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Liquid Petroleum Gas Access and Consumption Expenditure: Measuring Energy Poverty through Wellbeing and Gender Equality in India

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Contents

Abstract

Despite the acceleration of electrification in India, many communities still suffer from the direct and indirect effects of energy poverty. We investigate whether access to liquified petroleum gas (LPG) and consumption expenditure can be used as measures of energy poverty in India, with a particular focus on gender equality. A district-level, quantitative analysis of household survey data was performed for the energy-poor states of Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal. Wellbeing and gender equality indices were constructed from contextually relevant indicators, whilst LPG access was considered in terms of physical access, affordability, and awareness. Levels of consumption expenditure were considered based on the updated urban poverty line for India. We found that LPG access and consumption expenditure do not have significant relationship with wellbeing or gender equality. The result indicates that the traditional economic approach of using consumption expenditure cannot capture the multidimensionality of energy poverty. This has significant implications as it challenges the status quo of energy poverty measurement in India. The research also adds value to existing arguments that electricity access cannot be used as a sole indicator of energy poverty, by extending the argument to access to a modern cooking fuel. LPG access was however strongly associated with the education of women on the health effects of 'chulha' smoke. Consumption expenditure is also strongly associated with female property ownership which calls for future research on this novel relationship. Overall, this study calls for shifting energy poverty discussions to emerging concepts such as wellbeing and gender equality.

Key words: Energy poverty; modern cooking fuels; wellbeing; gender equality; India

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About the Authors

Dhilanveer (Dhilan) Teja Singh Bahi was a graduate from the University of Leeds (Sustainability Research Institute, School of Earth and environment) who sadly passed away on 20 June 2022. This work has emerged from his undergraduate dissertation. Dhilan is described by his family as “not afraid of hard work and wanting to help both society and the environment we live in. He embraced his Sikh faith and actively supported charitable campaigns. In particular, he was an advocate for conserving the planet and promoting sustainability for future generations. Dhilan was passionate about combatting energy poverty in India and completed his thesis on this topic. Dhilan was due to commence a graduate scheme at EDF Renewables and to continue his legacy, his colleagues have supported a charity, Barefoot College, which trains women in energy-poor states to become solar engineers. Dhilan believed in open access research and intended to publish his thesis in the hope of creating positive change. He continues to inspire us all. Dhilan was a diligent young man who always found time to support his family and friends, while infusing his playful sense of humour and memorable laugh to conversations. In between studies, Dhilan curated eclectic playlists to share the music he discovered, along with refining dance moves with friends. Dhilan showed great kindness, empathy and understanding to everyone he met and he truly believed in giving back to the community. Dhilan would say he was blessed, and we are truly blessed to have had him in our lives. Dhilan, you will always be remembered. A reflection from Dhilan (April 2020): *Every Act Of Selfishness Can Be Counteracted By Compassion*”.

Jouni Paavola is Professor of Environmental Social Science in the School of Earth and Environment at the University of Leeds and he was Dhilan’s dissertation supervisor. His research examines environmental governance institutions and their environmental, economic and social justice implications, with a focus on climate change and biodiversity.

1. Introduction

The World Economic Forum (2012) suggests that energy is the lifeblood of the global economy. Yet, 770 million people did not have access to electricity in 2019 and COVID-19 pandemic reversed much of the progress made (IEA, 2020b). In the recent COP 26, India ambiguously pledged to cut emissions to net-zero by 2070, leaving many critics sceptical of the lacking energy infrastructure (Malyan and Chaturvedi, 2021). India has experienced an acceleration of access to electricity and modern cooking fuel, liquified petroleum gas (LPG), through flagship programmes like the Pradhan Mantri Ujjwala Yojana (PMUY) scheme (Patnaik et al., 2018). However, whilst physical access is improving, affordability is still a challenge in rural India which is heavily dependent on traditional fuels (Dabadge et al., 2018). The traditional fuels, such as biomass, are not only time consuming to gather and of low energy efficiency, but they also pose serious health risks (Benti et al., 2021). Therefore, a more comprehensive view of access to modern cooking fuel in India is needed.

The definitions of poverty and energy poverty are based on what is measured and what is affected. Consumption expenditure has been traditionally used as a measure of poverty and can be defined as ‘the spending by households on goods and services to satisfy needs’ (Stoyanova, 2018, p.2). However, consumption expenditure cannot capture the multidimensionality of energy poverty (Pachauri et al., 2004; Thomson et al., 2017) which extends beyond economics to social provision and wellbeing, including education, health, and access to clean water (Njiru and Letema, 2018). Access to modern energy is a better indicator of energy poverty in developing countries although its use, particularly of electricity access, is contested (Kaygusuz, 2012; Nussbaumer et al., 2012; Roy, 2012). Lack of access to modern cooking fuel affects women more adversely than men in terms of premature death due to indoor air pollution (World Health Organisation, 2009). Yet, the understanding energy poverty as a gender issue and whether measures of energy poverty capture gender inequality is largely missing from the literature. Therefore, there is potential to challenge the status quo of economic approaches to energy poverty, judge whether access to modern cooking fuel is a useful measure, and propose new ways exploring the effects of energy poverty.

The aim of this paper is to determine whether LPG access and consumption expenditure can be used as measures of energy poverty, defined by wellbeing and gender equality, in India. The research objectives (ROs) are to:

1. Explore and determine the key effects of energy poverty associated with wellbeing and gender equality, and to formulate wellbeing and gender equality indices.
2. Interpret household survey data and establish the levels of LPG access and consumption expenditure in relation to the poverty line, wellbeing, and gender equality.
3. Analyse at the district level the statistical relationships between LPG access, wellbeing, and gender equality indices, and the statistical relationships between consumption expenditure, wellbeing, and gender equality indices.
4. Examine at the national level associations of LPG access and specific variables within wellbeing and gender equality indices, as well as the associations of consumption expenditure and specific variables within wellbeing and gender equality indices.
5. Assess the limitations of the methodology used to quantify energy poverty, LPG access and consumption expenditure as well as the established statistical relationships.
6. Recommend future research and policy priorities in light of the obtained results.

Next, Section 2 reviews the literature, considering theory, traditional approaches to measuring energy poverty and what has succeeded this. Section 3 explains the methodology, the creation of indices and the recoding of household survey data for quantitative investigation. Section 4 reports the results of the statistical analysis and Section 5 discusses the results. Section 6 closes with concluding thoughts.

2. Energy Poverty and its Measurement

2.1 Theory Behind Energy Poverty

Energy poverty is a critical issue that the energy sector has struggled to tackle. The international 2030 pledge to leave no one behind has spurred a wealth of literature on energy inequalities around the world (United Nations, 2019). Yet, there has been a great difficulty in formulating a singular definition of energy poverty. It has been argued that this difficulty relates to how poverty itself is understood. After all, poverty is a moral question that can refer to either economic or social positions (Piachaud, 1987). Characterising poverty has historically focused on income, with specific definitions dependent on international organisations' decision to utilise poverty lines based around median national income, or absolute poverty lines of a dollar amount per day (Bollino and Botti, 2017; Rademaekers et al., 2016). That is, the lack of a singular definition of poverty is the result of the promotion and use of different estimations of poverty (Ackland et al., 2013; Deeming and Gubhaju, 2015; United Nations, 2009).

The focus on income in the measurement of poverty has led to the energy ladder model of fuel choice in developing countries. In the model (Figure 1) households move upwards from dirty, inefficient fuels to more advanced fuels as income increases in a unidirectional way (Kowsari and Zerriffi 2011, p.7508; Leach, 1992). Yet, meta-analysis of household data indicates that people use multiple fuels at the same time based on availability, affordability, risk management or cooking preference (van der Kroon et al., 2013). Unidirectional leaping to new fuels is thus unlikely. The significance of this insight for policies seeking to accelerate electrification and LPG access in developing countries is clear; there is a need to move beyond simple ideas about income exclusively driving energy use and fuel choice.

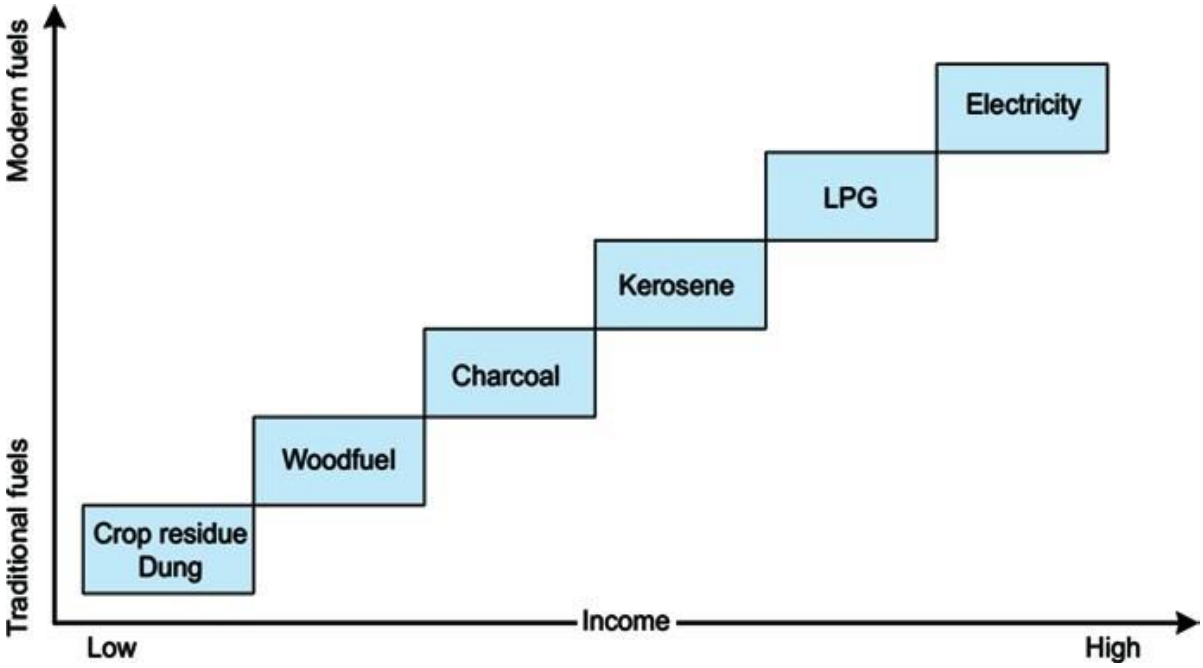

Figure 1. An energy ladder model of fuel choice change (Kowsari and Zerriffi, 2011, p.7508).

There is emerging literature which seeks to better account for the multidimensionality of energy poverty. Its starting point is, that the needs of people for wellbeing are social constructs based on different welfare ideologies (Doyal and Gough, 1991). For example, Maslow (1954) suggested a universal hierarchy of needs from physiological needs to more social concepts of needs of belonging and respect. Sen (1993) in turn suggested a capabilities approach to wellbeing, arguing that one should focus on what a person can do and choose to do, as opposed to what they have. These subjective perceptions of wellbeing proved pivotal for the Human Development Index (HDI) (Stanton, 2007). The upshot is that it is difficult to fully capture all dimensions of energy poverty for both developing and developed nations, each with their own priorities, social customs and demands. The question about energy poverty is: what one should consider as the effects of a lack of energy and how should they be measured?

2.2 Traditional Approaches to Energy Poverty

European approaches to energy poverty have been based on Boardman's (1991, p.30) definition that fuel poor households are unable to "*afford adequate warmth because of the energy inefficiency of the home*". The focus on warmth has remained central even after changes to the definition (Buzar, 2007). This kind of fuel poverty is more relevant for developed countries in which affordability is the greatest barrier to energy sufficiency (Boardman, 2012). In developing countries, interpretations of energy poverty are focused on their different societal issues, such as…. . Nevertheless, governments everywhere focus on economic factors when measuring energy poverty and designing policy interventions (Pachauri et al., 2004).

The economic threshold approach creates a monetary energy poverty line. But the literature is undecided whether income is an appropriate, universal proxy for energy poverty. Khandker et al. (2012) show that there are no strong correlations between income poverty and energy poverty among rural households in a developing country, unlike among urban households. An alternative economic threshold classes a household as poor and energy-poor if they spend little on goods and services like electricity. Whilst this approach goes one step further in considering what is spent on energy, (Gordiievska, 2015, p.16; Yaya et al., 2020, p.9), Figure 2 highlights the difference between consumption expenditure-based (in orange) and multidimensional energy (in green) poverty for Africa. Countries such as Kenya, Congo and Mali have moderate levels of consumption expenditure, yet suffer from severe multidimensional energy poverty. That is, consumption expenditure understates the level of deprivation. This demonstrates that at least in developing countries the economic and multifaceted measures of energy poverty are not the same.

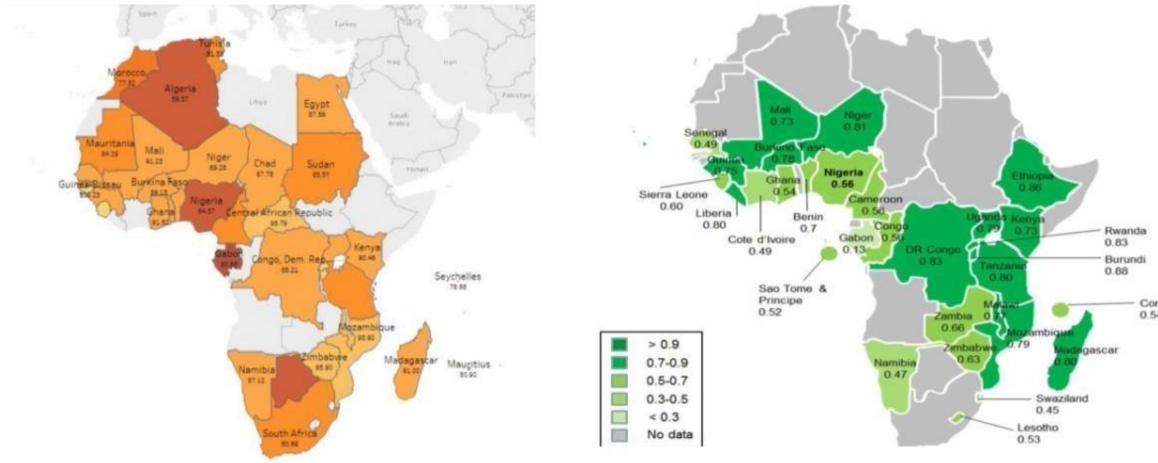

Figure 2. A gradient of light orange (high expenditure consumption) to dark orange (low expenditure consumption) denotes consumption expenditure in Africa, with grey indicating no data available (Yaya et al., 2020, p.9). Lighter green shades denote low multidimensional energy poverty and darker shades severe energy poverty in Africa (Gordiievska, 2015, p.16).

Another traditional approach to measuring energy poverty defines a physical threshold of energy consumption to determine the energy poor. For example, Goldemberg and Johansson (1995) use energy consumption as a measure of energy poverty, finding strong relationships with poverty indicators like the HDI. But there are two ways to quantify household energy consumption: measuring its total energy use or end-use energy. Whilst rural households may use a lot of energy in the form of cheap biomass, its energy efficiency is significantly lower than that of electricity or LPG (Viswanathan and Kavi Kumar, 2005). End-use energy methods have helped to show that rural households in India lose around 80% of the total energy they use, 25% more than urban households (Khandker et al., 2012). So, although it is easier and more common to measure total energy use, it is not a good indicator for the real experience of energy-poor rural households.

Another key weakness with physical thresholds of energy poverty is is that high consumption does not always mean absence of energy poverty. As already noted, rural poor may use a lot of inefficient bioenergy yet fail to meet their energy service needs. But vice versa, low energy consumption may not entail energy poverty and low wellbeing. For example, in Zambia, Vietnam and Nepal many households with a lower final energy use have achieved higher states of wellbeing if they have access to modern energy (Baltruszewicz et al., 2021). To conclude, there is no single physical threshold of energy consumption that could be used to define the energy-poor across all contexts, and even if it did exist it would add little value to emerging discussions on multifaceted energy poverty.

Foster et al. (2000) use a blend of physical and economic methods - energy consumption of a household if it falls below 10% of the income poverty line, 1 US dollar. They importantly find that access to electricity has the largest impact on energy poverty, not its pricing or household income (Foster et al., 2000). Similar conclusions have been reported in the poverty literature (Pachauri et al., 2004; Sambodo and Novandra, 2019). A key question therefore is, should we continue to use the traditional approach to energy poverty, or start looking at the issue at hand more broadly? The challenge of measuring energy poverty, resulting from the lack of clarity of its conceptualisation, is likely a key reason for the dominance of economic and physical approaches. The two approaches ensure objectivity and can be used to make comparisons across time, offering practical value in an uncertain field of study. Yet, as of late, energy poverty has become increasingly recognised as a multifaceted concept that should not be reduced to monetary notions. A review of alternative evidence is therefore crucial.

2.3 Beyond Energy Affordability and Consumption

The International Energy Agency (IEA) (2020a) has played a key role in establishing access and dependency on harmful energy sources as two key components of energy poverty in developing world. Together they help to define energy poverty as *"a lack of access to electricity networks* or *dependence on burning solid biomass in inefficient and polluting stoves to meet household energy needs"* (Laldjebaev et al., 2016, p.97). New indicators are also focusing specifically on access to electricity and clean cooking facilities.

A household-level analysis of energy poverty by Nathan and Hari (2020) suggests that access to modern cooking fuel should be a critical variable in the definition and measurement of energy poverty. They also consider that economic measures of energy poverty are only proxies for income poverty and therefore are not highlighting the roots of energy deprivation in developing countries (Nathan and Hari, 2020). They focus on urban India, prompting a question whether the same conclusions would pertain to rural communities. For example, stronger cultural and social barriers may exist in rural communities than in urban areas: as rural areas have a higher proportion of households that decline the use of modern energy due to personal preferences, although they have access (Jain et al., 2018).

The literature on critical importance of access for energy poverty suggests new avenues for investigating technological thresholds of energy poverty: the energy poor are those who cannot access modern energy services. Better socio-economic and infrastructure characteristics, as well as higher literacy rates, have strong correlations with access to modern energy such as LPG and electricity (Pachauri and Spreng, 2004; Pachauri et al., 2004). This is not apparent when households increase their consumption of biomass and kerosene (Pachauri and Spreng, 2004; Pachauri et al., 2004). Significant correlations also exist between access to LPG and food calorie intake suggests Shonali Pachauri (2014), a key expert on energy poverty in India. Further studies shed light on the direction of causality between access to modern energy and wellbeing (Dinkelman, 2008; Khandker et al., 2009). Research around access indicates that it is better tailored to multifaceted definitions of energy poverty, taking into consideration health and wellbeing, as opposed to energy consumption measures. Whether this is true in relation to the use of expenditure approaches in rural areas of developing countries has not yet been conclusively established. Furthermore, whether access alone, as a singular metric, can fully capture all elements of energy poverty is disputed (Kaygusuz, 2012; Nussbaumer et al., 2012; Roy, 2012). One thing is certain though, electricity access is being given much more attention than access to modern cooking fuels in academic literature and public policy (IEAa, 2010).

In Europe, criticism of the expenditure approach has led to proposals of a consensual method to quantifying energy poverty (Healy, 2004: Petrova et al., 2013; Thomson and Snell, 2013). In this approach, indicators are self-reported, for example by asking a household if they can afford to heat their home to a comfortable level (Healy and Clinch, 2002). This approach recognises the indirect aspects of energy poverty such as social exclusion (Halkos and Gkampoura, 2021) and favours a bottom-up approach for understanding the household struggles. But Boardman (2011) questions the validity of the consensual approach, suggesting that energy-poor households can decline to believe that they are uncomfortably cold even if that is their reality. Subjective variables, such as a comfort level, may also have different meanings in different cultural environments. Therefore, there are limitations to adopting consensual approaches to energy poverty outside of Europe.

2.4 Composite Energy Poverty Indices

As measures of basic poverty have been transformed into indices, energy poverty is following suit. A multitude of variables are considered to help explain how energy is related to human development. The IEA created an Energy Development Index (EDI) in an attempt to align it with the HDI. It includes variables like electricity consumption per capita and percentage of the population with electricity access (IEA, 2010b). The methodology is tailored to national measurements so it cannot fully capture wellbeing experiences at household level (Culver, 2017). In addition, by using variables like energy consumption per capita, the EDI is favouring countries that heavily subsidise electricity (Khatib, 2011). This omits energy efficiency, a fundamental component of sustainable development around energy. Iddrisu et al. (2015) attempted to correct this weakness with a composite Sustainable Energy Development Index (SED). Not only is there a positive correlation between the SEDI, EDI and HDI, but multiple dimensions of sustainability such as economic, social, environmental, and institutional aspects are also better captured with the SEDI (Iddrisu et al., 2015). This gives the SEDI a significant advantage over other indices. A high EDI or HDI score can very easily ignore energy unsustainability. For example, they would not highlight low self-sufficiency of a nation like Japan and how this may lead to knock-on effects at the household level. All in all, the SEDI recognises that, like most aggregated metrics, a masking effect is present in which strong results from some indicator variables hide very poor results from others (Iddrisu et al., 2015).

Other indices focus on energy-poor households. Mirza and Szirmai (2010) conducted an energy poverty survey in rural Pakistan to identify the characteristics of energy-poor and non-poor households. A composite Energy Poverty Index (EPI), was then formulated based on how rural energy markets function. For example, time spent collecting energy per week is an indicator of energy inconvenience (Mirza and Szirmai, 2010). The advantage of EPI is the focus on rural households in a developing country, an often-neglected subpopulation. The research highlighted that 92% of rural households in the Punjab province suffer from severe energy poverty (Mirza and Szirmai, 2010). The EPI also uses energy consumption as an indicator of energy shortfall for households, a subindex of energy poverty. This suggests that there could be a role for traditional energy poverty approaches to serve as a complementary metric. The EPI is praised by Culver (2017) because it recognises the imperative of having access to modern cooking fuel, labelling households that have electricity but not LPG as still energy poor. However, the index has a narrow focus on solely the needs of a household, with little consideration for wider issues of energy deprivation, such as low wellbeing.

2.5 Wellbeing and Gender

Energy poverty is a complex concept that includes life expectancy, housing quality, education, and access to social services (Njiru and Letema, 2018). Yet, only a few studies have investigated and measured the link between energy and wellbeing (Day et al., 2016; Pachauri and Spreng, 2002; Rao et al., 2019). The MEPI, developed by Nussbaumer et al. (2012), is focusing on energy deprivation within the idea of energy poverty. Indicators include access to modern cooking fuel, lighting, access to clean air inside homes and ownership of a telephone (Nussbaumer et al., 2012). Incidence and intensity of energy deprivation together constitute the overall MEPI value. Consequently, the multifaceted nature of the MEPI is capturing the link between energy and wellbeing more comprehensively and across both developed and developing countries and demonstrating its wide practical value and applicability (Okushima, 2017; Sadath and Acharya, 2017; Santillán et al., 2020). However, it does not consider the use of energy beyond domestic household use, for example for working at home (Culver, 2017). Furthermore, whilst its variables are indicators of energy poverty, small rural communities may not consider e.g. telephone ownership a priority.

The World Health Organisation (WHO) has played a crucial role in evidencing the association between the use of dirty fuels in households and its health effects, concluding that even in the most polluted cities, indoor pollution is far greater than outdoor pollution (Rehfuess, 2006). The ensuing health effects are not equally distributed across population. Women and children spend more time at home than men where energy poverty is common, leading to greater exposure (WHO, 2009). As a result, women are three times more likely to get pulmonary diseases and twice as likely to suffer from lung cancer (WHO, 2009), placing gender at the heart of the energy poverty problem.

A research drawing from a sample of 51 developing countries and a period between 2002-2017 found that when energy poverty was reduced and female salaried work increased, economic advantages were conferred for the households (Nguyen et al., 2021). Köhlin et al. (2011) in turn conclude that substantial gender benefits result from improving access to modern energy, including greater female decision-making. Electricity access in India has also been found to significantly improve the occurrence and duration of reading by women, regardless of their level of education (World Bank, 2004). But positive effects are not always guaranteed, as access to television is associated with an increase in child favouritism, for example male children sent to school instead of daughters (Jensen and Oyster, 2009). In Asian communities where limited funds require prioritisation, boys are almost always preferred (Kuglar and Kumar, 2017). But in Bangladesh when families have access to electricity, schooling of girls increases by 20% in both low- and high-income families (World Bank, 2009). Whether traditional measures of energy poverty fully consider gender equality is inconclusive. In South Asia, gender is given minimal attention in energy policy (Moniruzzaman and Day, 2020). Therefore, energy poverty should be extended to consider gender equality and there are substantial opportunities to explore these relationships further in India.

3. Methodology

The purpose of this research was to examine the relationships between the measures and effects of energy poverty, placing particular emphasis on the issue of gender. On one hand, it included LPG access and its relationship with wellbeing and gender equality. On the other hand, it involved consumption expenditure and its relationship with wellbeing and gender equality. The research involved district-level quantitative analysis of data from two large-scale household surveys in the states of Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal in India.

The unit of analysis was the district level. The choice was inspired by Vepa et al. (2013) who used district-level analysis of agricultural development in a richer way than household-level analyses can achieve. The research design was based on the literature on energy poverty associations which informed the use of a quantitative methods and data to test the relationships (Saunders et al., 2019). The research was largely exploratory - this was particularly true for investigating the links between the measures of energy poverty and variables of wellbeing and gender equality within the energy poverty indices. Because of the exploratory nature of the research, a further national-level analysis was used to complement the district level analysis as it was important to ensure ecological fallacies about households were avoided (Portnov et al., 2006).

The research used quantitative data from household surveys to extract variables related to wellbeing, gender equality, consumption expenditure and LPG access and to integrate them into an index. Variables were recoded as meeting or not meeting sufficient wellbeing, gender equality, consumption expenditure above the poverty line and access to LPG fuel, in a binary format. Quantitative data cases (households) were subsequently merged based on their district and what indices they fit within and then analysed using statistical testing. However, we recognise the constraints of quantitative methods, as access to energy, can be subjective and personal in marginalised communities (Allen, 2017).

Table 1 indicates all the variables used alongside the associated index. Table 2 shows the variables accompanied with the respective questions chosen from the household surveys; the recoding aspects are not of importance yet and is covered in the data analysis (Section 3.3). Both variable creation and question selection was grounded on extensive literature review and critical analysis. Short-term illness was chosen as an indicator of physical wellbeing. Cross-sectional, experimental and longitudinal studies associate physical illness with wellbeing, in particular happiness (Koivumaa-Honkanen et al., 2004; Lyubomirsky et al., 2005). However, using solely short-term illness is contentious. Verbrugge et al. (1994) show that serious long-term illnesses also reduce wellbeing. Therefore, one could argue that air pollution from chulhas due to poor modern energy access could directly relate to wellbeing due to both acute and chronic exposure (Sehgal et al., 2014). Despite this, a reduced timescale of illness was chosen because short-term illness also indirectly measures functioning and resilience of household wellbeing, as it can lead to lost wages (Rice et al., 1985).

Education was an obvious choice for the wellbeing index, as it contributes to economic wellbeing and personal development (Land, 2010). Lack of education is also attributed to social exclusion, as a denial of public services like schooling significantly correlates to poor social wellbeing and low perceived contribution to society (Boreham, 2013). It could be argued that access to education, as opposed to education completion, is more relevant. However, as primary education completion is compulsory in India, we focused on constitutional human rights of wellbeing (Alam and Halder, 2018). The social inclusion variable also fed into social wellbeing and sought to capture the social cohesion in terms of trust and reciprocation in districts and contributing to higher levels of wellbeing (Sampson, 2003).

Table 1. The indicator variables for each of the four indices and number of cases available.

Index	Variable	Valid Cases
Wellbeing	Short-term Illness	2832
	Education Completion	2832
	Social Inclusion	245
	Safety	245
	Water Availability	245
	Air Pollution	175
	Toilet Access	246
Gender Equality	Ownership of Property	2734
	Maternal Health	1136
	Education of Health Effects	2830
	Work	2193
Consumption Expenditure	Economic Activity	4532
LPG Access	LPG Availability	4532
	LPG Affordability	
	LPG Awareness	

The safety indicator also relates to social cohesion. As seen in Table 2, using a survey question based around themes of connectedness to community as well as security, which can reduce mental discomfort, led to holistically capturing the peace of mind of a household (Cummins et al., 2003). The safety indicator also goes beyond external forms of crime domestic violence, which is an impediment to multiple forms of wellbeing within a household. However, as most domestic violence is targeted at women in India, it was thought to be best excluded for an ungendered investigation of wellbeing (Menon, 2020).

Availability of drinking water is a contextually relevant indicator for India as over 91 million people lack access (Water, c2022). Unsafe water supplies lead to increased chronic and acute illness, reducing chances of completing education or participating in work (Water, c2022). Availability of drinking water in summer specifically was chosen variable, as the rural states focused on in this research suffer from extreme groundwater depletion (see Table 2) (Asoka et al., 2017; Rodell et al., 2009). It represents the resilience of the household and district at times of hardship. Indoor air pollution was also included as an indicator of wellbeing because its impact outweigh that of outdoor pollution in India (Kankaria et al., 2014). Health impacts negatively affect economic prosperity and happiness, but the variable also indirectly relates to household education, as smoke exposure is commonly known to be harmful (see Table 2).

We sought to capture gender equality through four key measures: work, ownership, education, and maternal health (Choudhuri and Desai, 2020; King and Mason, 2001; Malhotra et al., 2002). Women's employment in salaried work is not always a priority in rural communities, so the index focused on female empowerment and their ability to make decisions around work (see Table 2). A gender gap is also present in land rights in developing countries, and this deserved recognition as a variable, particularly as increased ownership can lead to reduced levels of domestic violence (Grabe, 2010). Maternal health also has an explicit link to gender equality and safety in rural India (Brahmapurkar, 2017). Finally, as most health effects of indoor air pollution inflict women, knowledge of the effects of smoke was also included (Austin and Mejia, 2017; Sehgal et al., 2014).

Table 2. The variables chosen for the study, alongside the questions asked in the household surveys that give the study's initial quantitative data. The initial coding of the data is also shown, followed by the new coding, and reasoning for this alteration (Aklin et al., 2016; Desai et al., 2018).

Variable	Question Asked	Initial Coding	Recoding	Reasoning for Recoding
Short-term Illness	How long was [NAME] unable to do usual activities (incl. work, school, domestic work) in the last 30 days?	0-30	0 days = 0 1-30 days = 1	Assumption that any number of days of illness leads to reduced wellbeing (Koivumaa-Honkanen et al., 2004; Lyubomirsky et al., 2005)
Education Completion	How many standard years has [NAME] completed?	< 1, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 1st year post-secondary, 2nd year post-secondary, Bachelors, above Bachelors	Compulsory education completed - 7 years or more = 0 Insufficient education - under 7 years = 1	7 years stand as the requirement for compulsory education in India and is a human right (Alam and Halder, 2018). Insufficient education would therefore be below this criterion.
Social inclusion	In some villages or neighbourhoods, when there is a community problem such as water supply problem, people bond together to solve the problem. In other communities, people take care of their own families individually. What is your community like?	Bond together or Individual family	Bond together = 0 Individual family = 1	

Safety	During the last twelve months, was anything stolen that belonged to you or to somebody in your household?	Yes or No	No = 0 Yes = 1	
Water Availability	Is the availability of drinking water adequate in Summer?	Yes or No	Yes = 0 No = 1	
Air Pollution	Is there a window or vent in the cooking area?	Yes, No or Outdoors	Yes or outdoors = 0 No = 1	Outdoor cooking gives ventilation from pollution, so was grouped with 'Yes'
Toilet Access	Does the household have a toilet of its own?	No facility (or open fields), Traditional pit latrine, Semi-flush latrine, or Flush latrine	Traditional pit latrine, Semi-flush latrine, or Flush latrine = 0 No facility (or open fields) = 1	Different types of toilets were grouped together as they are all relatively sanitary and reduce chance of disease. No facility or open fields mean no household toilet available
Ownership of Property	Is your name on the ownership or rental papers for your home?	Yes, No or No papers	Yes = 0 No = 1	'No papers' data was excluded as it gives no indication of gender equality
Maternal Health	When you were pregnant with [NAME] did you have an antenatal check-up?	Yes or No	Yes = 0 No = 1	
Education of Health Effects	Is smoke from a wood/dung burning traditional chulha good for health, harmful for health or do you think it doesn't really matter?	Harmful, No effect or Does not matter	Harmful = 0 No effect or Does not matter = 1	Responses of 'no effect' or 'does not matter' both indicate a lack of education of health effects, so were grouped together
Work	Who has the most say in decisions about your work?	Self, Husband, Senior male, Senior female, or Other	Self = 0 Husband, Senior male, Senior female or Other = 1	If female respondent does not have the most say in work decisions, then it indicates poor female em-powerment, regardless of the person in charge of the decisions.
Economic Activity	How much is your expenditure on household needs in a typical month (rupees)?	Any number	Above urban poverty line (1407 rupees and above) = 0 Below urban poverty line (<1407 rupees) = 1	Required recoding of above or below the poverty line. Poverty line was suggested by the Rangarajan Committee (Planning Commission, 2014). Urban line was used despite all the states being rural as a precautionary device as some districts may have urban characteristics.

LPG Availability	[A] Do you use domestic gas (LPG) for cooking?	Yes or No	For Question [A] Yes = 0 No = 1	This variable needed multiple coding
LPG Affordability LPG Awareness	[B] If no, why don't you have LPG: Is it not available or too far from your village? Is it too expensive to have an LPG connection? Is the monthly cost of LPG too high? Don't know how to get or whom to ask? Other?	For Q. [B] No=0 Yes=1 All values were totalled: Values of 0-1 (respondent either uses LPG or does not, but because of reasons not related to access) = 0 Values of 2 and above (respondent does not use LPG and has at least one access issue) = 1	access or lack thereof. If LPG was not used but it was not stated that the reasoning was because of access issue, it is not relevant to this variable (e.g. cooking preference)	LPG Affordability LPG Awareness

Using consumption expenditure and LPG access variables was logical due to research aims. The LPG variable went beyond connection to include economic accessibility and affordability because affordability is still an issue in rural India (Dabadge et al., 2018). Educational accessibility was also included, as households in marginalised communities may not know how to obtain an LPG connection (Saxena and Bhattacharya, 2018). The variable of consumption expenditure focused on how much a household spends on their needs per month. An urban poverty line of 1407 rupees, newly suggested by the independent consultation of the Rangarajan Committee, was adopted (Planning Commission, 2014). Whilst all the focused states are mostly rural, the research used a higher urban poverty line because some districts within the states could be urban.

3.1 Data Collection

Data was sourced from the India Human Development Survey 2 (IHDS II) and the Access to Clean Cooking Energy and Electricity: Survey of States (ACCESS). These data sources were selected due to the multitude of relevant questions they ask on energy and living conditions. IHDS II offered data on wellbeing and gender equality indicators for 2011-2012 whilst ACCESS provided data on LPG access and monthly consumption expenditure for 2015 (Aklin et al., 2016; Desai et al., 2018). All survey data was at the household level, quantitative in nature and collected from the answers to the questions indicated in Table 2.

This research focused on the states of Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal in India (Figure 3). The geographic focus arose from data availability: whilst IHDS II had data for all Indian states, ACCESS data was limited to the above 6 states. Although the states are unrepresentative of India due to a north-eastern dominance, they are the most populated and most energy-poor states (Jain et al., 2018). Uttar Pradesh, for example, has 166 million people and the largest share of unelectrified households unwilling to connect (Jain et al., 2018). All states are also in the top 11 for 'largest percentage of the population living in rural areas' - from 89% in Bihar to 68% in West Bengal - excluding states with a population below 10 million (Chandramouli, 2011, p.8). This means that urban populations are underrepresented in this study. However, when one considers that lack of access to LPG mainly exists in rural areas, the sample states represent well India's energy poverty (Jain et al., 2018). The 27 districts of the 6 states formed a meaningful sample for statistical analysis when merging ACCESS and IHDS II datasets.

A key strength of the IHDS II was the ability to capture a range of direct and indirect indicators for wellbeing and gender equality. Whilst obtaining data from one survey would have been preferable, and many studies use the National Sample Survey Organisation (NSSO), a difference of 3-4 years in the datasets is small (Bhattacharyya, 2006; Pachauri et al., 2004; Ravindra et al., 2019). IHDS II and ACCESS were both conducted by independent research institutions specifically to avoid political contention around the raw data, as Indian official statistics have data credibility issues (Himanshu, 2019; Waghmare and Mukherjee, 2020). We also conduct a brief secondary data analysis (Table 3) to assess the credibility of data sources.

Figure 3. A map of India, with sections in red indicating the chosen states for this research.

Household survey data was most appropriate for this research. India is a developing country where registration systems are limited, creating information gaps on poor rural communities in which energy access is most restricted (Development Initiatives, 2017). An advantage of the household survey is discretion, which is particularly relevant when considering the freedom of women in the context of traditional, socially prescribed gender norms (Wolff, 2015).

Table 3. Secondary data analysis of IHDS II and ACCESS datasets (Aklin et al., 2016; Desai and Vanneman, 2018).

	IHDS II	ACCESS
Purpose of data	The research program set out to document the conditions and changes to Indian households through a breadth of development indicators.	To evaluate the condition of energy access in India's most energy-poor states through the multidimensionality of the issue.

Methods used	1-hour, face-to-face interviews. Stratified random sampling for rural households. Stratified sampling using probability proportional to the population for urban households	Face-to-face interviews. A random sampling of one district from each of the administrative divisions. West Bengal was given two districts due to larger administrative divisions. Sampling was then stratified using probability proportional to population
Population studied	42,152 households from 33 states and union territories.	9,000 households spread across Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal
Credibility of creator	Conducted by researchers from the University of Maryland and the National Council of Applied Economic Research. Funded by the U.S. National Institutes of Health and the Ford Foundation. Credible research institutions and non-government organisations.	Conducted by Council on Energy, Environment and Water (CEEW) with support from Columbia University and Shakti Sustainable Energy Foundation. Credible research institutions and nongovernment organisations.
Limits of the data	Large amounts of non-response problems, where respondents have not provided requested data. Information of households beyond the district level, such as the respective village, is unavailable.	Many of the questions ask respondents for rough estimates across long timescales to quantify their energy consumption, likely leading to inaccurate data.

Table 4 indicates the number of cases of data for each state, totalling to 4,654 data points. The percentages of were not the same far all states, reflective of the sampling methods of IHDS II and ACCESS – proportionate stratified sampling based on population. Uttar Pradesh had the largest number of cases due to its high population. By utilising proportionate stratified sampling techniques, external validity was enhanced and the research could be better generalised to the entire population of the 6 states (Arnhab, 2017).

Table 4. The number of cases for each state with a percentage amount per state and totals.

State	Cases Value	Percentage
Uttar Pradesh	1680	36.1%
Bihar	503	10.8%
West Bengal	596	12.8%
Jharkhand	363	7.8%
Odisha	504	10.8%
Madhya Pradesh	1008	21.7%
Total	*4654*	*100%*

3.2 Data Analysis

Statistical Package for the Social Sciences (SPSS) 28 was used to conduct both descriptive and inferential statistical analysis. The IHDS II and ACCESS datasets were merged into one SPSS file. Data cleaning was then performed to eliminate coding inconsistencies and to handle missing data. Recoding the variables was the most important form of data cleaning. Table 2 highlights the recoding approach which was used to transform the data into a binary format, whereby a value of 0 would always equate to the most ideal outcome of the variable, and a value of 1 would equate to the worst possible outcome. For example, a value of 0 for education indicated that the household had completed compulsory education, whereas a value of 1 indicated that compulsory education had not been completed. Recoding of variables also involved grouping and categorising original data values together into this binary format of ‘ideal vs worst outcome'. Table 2 shows that economic activity was originally a continuous variable which was transformed into categories of above or below the urban poverty line.

Any districts that did not have data from both IHDS II and ACCESS were excluded. As displayed in Table 1, certain variables, like air pollution in the wellbeing index, had lower number of valid data points and higher levels of missing data; this limitation is explored further in Section 5.5. If cases were excluded based on not having data on all variables, this would have led to a considerably smaller amount of available household data and reduced the statistical power of the study (Brownlee, 2020). Instead, the case values for each index were totalled and the mean calculated for each of them, in a continuous data format. This limited the impact of missing data but also preserved the integrity of the data in the sense that 0, the minimum, always indicated the best outcome (e.g. 100% of the district population with the most ideal form of wellbeing) and 1, the maximum, indicated the worst outcome (i.e., 100% of the district with the worst wellbeing).

4. Results

This study aims to determine whether LPG access and consumption expenditure can be used as individual measures of energy poverty, defined by wellbeing and gender equality, in India. As mentioned, to conduct a district-level analysis, the scores of the indicator variables for the wellbeing, gender equality, LPG access and consumption expenditure indices were totalled for each household and averaged for each district. Table 5 shows an extract of the means for each index for the state of Madhya Pradesh, with Appendix A showing the full list of states. There was a data range of 0-1 (good to bad) for each index value due to the binary nature of the recoded data. Section 4.1 first characterises the data through descriptive statistics. Then, the relationships between the measures, LPG access and consumption expenditure, and the effects, wellbeing and gender equality, of energy poverty are distinguished and tested with the relevant inferential statistics (Section 4.2 and Section 4.3). Finally, further analysis of associations between the measures of energy poverty and individual indicator variables of wellbeing and gender equality is detailed (Section 4.4).

Table 5. Mean scores for all districts in the state of Madhya Pradesh for each respective index.

District	Wellbeing Score	Gender Equality Score	Consumption Expenditure Score	LPG Access Score
Katni	0.255	0.263	0.125	0.833
Hoshangabad	0.372	0.424	0.018	0.589
Shajapur	0.304	0.475	0.018	0.690
Satna	0.441	0.374	0.095	0.798
Damoh	0.481	0.337	0.113	0.875
Morena	0.425	0.523	0.036	0.893

4.1 Descriptive Analysis

For LPG access, the minimum score of 0.429, was for the district Muzaffarnagar, Uttar Pradesh and the highest score of 0.946 was for the district Supaul, Bihar (see Appendix A). Yet, the state of Odisha had the highest average score of 0.893, indicating the worst access to LPG in the 6 states. A Kolmogorov-Smirnov test for normality yielded a nonsignificant result (p-value > .05), so LPG access is considered to have a normal distribution. A normal Q-Q plot of the index corroborated normal distribution with a slight skew to the left, in line with a Skewness statistic of -0.876 (see Figure 4). An overall mean LPG score of 0.760 was obtained, and a standard deviation (SD) of 0.026. Therefore, LPG access had a much poorer average score in comparison to the other indices.

Consumption expenditure (Figure 5) was non-normally distributed, with skewing to the right and heavier tails in comparison to a normal distribution. An interquartile range of 0.024 and a median of 0.030 was found. The measure of central tendency was considerably lower than the values for the other indices, and alongside the histogram, indicates higher consumption expenditure and more 'ideal' scores. Outliers were present for consumption expenditure. However, all the outlier districts were in Madhya Pradesh: they were not removed as they may indicate higher consumption expenditure in the state (Osborne and Overbay, 2004).

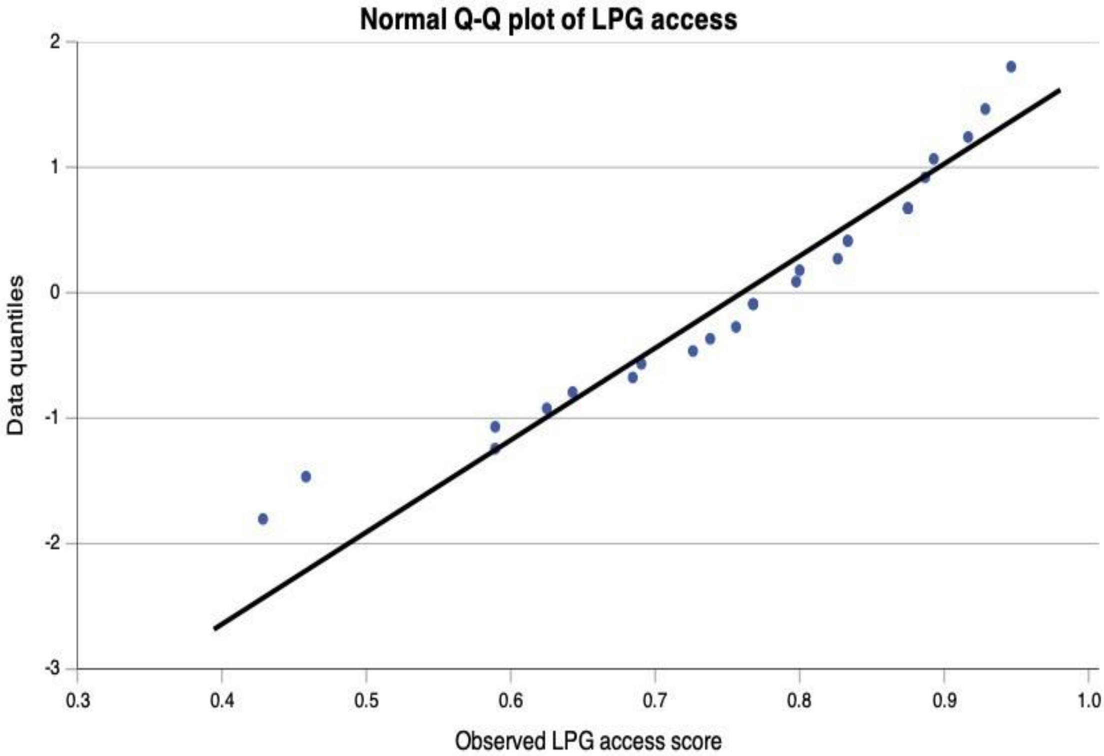

Figure 4. A normal q-q scatter plot of LPG access for all districts using dots to show the observed score relative to the data quantile, with a black line showing true, normal distribution.

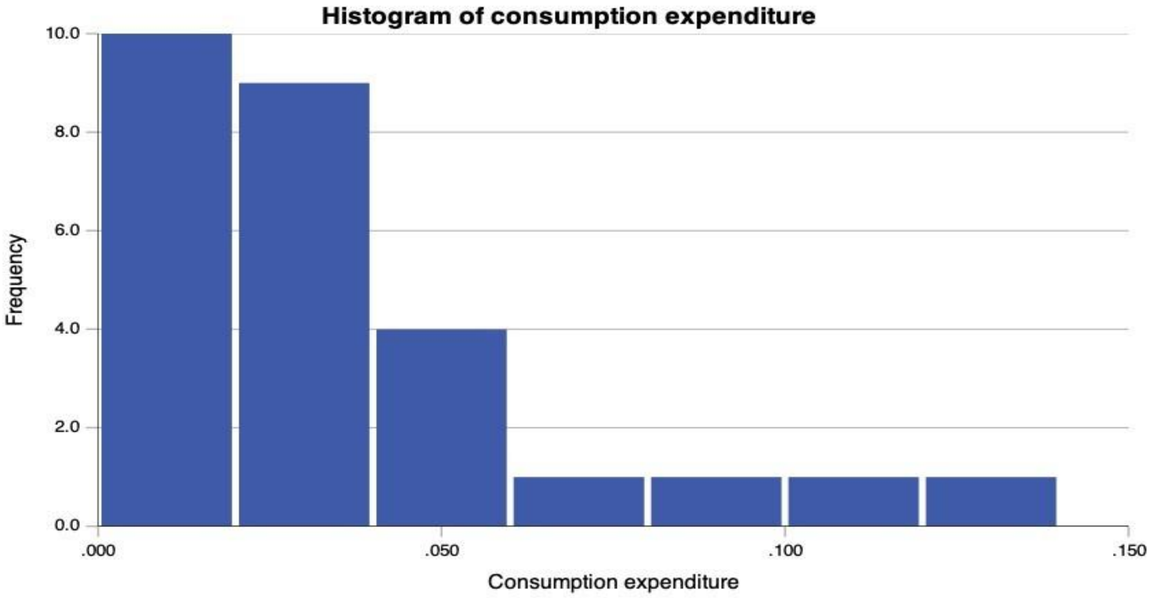

Figure 5. The distribution of consumption expenditure scores for all districts.

For the wellbeing index, the minimum value 0.255 was for the district of Katni in Madhya Pradesh whilst the highest score of 0.557 was for Supaul in Bihar (see Appendix A). Figure 6 shows that Bihar had the highest average wellbeing score and the largest range of results, so, had the poorest and most varied wellbeing. Skewness and Kurtosis statistics indicated fairly symmetrical data, -0.497 and -0.557 respectively. A Kolmogorov-Smirnov test for normality also yielded a non-significant result (p-value > .05) indicating a normal distribution. An overall average wellbeing score of 0.406 and an SD of 0.078 was found.

The gender equality index was similar to the wellbeing index, with a mean score of 0.466 (SD = 0.019). However, the Skewness and Kurtosis statistics of 0.561 and 0.920 indicate that the data skews slightly positive and has a more heavily tailed distribution. Nonetheless, a non-significant result (p-value > .05) for a Kolmogorov-Smirnov test suggested a normal distribution. A boxplot highlighted disproportionate tails and unveiled three outliers, Katni, Bargarh and Mayurbhanj from Madhya Pradesh and Odisha (see Figure 7). The outliers were not excluded from because Katni also had the lowest value and thus the best score for wellbeing: the data for the two indices may jointly indicate high social development in the district as opposed to data errors. Furthermore, Bargarh and Mayurbhanj are both in Odisha, a state with a smaller population and higher regard for gender equality (Nanda et al., 2015).

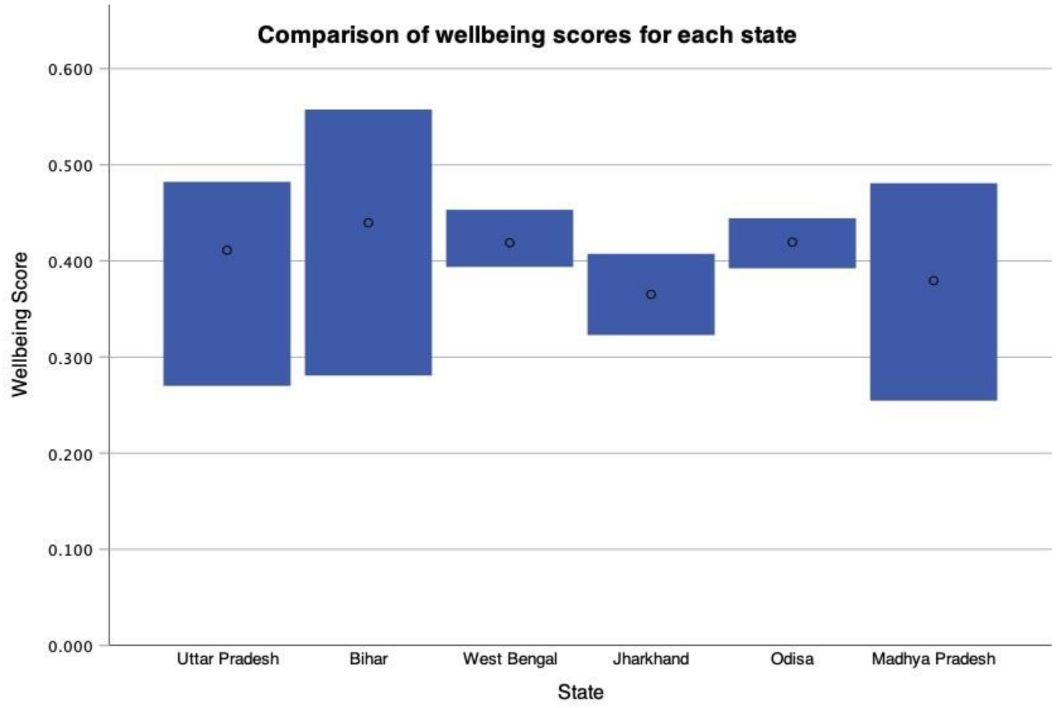

Figure 6. Wellbeing scores for the Indian states, with circles representing the mean score.

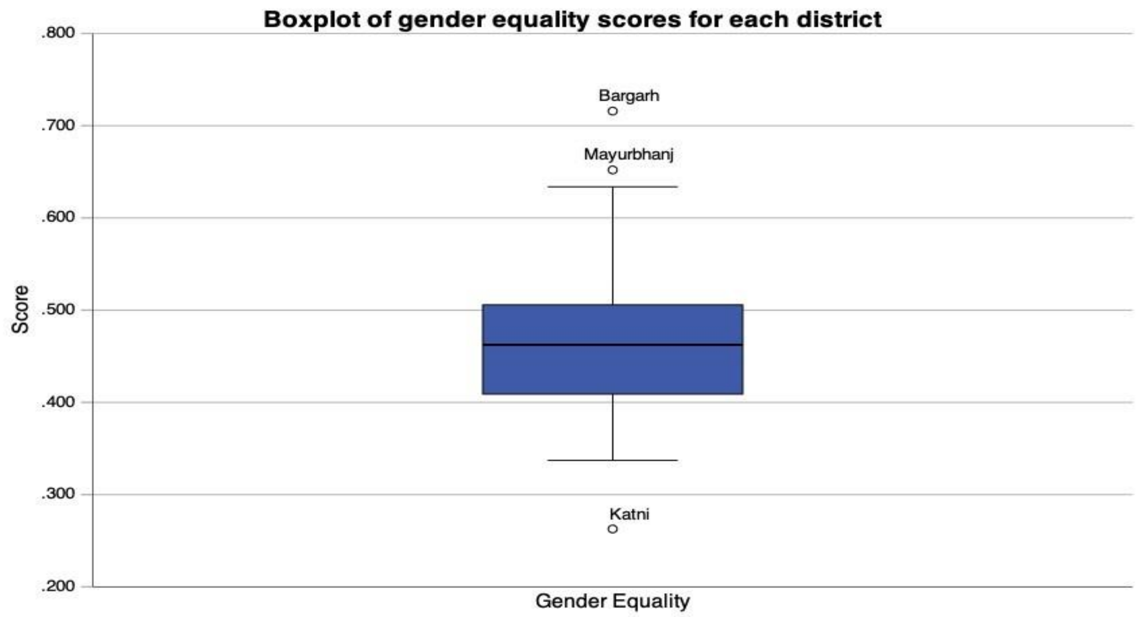

Figure 7. Gender equality scores for all districts, with three outliers represented by the circles.

4.2 LPG Access

When statistically testing LPG access with wellbeing, the null hypothesis was that there is no significant relationship between wellbeing and LPG access. To determine a level of association between the two continuous, normally distributed variables, a Pearson correlation test was used. At a 95% confidence level, there was no correlation between wellbeing and LPG access (Pearson's product-moment correlation, r = .072, n = 27, p > .05). The null hypothesis was therefore confirmed. Figure 8 presents the scatterplot for the relationship between LPG access and wellbeing which indicates that there were many districts with poor LPG access yet good wellbeing scores, which negated any positive relationship.

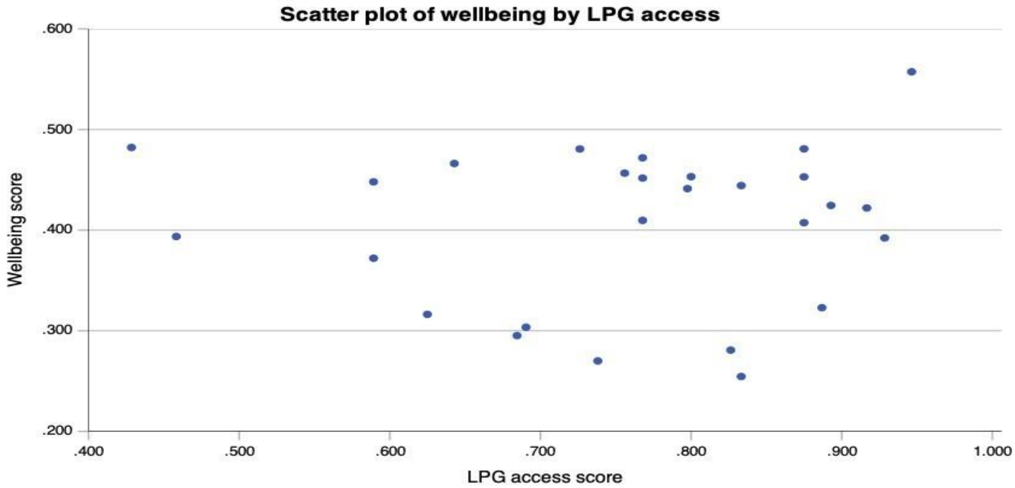

Figure 8. A scatter plot of the relationship between wellbeing and LPG access for all districts.

For LPG access and gender equality, the null hypothesis was that there is no significant relationship between gender equality and LPG access in Indian districts. A Pearson correlation test was used. At a 95% confidence level, there was no significant correlation between gender equality and LPG access ($p > .05$). The Pearson's product-moment correlation ($r = .276$, n = 27) suggested a low correlation, as seen in the scatter plot in Figure 9. Districts with poorer LPG access had worse gender equality. However, many districts also had poor LPG access and good gender equality. Thus, the null hypothesis was accepted.

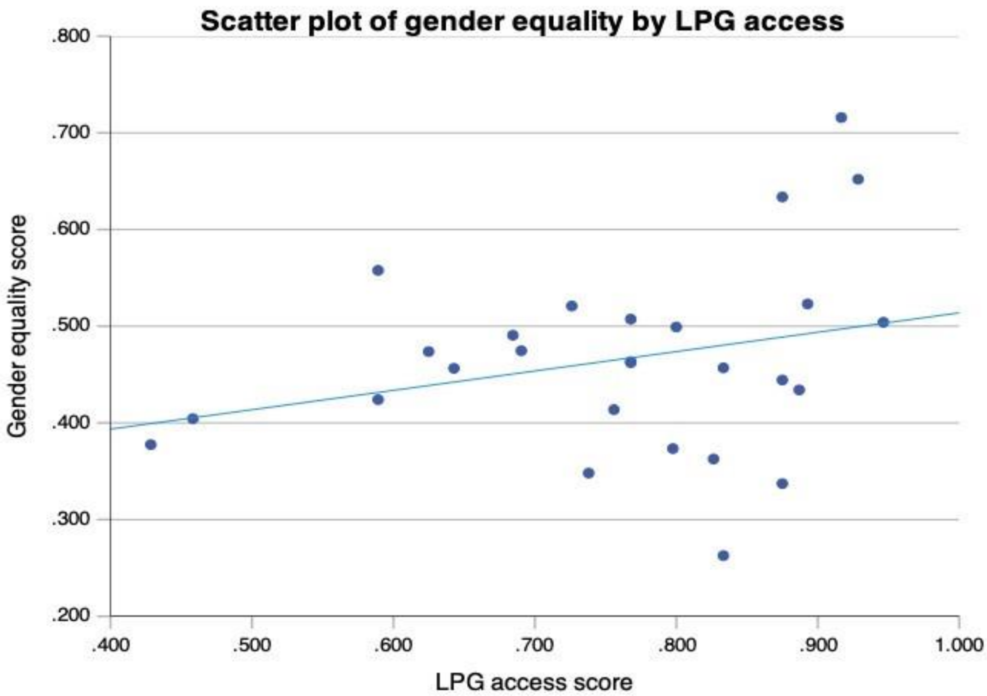

Figure 9. *A scatter plot showing the relationship between the scores of gender equality and LPG access for all districts, with a blue trendline ($R^2 = 0.076$).*

4.3 Consumption Expenditure

For consumption expenditure and wellbeing, the null hypothesis was that there is no significant relationship between wellbeing and consumption expenditure. Because consumption expenditure was not normally distributed, a non-parametric test was used. At a 95% confidence level, there was no significant correlation between wellbeing and consumption expenditure

(Spearman’s rho correlation coefficient, *r* = -.186, n = 27, p > .05). Therefore, the null hypothesis was accepted.

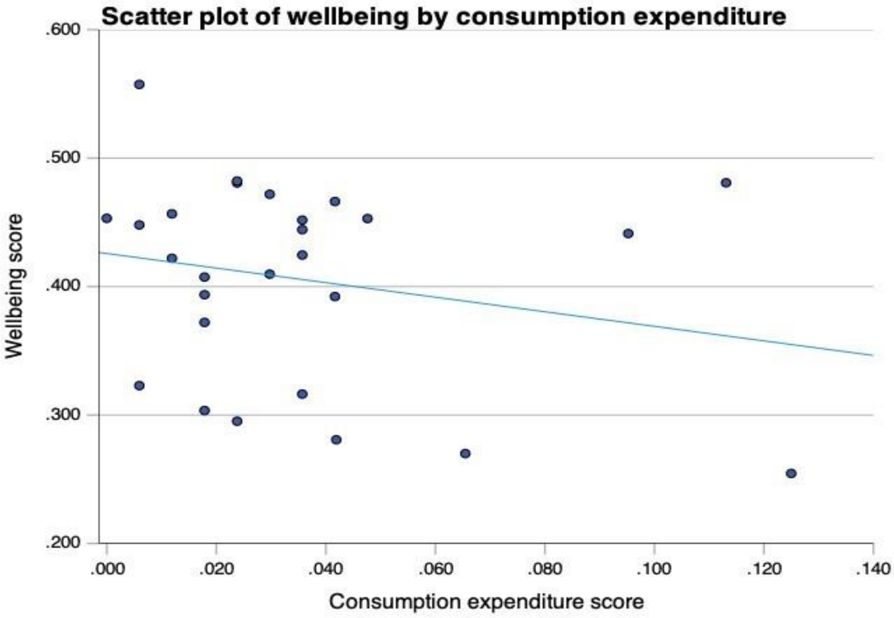

Figure 10. A scatter plot showing the relationship between the scores of wellbeing and consumption expenditure for all districts, with a blue trendline (R^2 = 0.052).

For consumption expenditure and gender equality, the null hypothesis was that there is no significant relationship between gender equality and consumption expenditure. The Spearman’s rho correlation test was used due to continuous but non-normal distribution of data. At a 95% confidence level, there was no significant correlation between gender equality and consumption expenditure (p > .05). The null hypothesis was subsequently accepted. The Spearman’s rho correlation coefficient (*r* = -.367, n = 27) suggested a moderate correlation, as seen in the scatter plot in Figure 11. Despite significant clustering of low consumption expenditure and high gender equality scores, a negative relationship was present; as consumption expenditure worsened, gender equality improved somewhat.

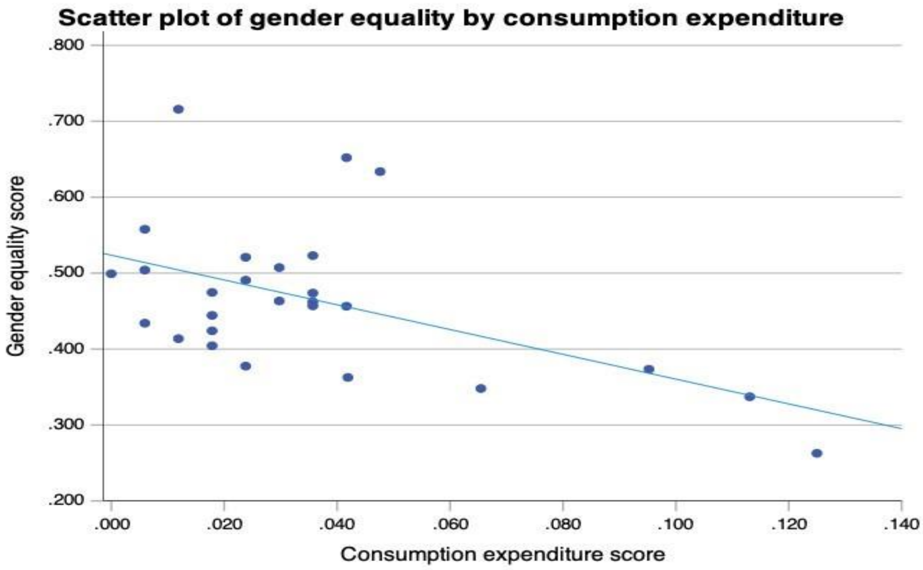

Figure 11. *A scatter plot showing the relationship between the scores of gender equality and consumption expenditure for all districts, with a blue trendline (R^2 = 0.267).*

4.4 Further Analysis of Indicator Variables

Non-significant results were found for the 4 relationships tested above. So, the association between LPG access, consumption expenditure and the individual indicator variables were explored next. Instead of district-level analysis, the associations were tested on a national scale using all 4,654 individual data cases. The national scale was used to see if there were any associations between the variables within the indices and whether masking effects could explain the lack of significance of results obtained above (Iddrisu and Bhattacharyya, 2015). As short-term illness and education had substantially more data points than other wellbeing variables and therefore greater weighting, this concern was relevant.

The means of variables were not used in the further analysis, only the binary format of 0 or 1. Therefore, a chi-squared analysis was adopted for testing. To compensate for only having two values for each variable, a Yates correction for continuity was used (Camilli and Hopkins, 1978). Table 6 indicates the results, with blue colour indicating a significant relationship. A chi-square test indicated a two-sided significant association between LPG access and education on health effects (χ^2 = 14.04, n = 2708, df = 1, p < .001). This meant the rejection of the null hypothesis, which was that there is no significant relationship between female education on health effects and LPG access. Table 7 indicates that higher proportion (92%) of women with LPG access understand the dangers of chulha smoke than women without LPG access (86.4%). A chi-square test also indicated a two-sided significant association between consumption expenditure and property ownership (χ^2 = 14.83, n = 2615, df = 1, p < .001). This meant a rejection of the null hypothesis that there is no significant relationship between female property ownership and consumption expenditure. Table 8 highlights that women below the poverty line were much more likely (25.6%) to have their name in the ownership documents of their accommodation than women above the poverty line (11.3%). No significant associations exist between the energy poverty and wellbeing variables.

Table 6. Chi-squared analysis for indicator variable's relationship with either LPG access or consumption expenditure: brown for no significant relationship, blue for significant relationship.

Indicator Variable	LPG Access	Consumption Expenditure
Short-term Illness		
Education Completion		
Social Inclusion		
Safety		
Water Availability		
Air Pollution		
Toilet Access		
Ownership of Property		
Maternal Health		
Education of Health Effects		
Work		

Table 7. Female education about indoor air pollution and LPG access.

Accessibility of LPG	Female Education on Indoor Air Pollution		Total
	Knowledge of Adverse Effects	No Knowledge of Adverse Effects	
LPG Access	589 (92%)	51 (8%)	640 (100%)
No LPG Access	1786 (86.4%)	282 (13.6%)	2068 (100%)
Total	2375 (87.7%)	333 (12.3%)	2708 (100%)
Chi-Squared = 14.04		*p < .001*	

Table 8. Reported female ownership of property and consumption expenditure.

Consumption Expenditure	Female Ownership of Property		Total
	Name on home/rental papers	No name on home/rental papers	
Above the Poverty Line	287 (11.3%)	2242 (88.7%)	2529 (100%)
Below the Poverty Line	22 (25.6%)	64 (74.4%)	86 (100%)
Total	309 (11.8%)	2306 (88.2%)	2615 (100%)
Chi-Squared = 14.83		*p < .001*	

5. Discussion

The aim of this research was to determine whether LPG access and consumption expenditure could be used as measures of energy poverty in India. Consumption expenditure has no significant association with wellbeing or gender equality, and no significant association were found for LPG access either. Next the results are unpacked and critically evaluated for LPG access and consumption expenditure. The significance, implications and limitations of the results, as well as future research needs are discussed in the end.

5.1 LPG Access

No significant association was found between LPG access and wellbeing which contradicts some past literature. Phoumin and Kimura (2019) used the lack of accessibility and affordability as energy poverty measures, very similar to this study’s use of LPG availability, LPG affordability, and LPG awareness. The recorded effects of energy poverty also have similar indicator variables of health, education and earning opportunities (Phoumin and Kimura, 2019). Yet Phoumin and Kimura (2019) find significant associations between energy poverty, wellbeing, and household deprivation. For instance, energy-poor households have a higher probability of respiratory problems and therefore lower earning opportunities (Phoumin and Kimura, 2019). It is possible that in this study the result was insignificant due to a limited number of data points (27 districts), which reduced statistical power (Button et al., 2013). The limitations of the use of a district-level methodology are discussed further in Section 5.5.

The lack of significant association between LPG access and wellbeing could exist because the used measure of energy poverty did not go beyond affordability, and consequently did not consider economic variables explicitly. Phoumin and Kimura (2019) included energy expenditure into their energy poverty measure unlike in this study. However, the use of actual energy expenditure as a measure of energy poverty has serious limitations (Castro-Sitiriche and Ndoye, 2013; Moore, 2012) because vulnerable households will often limit their energy use when facing urgencies or disconnect themselves from electricity supply (Herrero, 2017). Nevertheless, the insignificance of association found in this study suggests that economic methods could be used as a complementary approach to measuring energy poverty because access to modern cooking fuel does not have strong correlation with wellbeing. Although energy expenditure is a controversial indicator, greater multidimensionality in the measurement of energy poverty could be achieved by combining consumption expenditure and LPG access into a singular index for statistical testing.

When looking at the research in greater detail, a change of indicator variables and questions asked in the surveys would likely be needed for there to be significant association between LPG access and wellbeing. For example, the air pollution indicator is problematic: the households were asked if they had ventilation in their cooking area and got a bad score if they did not have it. The premise of the variable is that energy-poor households had poor ventilation because they had no access to LPG. However, the inverse relationship may also prevail: energy-poor households without LPG access could ensure that they have proper ventilation as they are reliant on dirtier fuels. Also, households with LPG access would not be as concerned with air pollution. Health indicators could also be improved. Phoumin and Kimura (2019), for example, use health spending and the occurrence of respiratory disease as health indicators. They have tangible links to energy poverty and wellbeing, as energy-poor households have a higher probability of suffering from respiratory problems (physical health) and therefore higher health bills (economic health), and higher school drop-out rate (education) (Oliveras et al., 2020). As a variable short-term illness has a weaker link to respiratory illnesses and could benefit from the inclusion of variable linked to long-term health problems. The further analysis of indicator variables found no significant association between the health indicator and LPG access and this was also the case for other wellbeing indicators. Either the choice of indicator variables and questions are not the best estimates of wellbeing affected by energy poverty, or there are issues with LPG access as a measure.

The non-significant association between access and wellbeing in this study resonates with the argument in the literature that energy access should not be used as a stand-alone indicator for energy poverty (Kaygusuz, 2012; Nussbaumer et al., 2012; Roy, 2012). This seems true also for access to modern cooking fuels (González-Eguino, 2015; Irwin et al., 2019). But the inclusion of the variable into composite indices is still accepted in the literature because strong correlations consistently occur between access to modern cooking fuel and favourable socio-economic household characteristics (Pachauri and Spreng, 2004; Pachauri et al., 2004). So, the results do not question LPG access as a component of energy poverty measurement, but highlights the need for greater multidimensionality in it.

The literature indicates that women are more likely to have serious health effects due to the lack of access to modern energy (Nguyen et al., 2021; World Bank, 2009; WHO, 2009). Yet no significant association was found between LPG access and gender equality in Indian districts. This may be due to an ignorance of the strong interrelationships that exist between caste and gender, particularly in the poorer states of India (Patnaik and Jha, 2020). Or the result could suggest that the link between measuring LPG access and gender equality is more complicated. For example, most energy poverty studies on gender equality use electricity access as the key measure. Nguyen et al. (2021) use access to clean cooking fuel only as one out of seven proxies for energy poverty, the rest relating to electricity access, consumption, and transmission. The use of LPG access as a sole indicator in this study might not readily associate with gender equality as strongly as seen with electricity indicators. There is little discussion on the gendered effects of energy access in developing countries. Further research is needed incorporate gendered energy poverty into the public measurement approaches as this would enable better-informed policy around female empowerment. For example, there has been traction to set aside funding to educate women on LPG use for gender inequality alleviation (Ministry of Petroleum and Natural Gas, 2019).

5.2 Further Analysis with LPG Access

Despite LPG access and gender equality yielding a non-significant result, in the further analysis a significant association was found between LPG access and the education about health effects for women. This relationship is well documented, but this study could establish that the relationship is specific to health effects and for the case of India (Longe, 2021; Rahman and Alam, 2021). The results are useful for the design of future schemes for generating tangible gendered benefits in India. When LPG connections are created, women could be tutored by grassroots educators on the health benefits of using LPG instead of biomass. This would not only improve women's health but also reduce poor households' use of biomass in their fuel mix after gaining access (Jain et al., 2018). However, the direction of the correlation should not be assumed: knowledge of the adverse health effects of chulha smoke may lead women to pursue LPG connections. Further exploring the direction of the relationship is thus important for public policy.

While a significant association between the education of health effects and LPG access is important, a critical lens is still required. Before the years when IHDS II and ACCESS data were gathered, policy in India focused on subsidising cooking fuels like LPG to improve access through greater affordability (Balachandra, 2011). The National Programme on Improved Chulhas was also established to reduce health effects on women (Greenglass and Smith, 2006). These programmes focused on poorer households whose education is often low (Balachandra, 2011). Whilst the ability of the subsidies to increase in LPG use is well documented, there is no quantifiable data on the education of women using dirty and clean energy (International Institute for Sustainable Development, 2014). The success of the schemes to educate women on health effects of cooking fuels could thus be marginal: energy-poor households may have improved their access to LPG without understanding the associated health benefits. Whilst this is conjecture, caution is needed in the choice of variables for a gender equality index.

5.3 Consumption Expenditure

The results indicate that there was no significant association between consumption expenditure and wellbeing, echoing the results of Pachauri et al. (2004) that there is no correlation between expenditure per capita and poverty in India. Whilst they do not focus on energy poverty, other studies suggest that energy expenditure alone is not an appropriate measure of energy poverty (Liddell et al., 2012; Moore, 2012). Therefore, the results clarify that governments cannot rely on consumption expenditure alone to measure energy poverty. The originality of this result stems from the consideration of broad wellbeing factors, such as safety and social inclusion. If developing country governments wish to pursue more progressive, multivariate energy poverty definitions, traditional economic approaches cannot support them and other measures and effects need to be explored. This will be a challenge, as India has in the past rejected the use of higher poverty lines in favour of old, lower ones (Gaur and Rao, 2020). But huge institutional barriers remain for the adoption of a new wellbeing index that would expose the hidden effects of energy poverty in India.

There are two issues around the results on consumption expenditure. Firstly, a Spearman's rank correlation, a non-parametric test, was used. It is not uncommon to use non-parametric tests for statistical analysis. However, there was less statistical power in the Spearman's rank correlation, so the tests were less likely to reject the null hypothesis (Siegel and Castellan, 1988). Having a relatively small sample size of 27 districts (despite 4,654 households within them) meant that the low statistical power was an even greater issue (Whitley and Ball, 2002). Consequently, a hidden significant correlation between consumption expenditure and both wellbeing and gender equality may exist. An increase in sample size would resolve this issue.

The second issue is that economic energy poverty may not have been captured by the used variable. Appendix A shows the consumption expenditure scores for each district. Damoh had a mean value of 0.113, which suggests very few households live below the poverty line. However, government estimates of below poverty line expenditure are 56.6% and 72.9% for rural and urban households in Damoh (Batra et al., no date). The same pertains to other districts. This could result from the use of different poverty lines. However, this research used a higher urban poverty line which should have captured greater levels of poverty. It is difficult to conclude which expenditure assessment is correct as they come from different sources – ACCESS and the NSSO. The use of consumption expenditure may lead to high levels of variability in self-reporting, especially when compared to concepts like income (Gray, 1995).

A novel result is the non-significant negative relationship between consumption expenditure and gender equality. Expenditure may not be a useful indicator for gender equality. Many authors consider that lack of energy access is important for the gendered impacts of energy poverty (Köhlin et al. 2011; Oparaocha and Dutta, 2011; World Bank, 2004). Only with access is women's situation improved by freeing their time and allowing them to pursue employment, increasing household income (Cecelski and Dutta, 2011). But higher income and consumption expenditure may not be the causal factors of gender equality: it may instead be the result of better access which leads to women's empowerment. Bradshaw (2018) casts doubt on this theory, arguing that the time saved from not having to collect traditional fuels is redirected to other domestic tasks for women. Nevertheless, the finding has important implications for policy as it suggests that the subsidisation of LPG, or promotion of cash transfer programmes, does not correct the imbalance between men and women seen in energy-poor households.

5.4 Further Analysis with Consumption Expenditure

One surprising result of the further analysis was the significant relationship between consumption expenditure and female ownership of property. Poorer women owned their property more often than women above the poverty line. The result is counter-intuitive, as gender equality is often linked to higher labour market participation (Morais Maceira, 2017). Female-led Indian households are poorer than male-led households due to low-wage occupation and childcare demands (Connell et al., 2012; Gangopadhyay and Wadhwa, 2004). The association between lower consumption expenditure and higher female ownership may reflect the larger proportion of female-led households in poverty. Increasing consumption expenditure could in turn be due to greater percentage of male-led households with higher income from salaried work (Reddy et al., 2021). Testing whether this socio-demographic, confounding variable plays a significant role at the household level in the relationship between female ownership of property and consumption expenditure is essential.

The role of income in gender equality is also contested. Studies from South Africa and Kenya suggest that men do not prioritise energy services like LPG for cooking no matter what their income level is (Fingleton-Smith, 2018; Makan, 1995). The influence women have in the household measured by the proxy variable - ownership of property – is thus crucial to energy poverty alleviation but may have no relationship to economic poverty. The findings from Africa do not agree with the further analysis of this Indian study regarding the association between consumption expenditure and female empowerment in households. It is possible that this result tells of a highly contextual nature of the gender-energy expenditure nexus and is geographically specific (Pachauri and Rao, 2013), calling for further research.

5.5 Limitations

A limitation is the district- instead of household-level analysis (see Ahmad et al., 2015; Lee et al., 2021; Rao and Reddy, 2007). Ethical considerations were the reason for this. Participants gave personal information in IHDS II about family dynamics, such as the level of female decision-making, which is why it does not provide information below the district level. Because of limited granularity, the data could not be aggregated and disaggregated e.g. to examine differences between rural and urban households. Focusing on 27 districts reduced the likelihood that insignificant results reflected a true effect, a type II error (Banerjee et al., 2009). A household-level analysis could have avoided this but a district may be more appropriate unit of analysis as social programmes are implemented at that level in India (Mondal et al., 2022).

Only energy-poor states were included into this study because they require interventions the most. However, this could explain the non-significance of results: if areas of good access are not included, it is harder to observe a change from low to high access and the associated wellbeing and gender equality change. This is also true about consumption expenditure as the included states are low-income ones (Anant, 2016). A significant association may thus exist between LPG access or consumption expenditure and wellbeing or gender equality. Future research could include data from all Indian states to avoid the issue.

Finally, the selection and weighting of variables and the construction of indices is subject to what is deemed most crucial in reducing energy poverty. Whilst the variables in wellbeing and gender equality indices have tangible links to energy poverty, their choice was not grounded on empirical analysis. The decision not to use income level in wellbeing index contradicts practice in HDI (United Nations Development Programme, 2022). Also, maternal deprivation has not been used earlier as an effect of energy poverty. Indices like the MEPI categorise indicators into sub-indices, giving different weights to variables related to different components of energy poverty (Nussbaumer et al., 2012). However, weighting is controversial; whilst not all indicators of energy poverty are of the same importance, a theoretically sound framework for weighing is challenging to come by (Freudenberg, 2003).

6. Conclusion

This research sought to determine whether LPG access and consumption expenditure can be used as measures of energy poverty in India. LPG access was shown to be a poor measure of energy poverty. This research corroborates arguments that electricity access cannot be used as a sole indicator of energy poverty, by establishing the same for access to modern cooking fuel. LPG access relates strongly to the education of women regarding 'chulha' smoke. If the direction of the relationship can be confirmed by future research, and LPG access affects female health education, this study recommends grassroots education of women when LPG connections are implemented. This would generate significant co-benefits to health and wellbeing in the 6 energy-poor states. Consumption expenditure is also found to be an ineffective measure of energy poverty. This resonates with existing view that expenditure per capita does not measure poverty well, and energy expenditure is not significantly associated with energy poverty. This suggests that economic approaches to gender inequality alleviation around energy poverty are unsuitable.

To conclude, energy poverty is a challenging issue for developing countries. The contribution of this research arises from questioning the status quo of economic energy poverty measurement as it does not fully benefit the people it supposedly serves. The statistical tests and the design of the study have limitations but also a promise in shifting energy poverty discussions to emerging concepts such as wellbeing and shining a light on the interplay between gender equality and energy. Future research should use similar approach to household level data from all states in India, incorporating subjective experiences within wellbeing and gender equality. Combing both LPG access and consumption expenditure into a more multidimensional index also holds promises, as would the use of a mixed methods approach including qualitative methods, to unpack the complexities of the phenomenon.

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Appendices

Appendix A - district scores for LPG access, consumption expenditure, wellbeing, and gender equality

State	District	LPG score	Consumption expenditure score	Wellbeing score	Gender equality score
Madhya Pradesh	Katni	.833	.125	.255	.263
	Hoshangabad	.589	.018	.372	.424
	Shajapur	.690	.018	.304	.475
	Satna	.798	.095	.441	.374
	Damoh	.875	.113	.481	.337
	Morena	.893	.036	.425	.523
Odisha	Ganjam	.833	.036	.444	.457
	Mayurbhanj	.929	.042	.392	.652
	Bargarh	.917	.012	.422	.716
Jharkhand	Ranchi	.887	.006	.323	.434
	Bokaro	.875	.018	.407	.444
West Bengal	Nadia	.768	.030	.410	.463
	Maldah	.800	.000	.453	.499
	Darjiling	.458	.018	.394	.404
Bihar	Patna	.826	.042	.281	.363
	Siwan	.726	.024	.481	.521
	Supaul	.946	.006	.557	.504
Uttar Pradesh	Varanasi	.756	.012	.457	.414
	Gorakhpur	.685	.024	.295	.491
	Sultanpur	.768	.036	.452	.462
	Banda	.875	.048	.453	.634
	Jhansi	.738	.065	.270	.348
	Kannauj	.768	.030	.472	.507
	Sitapur	.643	.042	.466	.457

	Bareilly	.625	.036	.316	.474
	Bijnor	.589	.006	.448	.558
	Muzaffarnagar	.429	.024	.482	.378

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