correlation between k = 0.7 and k = 0.8 is 1 in both tests. In the Kendall test, the *Tau* is 0.5933 between k = 0.5 and both k = 0.2 and k = 0.3. Similarly, the correlation between k = 0.5 and both k = 0.7 and k = 0.8 is 0.6975. The results of the Kendall test are somewhat lower, as expected. To validate the robustness of the results, it would be ideal to have higher correlation coefficients (in Nussbaumer et al., 2011 the correlation coefficients in both tests for all pairs of variables are higher than 0.9).

The low correlation between the rankings of the MEPI-2 scores could be explained by the fact that when the cut-off is changed, the evaluation of whether an individual is energy poor or not is being determined by another dimension than before. Because the achievements in the dimensions vary widely (as shown in the results in Figure 9), it has a large impact on the MEPI-2 score whether it is suddenly not enough to only have cooking or lighting and quantity. With the cut-off equal to 0.2, an individual must have access to both cooking and quantity to be out of energy poverty. Table IV in the appendix (Annex E) shows the change in the MEPI-2 decile classification of each state when changing the multidimensional cut-off. It is quite evident also from this table that when the cut-off becomes less strict, the MEPI-2 scores decrease and the opposite when the cut-off becomes stricter.

Table 8: Spearman Rank Correlation Test of MEPI-2 for change in multidimensional cut-off

k	**0.2**	**0.3**	**0.5**	**0.7**	**0.8**
0.2	1				
0.3	0.9994*	1			
0.5	0.7695*	0.7703*	1		
0.7	0.5625*	0.5650*	0.8541*	1	
0.8	0.5625*	0.5650*	0.8541*	1.0000*	1

*N = 35, *Statistically Significant at 5 % significance level*

Source: Own calculations based on NSS-data.

Table 9: Kendall Rank Correlation Test of MEPI-2 for change in multidimensional cut-off

k	**0.2**	**0.3**	**0.5**	**0.7**	**0.8**
0.2	1				
0.3	0.9933*	1			
0.5	0.5933*	0.5933*	1		
0.7	0.4118*	0.4118*	0.6975*	1	
0.8	0.4118*	0.4118*	0.6975*	1.0000*	1

*N = 35, *Statistically Significant at 5 % significance level*

Source: Own calculations based on NSS-data.

7.2 Suggestions for Improvement

Based on the discussion above, following recommendations are given when using this methodology in further work. Firstly, using data with improved quality and focused on end-services rather than energy consumption would give more viable results. One aim of this thesis is to create awareness around this issue so that data collection in the future can be tailored for the purpose of measuring energy poverty (with a focus on the capability approach)

Further on, it would also be recommended to test the robustness of the dimensional weights using a Montecarlo-simulation to apply probabilistic functions to account for the uncertainty in the weights as in Nussbaumer et al. (2011). This could further confirm the validity of the sensitivity analysis of the weights in Section 7.1.1, but is considered as being out of scope for this thesis.

The sensitivity analysis of the multidimensional cut-off has illustrated that the results are unfortunately somewhat sensitive to changes in the cut-off. However, this can be reasoned by the limited number of variables representing each dimension and thus the dramatic change in which dimensions that essentially determine energy poverty (based on the cut-off used). This issue is also related to the availability of data, and the solution would be to include multiple ends-based variables in each dimensions, so that the possibility space for different combinations of achievement is larger. For example, within the cooking dimension, both the access to clean cooking fuels and to clean cooking facilities could be included (as in Nussbaumer et al. (2011). Including more variables would also require a discussion on the weights and the multidimensional cut-off.

Regular energy poverty measurement in India should be continued to be able to measure progress and changes in the situation. It would also be useful to compare with other countries and regions; thus further work could also involve extending the analysis to other geographical areas.

8. Conclusion

This thesis presents an amended index for energy poverty, the “MEPI-2”, based on the Multidimensional Energy Poverty Index developed by Nussbaumer et al. (2011). The novelty of the model is to study only the most basic energy services required for a person to strengthen their basic capabilities, and includes a new dimension of the ability to meet these basic needs regardless of the type of energy fuel consumed. The model is used to analyse energy poverty in India using household data from 2011-2012, which adds to the research of energy poverty in India with newer estimates.

Based on the analysis, 31 percent of the Indian population is found to be energy poor. However, large regional differences are uncovered, with the North-Eastern states being the most energy deprived. When comparing the rural and urban areas, the rural areas have more energy poverty than the urban ones. In addition, there is also a correlation between income and energy poverty as there is more energy poverty in the lower income groups. Within the dimensions, most people lack access to clean cooking fuels, while a relatively high proportion have access to both electricity and a minimum amount of energy needed for the basic energy services. A correlation is shown between energy poverty and the HDI and the income poverty ratio, but it is not a perfect correlation.

Based on the findings, I firstly recommend policy and decision-makers to be aware of the concept of energy poverty and that it is not directly correlated to income poverty. Being aware of the existence of energy poverty and the need for measurement and intervention will also enable the collection of tailored datasets for the purpose. Further on, policy efforts should primarily be directed towards supplying clean and efficient cooking fuels and appliances, while simultaneously meeting market and consumer needs. To align with the climate change goals, focus should also be put on off-grid renewable solutions such as solar cook stoves and mobile solar electricity generation solutions. The North-Eastern states of India are the ones most in need of interventions, especially the state of Bihar, and it could be advisable for national authorities to influence the state-level regulation to ensure access also in this part of the country. Rural and lower income groups should also be given priority in this matter. It could also be useful to study the policies in the states that have less energy poverty, to find solutions that can be adapted to the other states.

The sensitivity analysis shows that the results are robust to changes in the dimensional weights, however we see more pronounced changes in the MEPI-2 scores when altering the multidimensional poverty cut-off. With access to better datasets, it would be advisable to include more indicators/variables to represent each dimension so that there are different combinations of deprivation that would determine energy poverty (and not only whether an individual has access to cooking or to lighting and sufficient amount of energy).

In order to reach the targets of the SDGs, and in particular Goal 7, increased focus on energy access and energy deprivation is necessary. I hope to create some awareness around the issues that need to be addressed, through the work presented in the thesis. The MEPI-2 is one possible measure to identify energy poverty, that captures the multidimensional nature of energy poverty and is suitable for analysis at multiple levels. With increased access to suitable data, the index can be improved and applied to measure progress in reducing energy poverty in India as well as other regions.

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APPENDIX

A. Regression Results for Household Scale Economies

Table I: Results from regression of daily per capita energy consumption against household size dummy variables

Independent variable	Dependent variable: Log of daily per capita energy consumption
Log of Monthly per capita expenditure	0.398*** (0.00301)
Household size = 1	0.0948*** (0.00865)
Household size = 2	0.405*** (0.00716)
Household size = 3	0.243*** (0.00633)
Household size = 4	0.109*** (0.00562)
Household size = 6	-0.103*** (0.00659)
Household size = 7	-0.197*** (0.00826)
Household size = 8	-0.283*** (0.0105)
Household size = 9	-0.311*** (0.0138)
Household size = 10	-0.344*** (0.0163)
Household size = 11	-0.402*** (0.0220)
Household size = 12	-0.479*** (0.0284)
Household size = 13	-0.408*** (0.0366)
Household size = 14	-0.468*** (0.0421)

Household size = 15	-0.528*** (0.0473)
Constant	-2.815*** (0.0222)
Observations	101,280
R^2	0.2900
Adjusted R^2	0.2899

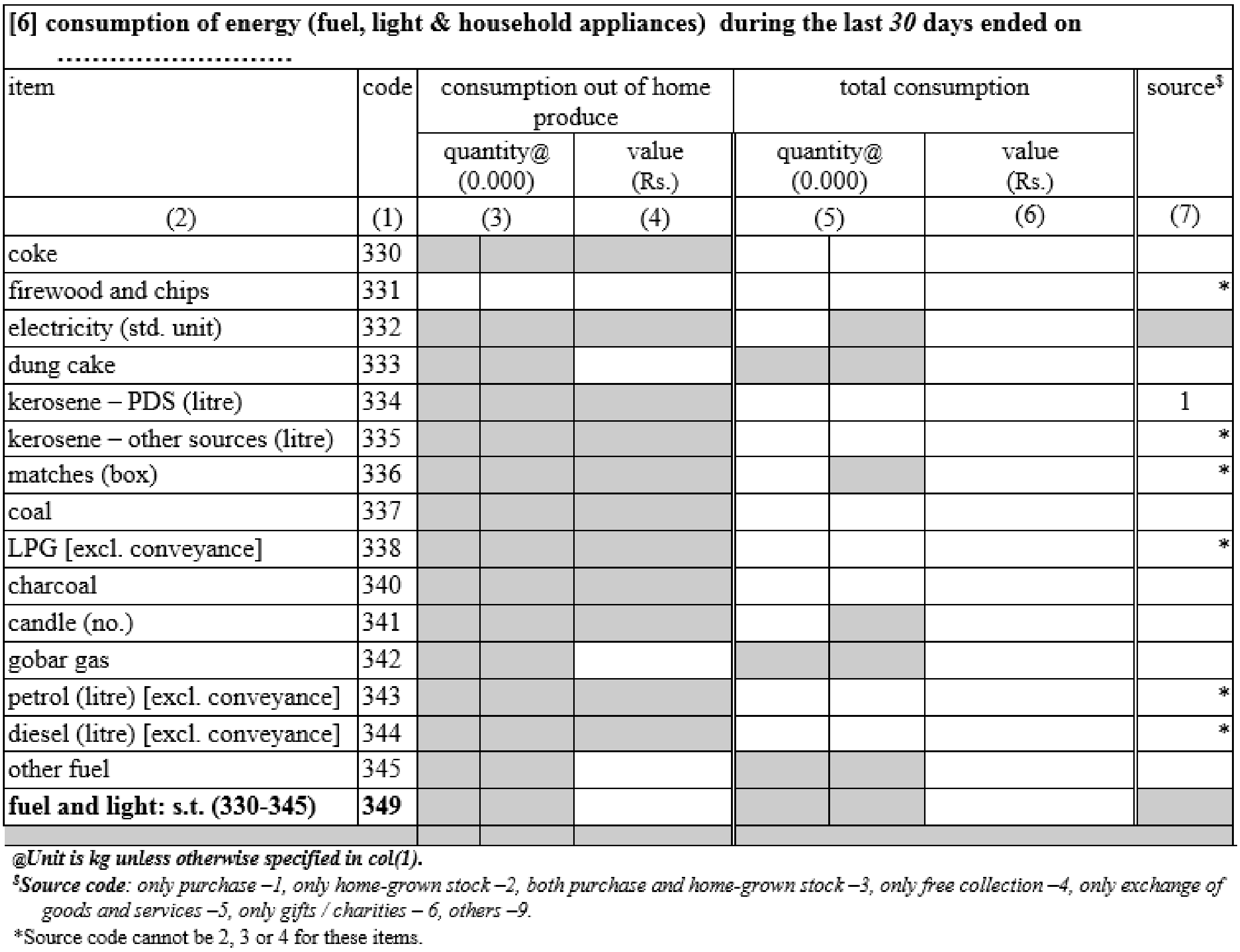
Standard errors in parentheses
*** p < 0.10, ** p < 0.05, *** p < 0.01**

Note: The regression has a R^2-value of 0.29, which is satisfactory and all coefficients for household size have p-values significant at 1 percent.

Source: own estimations done in Stata based on NSS-data

B. Survey Schedule on Fuel Consumption

Figure I: Overview of the survey schedule for the fuel consumption



[6] consumption of energy (fuel, light & household appliances) during the last *30* days ended on ………………………

item	code	consumption out of home produce		total consumption		source[$]
		quantity@ (0.000)	value (Rs.)	quantity@ (0.000)	value (Rs.)	
(2)	(1)	(3)	(4)	(5)	(6)	(7)
coke	330					
firewood and chips	331					*
electricity (std. unit)	332					
dung cake	333					
kerosene – PDS (litre)	334					1
kerosene – other sources (litre)	335					*
matches (box)	336					*
coal	337					
LPG [excl. conveyance]	338					*
charcoal	340					
candle (no.)	341					
gobar gas	342					
petrol (litre) [excl. conveyance]	343					*
diesel (litre) [excl. conveyance]	344					*
other fuel	345					
fuel and light: s.t. (330-345)	**349**					

@Unit is kg unless otherwise specified in col(1).

[$]***Source code****: only purchase –1, only home-grown stock –2, both purchase and home-grown stock –3, only free collection –4, only exchange of goods and services –5, only gifts / charities – 6, others –9.*

*Source code cannot be 2, 3 or 4 for these items.

Source: NSSO (2012)

C. Constructing The Daily Per Capita Energy Consumption Variable

Table II: Overview over energy content and efficiency for different fuels

Fuel	Unit	Energy content per unit (MJ/Unit)	Efficiency (%)	Useful energy (MJ/Unit)	Useful energy (kWh/Unit)
LPG	Kg	45.5	60	27.3	7.58
Kerosene	L	35.3	45	15.9	4.41
Biogas (60 % methane)	Kg	20.2	60	12.1	3.37
Charcoal	Kg	30.0	25	7.5	2.08
Bituminous Coal	Kg	22.5	25	5.6	1.56
Coke	Kg	27.0	15	4.1	1.13
Fuelwood	Kg	16.0	20	3.2	0.89
Electricity	kWh	-	75	-	0.75

Note: MJ= Mega joule, Kg = Kilograms, L = Litres

Sources:

LPG, Kerosene, Charcoal, Bituminous coal, Fuelwood: O'Sullivan & Barnes (2006)

Coke: Sarkar & Kadekodi (1988), UC Berkeley (Accessed 2016)

Biogas: European Union (2009), O'Sullivan & Barnes (2006)

Electricity: Barnes, Krutilla, & Hyde (2004)

D. Table of Results

See next page for table with overview over all main results, including the MEPI-2, headcount ratio, intensity of energy poverty, access to minimum amount of energy, modern cooking fuels and electricity, HDI and poverty ratio for each state (where available).

Table III: Overview over main results from analysis, by state

Sources: Columns one to six: own calculations based on NSS data 68th round; HDI: Institute of Applied Manpower Research, Planning Commission, Government of India (2011); Poverty ratio: Planning Commission, Government of India (2013).

	MEPI	Headcount ratio	Intensity of energy deprivation	Access to min. amount of energy (%)	Access to modern cooking fuel (%)	Access to electricity (%)	HDI	Poverty ratio
Andaman and Nicobar Islands	0.053	0.07	0.71	98.4	68.8	93.5	N/A	0.01
Andhra Pradesh	0.050	0.06	0.81	91.9	50.1	98.3	0.473	0.09
Arunachal Pradesh	0.235	0.30	0.78	85.3	41.3	73.0	0.573	0.35
Assam	0.297	0.40	0.74	92.0	24.3	61.8	0.444	0.32
Bihar	0.728	0.81	0.90	35.3	10.7	31.3	0.367	0.34
Chandigarh	0.038	0.05	0.80	89.9	91.4	98.4	N/A	0.22
Chhattisgarh	0.171	0.22	0.77	87.6	11.3	87.4	0.358	0.40
Dadra and Nagar Haveli	0.032	0.04	0.75	94.6	38.9	97.9	N/A	0.39
Daman and Diu	0.011	0.01	0.76	91.1	82.5	99.2	N/A	0.10
Delhi	0.028	0.04	0.80	95.1	90.1	98.6	0.750	0.10
Goa	0.018	0.02	0.89	97.2	85.2	97.9	0.617	0.05
Gujarat	0.076	0.09	0.83	89.8	41.6	96.6	0.527	0.17
Haryana	0.133	0.16	0.81	83.4	42.7	96.4	0.552	0.11
Himachal Pradesh	0.008	0.01	0.71	99.2	30.8	97.8	0.652	0.08
Jammu & Kashmir	0.031	0.04	0.76	97.4	40.7	97.1	0.529	0.10
Jharkand	0.265	0.34	0.78	88.2	12.9	69.2	0.376	0.37
Karnataka	0.058	0.07	0.79	92.5	38.7	97.8	0.519	0.21
Kerala	0.046	0.06	0.78	95.5	37.6	96.6	0.790	0.07
Lakshadweep	0.004	0.01	0.80	99.5	33.5	100.0	N/A	0.03
Madhya Pradesh	0.260	0.31	0.83	72.3	21.6	87.8	0.375	0.32
Maharashtra	0.117	0.15	0.80	86.8	54.5	94.8	0.572	0.17
Manipur	0.099	0.13	0.73	94.6	45.6	89.8	0.573	0.37
Meghalaya	0.119	0.17	0.72	96.5	23.6	84.9	0.573	0.12
Mizoram	0.081	0.10	0.82	93.1	63.4	92.0	0.573	0.20
Nagaland	0.003	0.00	0.70	99.3	65.8	98.3	0.573	0.19
Orissa	0.250	0.33	0.75	90.9	10.8	72.1	0.362	0.33
Pondicherry	0.016	0.02	0.80	97.1	87.4	99.0	N/A	0.10
Punjab	0.109	0.13	0.81	85.4	50.8	98.3	0.605	0.08
Rajasthan	0.154	0.20	0.76	92.3	23.5	83.2	0.434	0.15
Sikkim	0.026	0.03	0.80	93.2	61.8	99.8	0.573	0.08
Tamil Nadu	0.045	0.06	0.81	94.2	60.7	97.9	0.570	0.11
Tripura	0.101	0.14	0.70	99.0	13.9	85.9	0.573	0.14
Uttar Pradesh	0.548	0.62	0.88	51.4	18.4	51.8	0.380	0.29
Uttaranchal	0.035	0.05	0.71	98.9	41.0	94.7	0.490	0.11
West Bengal	0.311	0.38	0.82	73.6	22.1	77.8	0.492	0.20
ALL INDIA	**0.259**	**0.31**	**0.85**	**77.3**	**32.2**	**78.5**	**0.467**	**0.22**

E. Sensitivity Analysis

Table IV: Overview of state classification by MEPI-2 deciles for changes in the multidimensional cut-off

k / MEPI deciles	0.2	0.3	0.5	0.7	0.8
1 (lowest MEPI)	Chandigarh Delhi Goa Pondicherry	Chandigarh Delhi Goa Pondicherry	Andaman and Nicobar Islands Andhra Pradesh Chandigarh Dadra and Nagar Haveli Daman and Diu Delhi Goa Gujarat Himachal Pradesh Jammu and Kashmir Karnataka Kerala Lakshadweep Manipur Mizoram Nagaland Pondicherry Sikkim Tamil Nadu Uttaranchal	Andaman and Nicobar Islands Andhra Pradesh Arunachal Chandigarh Chhattisgarh Dadra and Nagar Haveli Daman and Diu Delhi Goa Gujarat Himachal Pradesh Jammu and Kashmir Karnataka Kerala Lakshadweep Maharashtra Manipur Meghalaya Mizoram Nagaland Orissa Pondicherry Rajasthan Sikkim Tamil Nadu Tripura Uttaranchal	Andaman and Nicobar Islands Andhra Pradesh Arunachal Chandigarh Dadra and Nagar Haveli Daman and Diu Delhi Goa Gujarat Haryana Himachal Pradesh Jammu and Kashmir Karnataka Kerala Lakshadweep Madhya Pradesh Maharashtra Manipur Mizoram Nagaland Orissa Pondicherry Punjab Rajasthan Sikkim Tamil Nadu Tripura
2	A and N Islands Daman and Diu Nagaland	A and N Islands Daman and Diu Nagaland	Chhattisgarh Haryana Maharashtra Meghalaya Punjab Rajasthan Tripura	Haryana Jharkand Punjab	Chhattisgarh Meghalaya Uttaranchal
3	Andhra Pradesh Mizoram Sikkim Tamil Nadu Maharashtra Punjab	Andhra Pradesh Mizoram Sikkim Tamil Nadu Maharashtra Punjab	Arunachal Assam Jharkand Madhya Pradesh Orissa	Madhya Pradesh West Bengal	Jharkand West Bengal
4	Dadra and Nagar Haveli Gujarat Himachal	Dadra and Nagar Haveli Gujarat Himachal	West Bengal		

	Jammu and Kashmir Karnataka Kerala Lakshadweep Manipur Uttaranchal Haryana Arunachal	Jammu and Kashmir Karnataka Kerala Lakshadweep Manipur Uttaranchal Haryana Arunachal			
5	Meghalaya Rajasthan Tripura Assam Madhya Pradesh	Meghalaya Rajasthan Tripura Assam Madhya Pradesh		Uttar Pradesh	Uttar Pradesh
6	Chhattisgarh Jharkand Orissa West Bengal	Chhattisgarh Jharkand Orissa West Bengal	Uttar Pradesh		
7	Uttar Pradesh	Uttar Pradesh		Bihar	Bihar
8	Bihar	Bihar	Bihar		
9					
10 (highest MEPI)					

Source: Own table based on calculations using NSS-data.