Intersectional aspects of energy poverty in India

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Abstract:

Energy poverty indicates difficulty in securing levels of decent living energy services. This study examines the intersectional dimensions of energy poverty, with a focus on social class, geography, income, education and gender. Using a nationally representative household survey from India, it demonstrates how overlapping inequities along these dimensions leads to significant disparities in reliable access, affordable use and clean and efficient energy service delivery. Additionally, it finds that these effects differ by the type of energy service as well the dimensions of energy poverty. A counterintuitive finding emerges: urban poor households face the highest cooking fuel affordability burden due to lack of biomass fallback options. This pattern of "reverse intersectionality," where adding rural location to a deprivation profile reduces affordability pressure through access to non-market fuel sources, challenges standard assumptions of compounding harm. Such systemic inequities extend beyond income poverty and disproportionately affect households with multiple deprivations, whereas households without any of the underlying structural inequities are always considerably better off than the national average. No prior empirical work examines whether intersectional effects vary across energy poverty dimensions or fuel types, a gap with significant implications for measurement and targeting.

These findings have important implications for policy, as they suggest that interventions aimed at reducing energy poverty in India must take into account the intersecting identities and experiences of different social groups, as well as the multidimensional nature of energy poverty beyond access alone. Targeted policies and programs that address the specific barriers faced by disadvantaged communities are suggested in order to promote greater energy access and equity in India.

Keywords: energy poverty; intersectionality; India; household energy; SDG 7; equity

Significance Statement:

This study demonstrates that intersectional effects on energy poverty vary systematically by dimension (access, affordability, services) and fuel type (electricity, cooking fuels); a finding absent from prior empirical work that treats energy poverty as unitary. We identify "reverse intersectionality" in cooking fuel affordability, where multiply-deprived households appear better off due to reliance on collected biomass, exposing how standard metrics can mask gendered labor costs. These findings have implications beyond India: approaches that aggregate energy poverty into a single measure risk misidentifying vulnerable subgroups and misallocating policy resources in any context where overlapping deprivations exist. This study provides the first empirical evidence that intersectional effects are dimension-specific, a finding that should inform both measurement design and policy targeting.

1. Introduction

Energy poverty is a complex and multifaceted phenomenon that continues to pose significant challenges for millions of individuals worldwide, particularly in the Low- and Middle-Income Countries (LMICs). Characterized by a lack of access to affordable and reliable energy services, it encompasses various dimensions, including access, reliability, affordability, and quality of services [1-3]. While energy poverty's consequences are manifold, its adverse effects on human well-being are particularly pronounced. Inadequate access to modern and reliable energy services has been linked to a host of adverse health outcomes, including respiratory illnesses, as well as negative impacts on education, economic opportunity, and gender equality [4-11].

Despite considerable progress in measuring and addressing energy poverty and the rich literature on linking energy poverty to underlying factors, several questions remain unexplored, including the interplay between energy poverty and social exclusion and the implications of energy transitions on marginalized communities. Energy poverty is a unique deprivation and its links to other deprivations needs study [12]. Very little is known about the joint relationships of different deprivations and their links to energy impoverishment. Drawing on the energy poverty and intersectionality literature, we address a conceptual gap on the underlying social structures and their influence on different aspects of household energy vulnerability. The misrecognition of energy poverty leads to marginalization [13].

The intersection between energy poverty and climate change mitigation and adaptation has also emerged as a salient issue of global significance [14]. Existing or prospective climate policies may have unintended consequences for the energy poor, such as higher energy prices or a loss of access to traditional energy sources. Households will experience problems when external conditions can suddenly change due to rapid energy transitions that demand coping capacity. There is a need to ensure that policies and programs recognize the differing needs and impacts for different groups, and do not exacerbate existing inequalities, and stimulate greater support for climate policy [15].

This paper proposes an intersectional framework of analysis, seeking to inform more nuanced and inclusive energy policies that prioritize the needs of marginalized communities, particularly those most vulnerable to the adverse effects of rapid energy transitions. Intersectionality, originating in the work of Kimberle Crenshaw [16], seeks to explain complex and overlapping forms of inequality and discrimination that individuals and communities may face. Intersectionality is a way to examine issues to understand how different social identity characteristics interact with each other and prevailing power structures to create and reinforce power, privilege, disadvantage and discrimination [17]. The term's presence in academia is relatively new, though it has been popular in social justice communities for more than a century [18]. It has been proposed that intersectionality can be used to generate critical and constructive insights, generating alternate knowledge on power relations and institutional practices crucial for the formation of effective and legitimate climate policy [19].

Previous attempts at applying intersectionality empirically include Winker and Degele [20] on the reciprocities between gender, race and class. Other applications of intersectional analysis relate to feminist studies and climate change [21], health inequalities [22-24], criminology [25], disadvantages to employment and internet access during the pandemic [26-27], food insecurity [28-29], political behavior and representation in different countries [30-32], and even the inequities in the US scientific workforce [33].

In the energy poverty context, the literature often examines the relative influence of singular socioeconomic factors explaining energy poverty, especially in the Global South [34-38], without examining their interactions. Recent empirical work has begun addressing this gap: Hernández and Reames document how race intersects with housing conditions and energy burden among African-American households in the US [39-40], Ngarava et al. examine coupled effects of gender and ethnicity in South Africa [41], and Robinson explores gendered dimensions of energy poverty in England [42]. Sharma et al. examine interactions between income, housing quality and energy poverty in Mumbai [43]. Empirical applications explicitly framed as intersectional have also emerged, including Mejía-Montero's work on Mexico [44], Tandrayen-Ragoobur's analysis of gender and energy poverty across 20 Sub-Saharan African countries [45], and gender-disability intersections in South Africa [46]. Theoretical explorations have developed alongside this empirical turn [47-48], while systematic reviews have begun mapping the terrain [49-50]. However, these studies treat energy poverty as a unitary outcome. No prior work examines whether intersectional effects differ systematically across energy poverty *dimensions* (access, affordability, services) or across fuel types, a gap with significant implications for measurement and targeting.

India provides a compelling context to examine intersectionality in energy poverty for several reasons: its well-documented social stratification along caste, geography, and gender lines; the availability of nationally representative household survey data with sufficient granularity; and its scale, representing roughly a quarter of the global population lacking clean cooking access at the time of data collection. However, the analytical framework and findings have broader relevance for contexts characterized by hierarchical social structures and multidimensional deprivations, including much of Sub-Saharan Africa, South Asia, and parts of Latin America.

Our research tries to identify the energy poor (particularly in a Global South context), while also seeking to examine the underlying factors and manifestations of energy poverty. We apply an intersectionality framework to scrutinize how the overlap of underlying deprivations affects energy poverty in India. We provide empirical support showcasing how different aspects of energy poverty, which is defined as the lack of access to modern energy services, can be influenced by various intersecting factors such as income, gender, race, and location. We also examine what it means to be energy poor by examining it across the 3 dimensions of reliable access, affordability and services.

We make both theoretical and empirical contributions to the energy poverty literature, using a case study of India. Firstly, we examine how horizontal inequalities (group-based disparities along caste, geography, and education [51]) interact with vertical inequalities (income-based hierarchies) in shaping energy poverty outcomes. Framing energy poverty in an intersectional context allows us to explicitly consider groups which face multiple deprivations, and which may be missed in traditional energy poverty analyses. Secondly, we explore how the multiple dimensions of energy poverty - access, affordability and energy services may differ in terms of how they are influenced by underlying inequities. Understanding these missing pieces is important to analyze the compounded vulnerability to a rapid energy transition. Notably, our third contribution is to provide empirical evidence that intersectional effects vary by energy poverty dimension and fuel type, extending beyond prior work that treats energy poverty as a unitary outcome. Our findings also supplement existing research on the distribution of energy poverty and its variation across the dimensions of access, affordability and services. We showcase how the magnitude of and relationship between these deprivations vary by the fuel.

This paper is organized as follows: Section 2 elaborates the framework of analysis we develop and use in this paper, classifying different energy sources and applications under the 3 dimensions relevant to the UN SDG 7. It also describes the choice of the case study and data sources. Our main results are showcased in Section 3, with more detailed analysis in the Supplementary Information. It provides statistical evidence of intersectionality and its variation across fuels and energy poverty dimensions, before delving into the distributional aspects and further downstream effects of energy poverty. The implications of these results for policy and research are discussed in Section 4 and our key findings are summarized, with caveats, in Section 5.

2. Material & Methods

This study explores intersectionality in the energy poverty context using an example of India. Despite considerable progress in expanding electricity access, roughly 240 million people in India still lack access to electricity, with rural communities disproportionately affected. Access to clean cooking fuels is also a significant issue in India, with an estimated 840 million people relying on traditional biomass for cooking, leading to indoor air pollution and other health issues.

To account for the multiple dimensions of energy poverty along access (reliability of supply), affordability (share of income spent on household energy services) and services (ownership of appliances or means to efficiently and cleanly convert energy to useful forms), we build on the Alternative Framework [2, 52, see Tables 1a and 1b for details]. A similar approach was demonstrated by Jain et al. [53], though it was inherently susceptible to mixing fuel type and dimension of poverty. While multiple other metrics exist in the literature, this Framework allows for easy characterization of key dimensions of energy poverty including separation of services and fuels, household conditions and supply conditions, and the ability to use publicly available household surveys across the world. These dimensions are also the key aspects relevant to attainment of UN SDG-7 goals of clean and affordable energy access. We analyze electricity and cooking fuels separately, due to the wide variation in application and the limited use of electricity in cooking in India.

Table 1(a): Application of AF to electricity access in India

Energy poverty level	Access (hrs)	Affordability (% of HH spending)	Service levels	Tier
Impoverished	0	>10%	None	Tier 0
Burdened	<8	7.5-10%	Minimal	Tier 1
Stressed	8-16	5-7.5%	Decent	Tier 2
Non poor	>16	<5%	Affluent	Tier 3

Table 1(b): Application of AF to cooking fuels in India

Energy poverty level	**Access**	**Affordability**	**Service levels**
Impoverished	Firewood, twigs, dung cakes, crop residue	>10%	Wood stove, open flame
Burdened	Coal, charcoal	7.5-10%	Chulha without chimney
Stressed	Kerosene, LPG stacking, LPG from black market	5-7.5%	Chulha with chimney
Non-poor	LPG use only	<5%	LPG/kerosene stove, electric cooking

For appliance ownership and service levels, an impoverished household is defined as one with mere subsistence services of lighting, minimal appliance ownership implying lighting, fans and phone charging. A decent level is defined as the addition of a television or means of entertainment, and addressing the refrigeration needs to a degree (an air cooler) and food preservation means (refrigerator), while the affluent tier would further have air conditioning options and other electronics. We adopt a similar structure for cooking fuels, accounting for the wider basket of fuel sources possible and unique difficulties in sourcing them, such as the black market. The appliance ownership tiers in this case evolve to consider the cooking stoves which are the means of converting the energy to service and the aspects of indoor air quality which may be affected by them. The affordability tiers in both cases are largely congruent with existing literature, though it may also vary with regional contexts.

The data for this analysis is based on the nationally representative Indian Human Development Survey (IHDS)- Round II which covered over 45000 households in 2011-12 [54]. It remains the most comprehensive, open source data set available as of now. More recent surveys like ACCESS have greater detail but lack national representation, covering only 6 states [55]. NFHS-5 (2019-21), though more recent, lacks the detailed energy expenditure, appliance ownership, and fuel collection time data required for multidimensional energy poverty measurement across the framework used here. The pre-policy timing also establishes a baseline against which the distributional impacts of these programs on intersectionally disadvantaged groups can be evaluated. The IHDS results and inferences is supported by analysis of income deciles using the National Sample Survey (NSS) Round-66 from the same time period. While the data precede major recent policy interventions such as Saubhagya (2017) and Ujjwala (2016), this study's primary contribution is analytical rather than descriptive: demonstrating that intersectional effects on energy poverty are dimension-specific. The structural inequalities examined here, rooted in caste, geography, and gender, predate and may persist beyond any single policy intervention. The pre-policy timing also establishes a baseline against which the distributional impacts of these programs on intersectionally disadvantaged groups can be evaluated.

Since income alone is insufficient to characterize the energy consumption behavior and fuel choices of households in India [34], we analyze how other socioeconomic deprivations are embedding high levels of inequality in access, affordability, service and consumption. Therefore, we examine different horizontal inequities along social class (considered as caste "C" for the purposes of this analysis and includes the federal classifications of Scheduled Castes and Scheduled Tribes in India), geography ("R", for rural-urban disparities) and education levels ("U", indicating household head's access or attendance at some college or professional education beyond high school), and how these couple with income poverty ("P"). This (non-comprehensive) set of factors is explained in Supplementary Information (SI Table S1) and was chosen based on the existing literature indicating their salience to distributional inequities in energy poverty in India and other countries [38-40, 43]. The distribution of the sampled population in IHDS across the different overlaps of these underlying deprivations in shown in SI Fig. S1, with a high share lying in the rural and less-educated category.

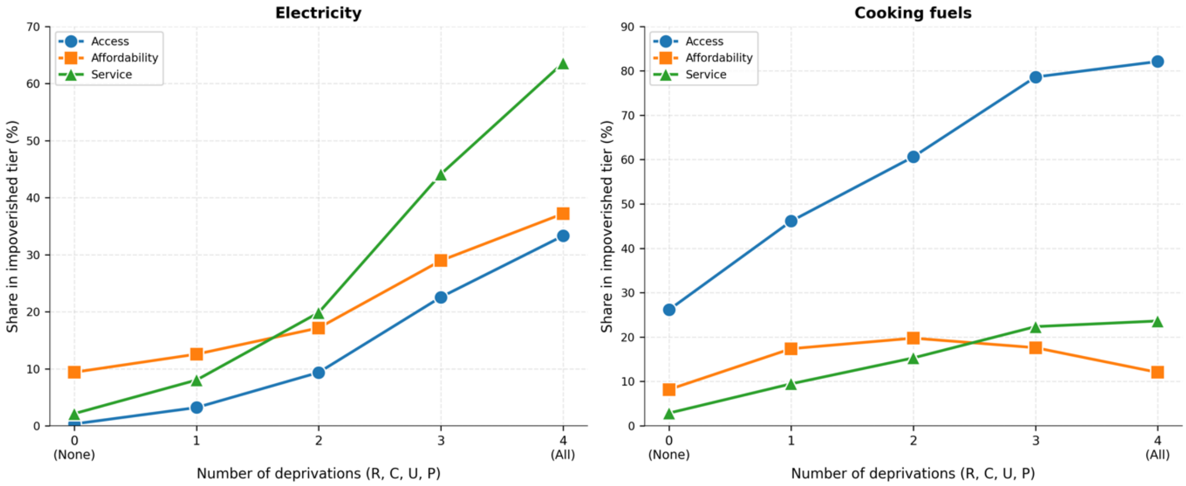
3. Results

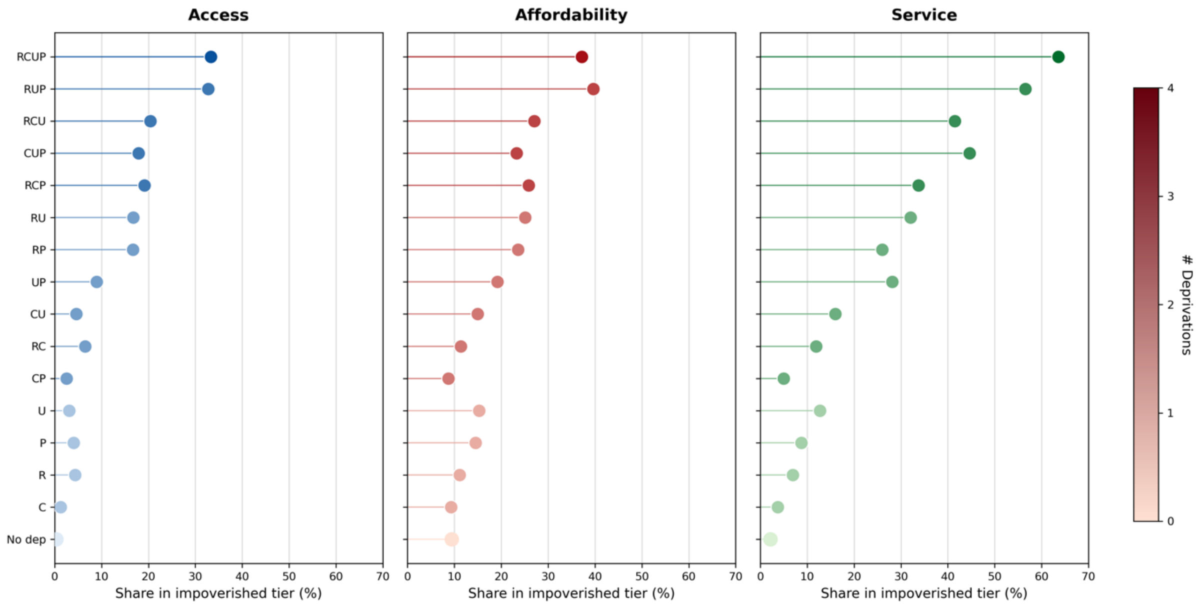
3.1 Intersectional effects of deprivations

Applying the framework described in Section 2, we find that households at the intersection of these inequities (i.e. with multiple deprivations) are more likely to belong to the lowest tier of energy poverty, with the effect magnified by increased intersectional deprivations. This finding generally holds true for both electricity and cooking fuels (Fig. 1 a, b). While only 1 in 10 households deprived along geography or caste, education or income are impoverished, 7 in 10 households which face these combined inequities may fall in the bottom tier of energy poverty for electricity. The intersectional effects vary by dimension and fuel. For example, the intersectionality relationship is reversed for affordability in cooking fuels, with households showing combined deprivations less likely belong to the impoverished tier. Also, factors such as geography have much stronger impact relative to other deprivations when connected to the access dimension for cooking fuels.

In contrast, households with "no deprivations" (implying urban, non-caste, educated, and above the income poverty threshold) are always significantly better off than the national average (SI Fig. S2), indicating positively reinforcing intersectionality.

Intersectional effects may be sub- or super-additive, and even partial overlaps along some underlying deprivations can leave households energy poor (SI Fig. S3a-b). However, as the order of overlaps increases, the proportion of energy deprived households increases.


Electricity
Cooking fuels
Access
Affordability
Service
Share in impoverished tier (%)
Number of deprivations (R, C, U, P)
0 (None)
4 (All)


Access
Affordability
Service
RCUP
RUP
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No dep
Share in impoverished tier (%)
Deprivations

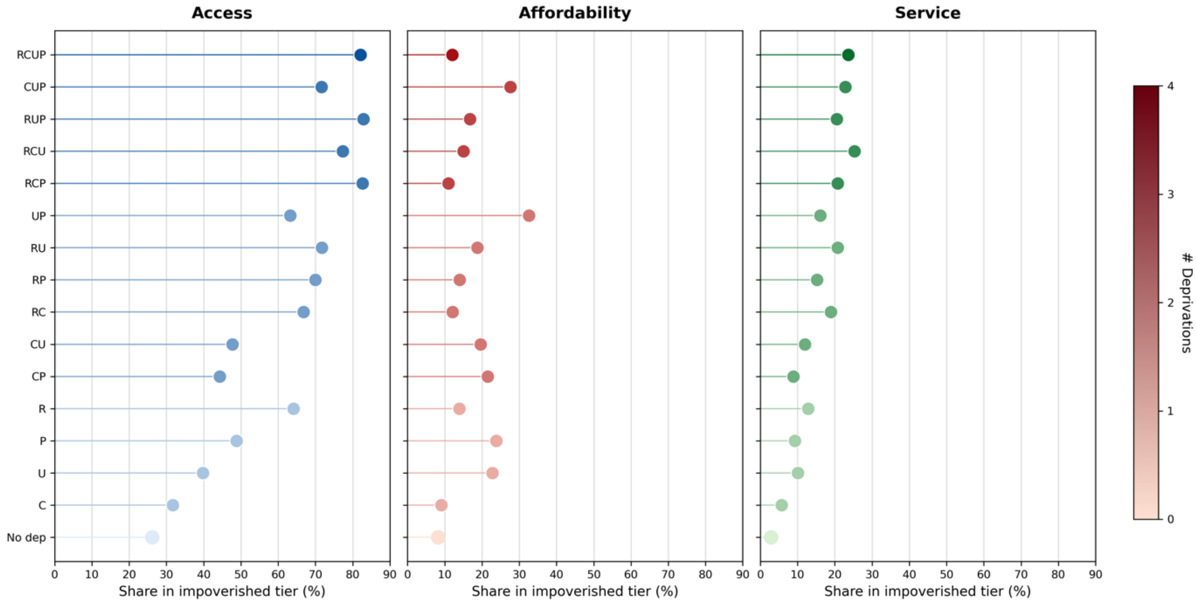

Figure 1. (a) Aggregated intersectional effects on electricity by deprivation count across three dimensions. (b) Aggregated intersectional effects on cooking fuels by deprivation count. (c) Detailed breakdown by intersectional category for electricity. (d) Detailed breakdown by intersectional category for cooking fuels. Note: Panels (a-b) show average share in impoverished tier by number of deprivations (0-4). Panels (c-d) show all 16 intersectional categories with color intensity indicating deprivation count.

A counterintuitive finding emerges for cooking fuel affordability (Fig. 1d, Affordability panel): households with urban and poverty deprivations (U+P) face the highest affordability burden (32.6%), substantially exceeding even the fully deprived R+C+U+P category (11.6%). This reflects the absence of biomass fallback options in urban settings. Rural households, despite greater access deprivation, can offset affordability pressure through free or low-cost traditional fuels. Urban poor households are effectively locked into purchasing LPG or kerosene at market rates, suggesting that urban LPG subsidy targeting warrants closer scrutiny.

Standard intersectionality theory predicts that compounding deprivations produce additive or multiplicative effects. However, we observe ‘reverse intersectionality’ for cooking fuel affordability (visible in Fig. 1d): adding rural location to a deprivation profile *reduces* affordability burden (e.g., P alone: 23.8% vs R+P: 14.0%). This occurs because rural residence enables access to non-market fuel sources. The finding suggests that intersectionality frameworks require dimension-specific calibration in energy poverty contexts, as some deprivations may be protective along certain dimensions while harmful along others.

Caste (C) shows weak independent effects on energy poverty dimensions but compounds super-additively with rural location (Fig. 1c, Service panel). For electricity service, R alone yields 6.9% impoverished, C alone 3.7%, but R+C yields 11.9% (vs 10.6% expected under additivity). This suggests caste may proxy for unmeasured correlates (asset ownership, network access) that amplify rural disadvantage, but may have less significant implications in urban contexts.

We examine the statistical significance of these results using an ordered logit approach. The consideration of the product term in a multiple regression has been shown to be a legitimate way to test for interactions [51]. We find that these dimensions are generally statistically significant at the 95% level (Fig. 2 and SI Table S2), except for the link of caste and affordability of electricity. Intersectional effects are dominant for affordability and services in electricity and have a negative correlation for affordability in cooking fuels consumption. While statistically significant, the impacts of geography dominate for access and service dimensions of cooking fuel related energy poverty.

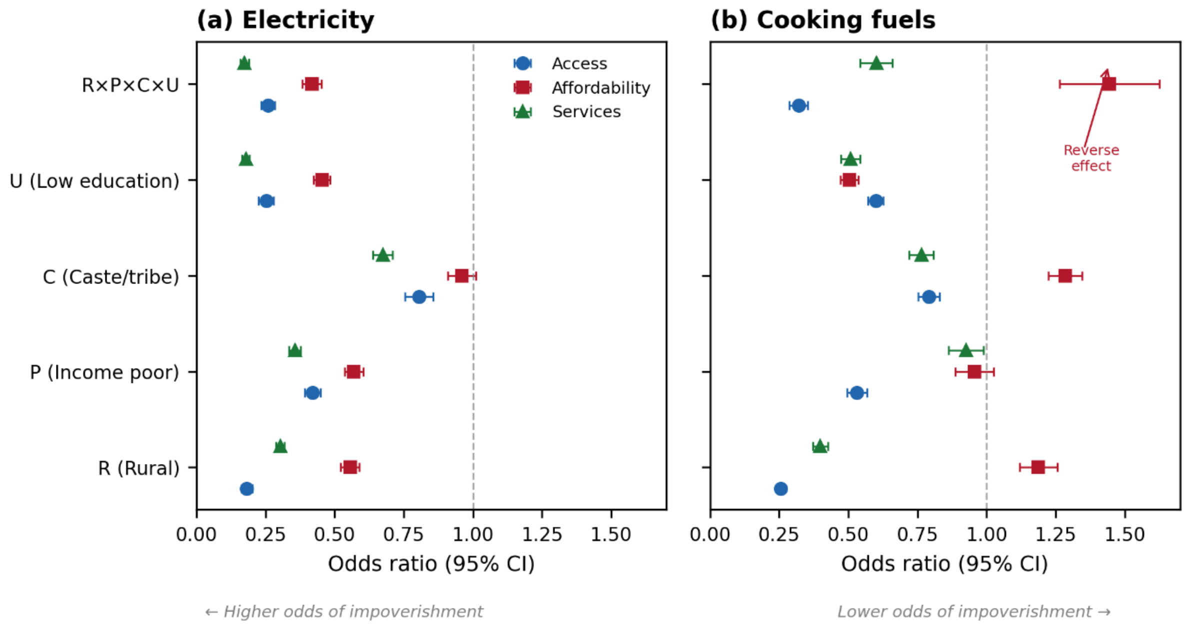

Figure 2 (a-b): Results from ordered logit regression: Coefficients with 95% significance limit

The results indicate insignificant impacts of caste on electricity affordability and income poverty on cooking fuels affordability. This is plausible since cooking fuels affordability is skewed by the prices of solid biomass fuels. While residential electricity tariffs vary by state and follow tiered consumption slabs, the price variation across social categories is considerably smaller than the variation in cooking fuel costs, where the gap between market fuels and collected biomass is substantial. The intersectional effects are statistically significant, although weaker than some of the component variables such as rural geography. As discussed above, cooking fuels affordability shows a reverse pattern due to fuel stacking behavior, with downstream implications for women's time burden in fuel collection. The detailed patterns are shown in SI Fig. S3a-b, where we observe varying degrees of additive deprivations for both electricity and cooking fuels across dimensions.

3.2 Downstream intersectional effects

The seemingly surprising effects of intersection of multiple deprivations for affordability of cooking fuels conceals the effect of fuel choice and the use of less efficient, more polluting solid fuel sources. The effects of such fuel choices actually show up in downstream intersectionality, along gender dimensions.

While the energy poverty levels overall convey significant disparities between households, individuals within households may face 'double burdens' due to layers of gender disparities. The gendered division of labor generally assigns the responsibility for the provision of household energy in relation to the spheres of influence in the household. Women are disproportionately affected by energy poverty and the conditions get worse when gender inequities intersect with R-C-U-P factors. Fig. 3(a) shows that households with a combination of deprivations spend much higher share of time on fuel collection, and even within those households, the average amount of time spent by women on fuel provisions is significantly higher when other deprivations coexist (Fig. 3b). In contrast, for households with none of the underlying deprivation factors, almost no time is spent on fuel collection even in the presence of stacking. A description of fuel collection time and tiers is provided in SI Table S3.

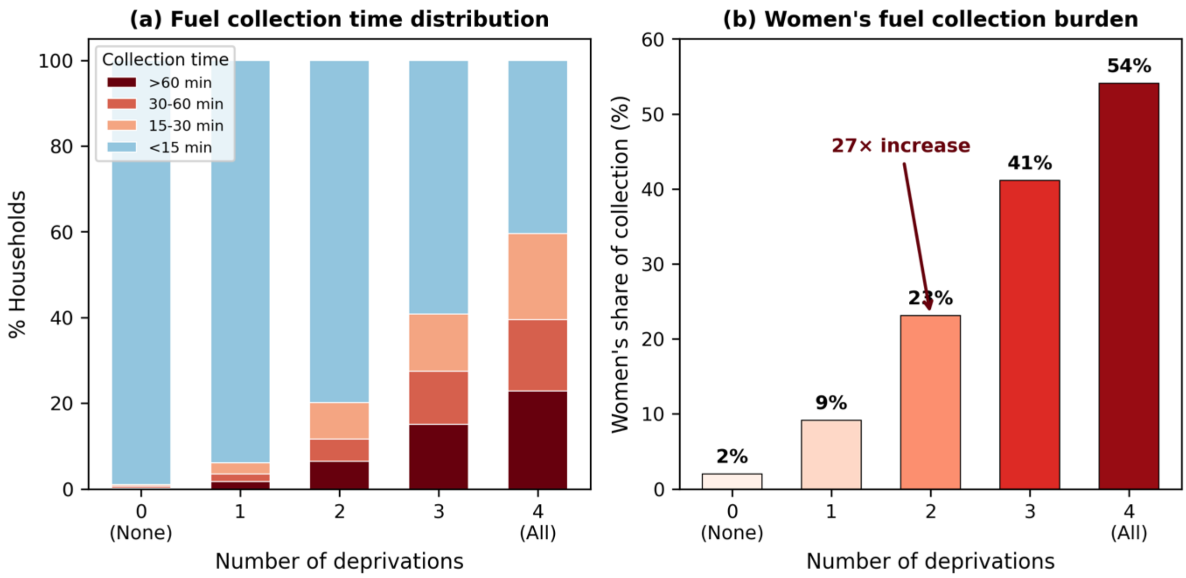

Figure 3: (a) Distribution of households across fuel collection time tiers by number of deprivations. (b) Women's share of fuel collection burden by number of deprivations. Note: Detailed breakdown by intersectional category is provided in SI Fig. S9.

Women's disproportionate vulnerability to energy poverty is linked to an array of economic reasons, particularly the uneven share of unpaid work and gender pay gaps [2, 47, 51]. Additional intersectionality of effects based on gender related to: fuel collection, security and injury risks, indoor air pollution, risks of fuel use and burns, impaired health and lack of refrigeration services, education, employment and fertility impacts [13, 50].

3.3 Distribution of multidimensional energy poverty

We also examine regional variations between states and how certain dimensions are more evident in some regions. It is found that significant proportion of households in the intermediate tiers who may have access to energy but are at the margins when it comes to reliability, affordability or services derived and remain vulnerable in a rapid energy transition. The results along 3 dimensions of access, affordability and service provision are shown separately for electricity and cooking fuels in Figure 4.

The states with the greatest share of households impoverished on the access or reliable electricity dimension are also similar for affordability and service dimensions. This indicates extreme energy poverty vulnerabilities are likely for some regions. It also implies that one dimension (such as access to reliable supply) may inhibit progress on others. For urban areas like Delhi/Chandigarh, we also note relatively high service availability being linked with increased vulnerability on the affordability metrics.

For cooking fuels, the outcomes are more complicated. Affordability and appliance ownership trends seem to be completely de-linked from clean cooking fuel access. Increased access does not necessarily imply any effects on affordability since affordability is skewed by use of cheaper traditional biomass options. The service/appliance ownership outcomes are also different since although households may own a Tier 3 appliance (LPG cookstove), there would be significant levels of fuel stacking. We find evidence of the use of a combination of fuel sources often dominated by firewood and cow dung cakes (SI Fig. S4). Even the richest income deciles employ fuel stacking, indicating affordability challenges, apart from cultural aspects related to cooking fuel choices. Fuel stacking among higher-income households also reflects the undervaluation of women's time in fuel collection and preparation, as well as incomplete information about the health impacts of solid fuel combustion, both of which reduce the perceived cost of maintaining traditional fuel use alongside LPG.

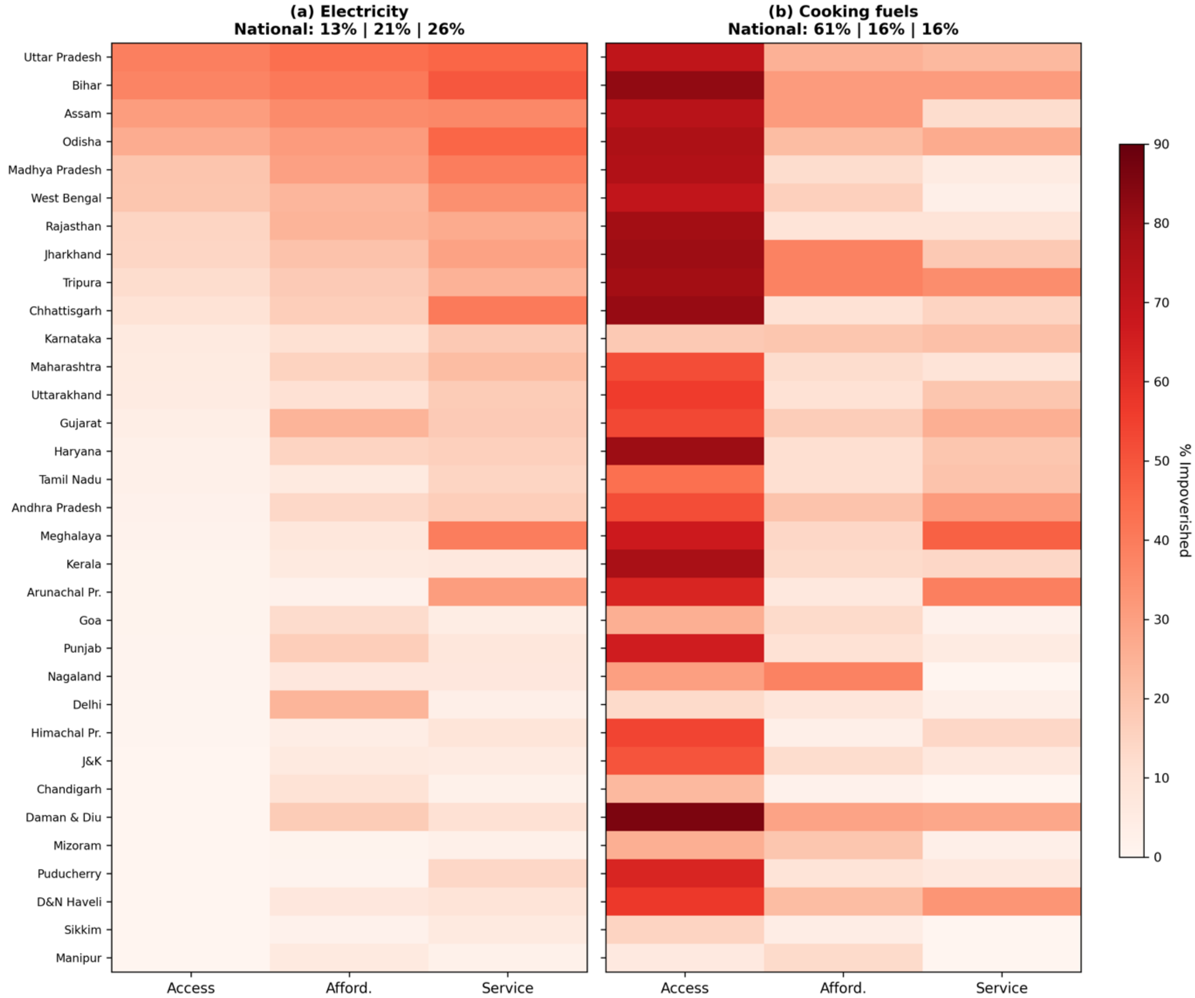

Figure 4: Indian states[1] arranged by share of households in impoverished tier for electricity access, with corresponding outcomes on affordability and service dimensions. Panel (a) Electricity. Panel (b) Cooking fuels. Color intensity indicates impoverishment rate; national averages shown in subtitles.

While there are significant regional differences, even at the national level, we find high levels of inequality in energy services by income strata (SI Fig. S5). The results confirm the lack of a strong link between income levels and energy use in India [34]. While electricity access and affordability improve significantly with income tiers, appliance ownership is still limited except for the 95th or

[1] Indian states vary enormously in population (from under 1 million to over 200 million) and area. States ranking poorly on energy poverty dimensions here also tend to rank low on broader development indicators including the Human Development Index and SDG achievement scores, suggesting correlated structural disadvantages.

99th percentile households which are able to access multiple appliances providing for a decent standard of living. The relationship is further askew for cooking fuels, where appliance ownership does improve with income, but access gains are limited, and affordability concerns remain even for the highest quantiles (SI Fig. S6).

The energy Gini index has often been used to characterize the distribution of energy poverty using consumption [57]. The Lorenz curve for electricity (SI Fig. S7) reveals high levels of inequality in consumption with a Gini of 0.43. For comparison, the Ginis for USA, Norway, Kenya and Thailand are 0.37, 0.19, 0.87 and 0.61 respectively [57]. Since the Gini index has been known to conceal the impacts on the most vulnerable, we also examine the 90/10 ratio showing that the top decile of households consumes about 49.83 times that of the bottom decile household. Similarly, the Palma ratio which computes the ratio of energy consumption by the top 10 percentiles against the bottom 40th percentile [58], shows significant distributional variation in consumption with a value of 0.44.

Albeit an imperfect metric in the context of solid fuels with lower efficiencies, we compute similar coefficients for cooking fuels using the Lorenz curve in SI Fig. S8a revealing Gini = 0.496, 90/10 ratio of 64 and Palma ratio = 0.31. For a more balanced comparison considering households which use LPG as the primary fuel, the inequality reduces substantially (SI Fig. S8b) with Gini = 0.11 and a 90/10 ratio of 28. This is due to the higher efficiency of LPG and more even distribution of cooking needs across households. However, we still find a high Palma ratio of 1.3 implying that LPG access is highly skewed towards the top deciles.

The Gini coefficient for LPG consumption (0.11) indicates near-equality among LPG users, driven primarily by the relative uniformity of cooking energy needs across households: unlike electricity, where consumption scales with appliance ownership and varies dramatically by income, cooking demand has a narrow range. However, the prevalence of fuel stacking (SI Fig. S4) suggests this low Gini also partly reflects partial rather than complete LPG adoption, with many households supplementing LPG with collected biomass. This compresses the consumption distribution without indicating equitable reliance on clean fuels. The relevant inequality thus lies not in how much LPG users consume, but in who transitions to LPG in the first place, and whether that transition is sustained. This has implications for consumption-based poverty metrics, which may understate inequality by excluding non-users.

4. Discussion

Our results show empirically that energy poverty is often a symptom of other underlying deprivations and their interactions and overlaps. It is not just the income poor who are also energy poor across dimensions. Households disadvantaged on multiple axes have higher odds of facing more severe forms of energy impoverishment and would find it more difficult to escape it as well.

The current definitions of energy poverty in the Global South often take a narrow view, resulting in policy focus around connections and delivering LPG access to low income households, while definitions in the Global North focus mainly on energy insecurity related to expenditures. Policies seeking to improve connectivity will surely have positive effects for many households but are unlikely to address all the facets of a complex problem. Vulnerable households often experience different dimensions of energy poverty bundled with other hardships.In European and OECD contexts, housing quality and energy efficiency of dwellings are well-established correlates of energy deprivation [59, 60], while in LMICs the bundling of energy poverty with caste, geography, and gender-based exclusions introduces distinct structural dimensions.

It is also found that different energy poverty dimensions for different energy services may interact differently with underlying inequities. For example, caste did not seem to have as significant a relationship to affordability as other factors such as being a rural household. However, caste often reinforces other deprivations. Horizontal inequalities result from overt discrimination, or covert discrimination through exclusivity of public goods and unequal access to resources, which may be the result of underlying political, social or economic structures. Such inequalities then persist due to limited mobility between social groups. Some social networks can amplify inequalities by fundamental mechanisms of social tie formation, sharpening social segregation, geographical impediments such as distance. Urban/rural divides and physical and administrative boundaries also reinforce social segregation. Some disparities may have historical roots, where unequal access to technology or public services are a self-reinforcing mechanism compounding energy poverty across generations.

Living in inadequately energy-serviced households has negative implications on respiratory and cardiovascular systems, apart from mental health and well-being. It is also important to highlight the resulting social exclusion where limited energy services or stigmatization hinders everyday life, including education and employment. We do not posit evidence that these interactive effects are deliberate mechanisms, but they can be the results of subtle power imbalances and not the result of explicit or intentional prejudices.

Energy poverty research and policy focused solely on vertical inequities such as income or economic factors leads to policy proposals for financially motivated interventions. Energy subsidies become a more popular option than structural measures such as energy efficiency upgrades or improving housing quality and urban planning. Since we find that energy poverty dimensions involve more than income effects, similar to the misplaced focus on connections alone, policies motivated on financial relief alone indicates only a partial awareness and recognition.

Policies flowing from the intersection of two or more axes of subordination create burdens and further disempowerment [61]. Hence, generic or 'power-neutral' approaches to an energy transition will not automatically lead to a Just Transition, and in many cases, will perpetuate existing structures of inequalities. Our results indicate support for the hypothesis that Just transitions are highly risky for households which enter the rapid transition at a disadvantage [49]. With systems producing 'winners' and 'losers', the vulnerabilities can exacerbate the varying abilities to cope and respond to energy-climate policies. Along the same lines, technology alone would not determine the benefits of an energy transition, and outcomes may differ depending on power relations and spatial and social contexts. Different forms of intersectionality will play a role in social, political, economic and cultural processes of decision making and implementation and influence the distribution of benefits and impacts.

The results also show that gender, in concert with other identities such as geography, class, education, etc. has powerful influence on how household members will experience the co-benefits or tradeoffs of energy-climate policies by shaping their ability to adapt. Our work also suggests the need for gender-aware approaches to addressing energy poverty.

We also highlight the transitional nature of energy poverty for large sections of the Indian households and its geographical distribution, as well as the high levels of inequality in access.

5. Conclusion

We show that an intersectional framework can help explore the complex and overlapping experiences beyond income levels that spur different vulnerabilities. Energy-climate policies should explicitly address the factors beyond the vertical inequalities of income, such as geography, class, race, ethnicity, education and gender which can influence an individual and household's vulnerability to energy poverty dimensions and should therefore be considered when applying solutions. The development of gender and intersectionality indicators of energy poverty would be an important step in influencing such policies to address the most vulnerable.

This study can be seen as uniting two disparate strains of analysis, energy poverty dimensions and intersectionality, in a single framework. This analysis shows, for the first time, how intersectional effects vary systematically across different energy poverty dimensions and fuel types.

We find that it not just the income poor who are energy poor, and this effect varies by the dimension considered (reliable access, affordable use or clean and efficient service). This matters for energy-climate policy success since households which are otherwise deprived would not be able to benefit from certain policies, while climate policy affecting energy consumption would also disproportionately affect such households and groups. Without addressing existing power asymmetries related to access and resource distribution upfront, these inequities will be replicated and transferred to the new energy regimes.

The findings highlight the complex and intersecting nature of disadvantage in determining energy access in India. Addressing this issue will require multi-dimensional strategies that take into account the specific contexts and needs of different communities. For example, targeted interventions that improve energy access for households in rural areas and those belonging to lower castes may be necessary to ensure that these communities are not left behind. Improving energy access across social groups and facilitating social cohesion through civic planning and supporting more equal service distribution can mend and improve outcomes for all.

Intersectional thinking can offer different potential approaches to addressing energy poverty under rapid energy transitions. While projects and processes can be designed or planned to address the most vulnerable sections with overlapping inequities, in many cases, simply bringing these aspects to their thinking can be helpful to policy makers.

We do note a few caveats, especially that we omit consideration of the mediating processes, i.e. the specific discriminatory actions through which intersectional attributes impact outcome inequalities. Hence, it does not prove a cause-effect relationship since there may be other confounding factors influencing some of these findings at the local level. Nevertheless, the observations suggest that an intersectional lens is important for examining the effects of energy policy choices and the distributional consequences of rapid energy transitions. Another important limitation here is the claim of 'comprehensiveness': we intentionally forgo efforts to identify all possible classifications and determinants, opting instead to focus on uncovering the most useful evidence. It could be inefficient and impractical to attempt comprehensive coverage since it may potentially draw from a wide variety of topics. We wish to clearly acknowledge this unavoidable limitation of this work, which aims to a more purposeful and targeted approach to the significant factors.

Future work can use this pre-policy baseline to evaluate whether Saubhagya and Ujjwala [62-63] have differentially reached intersectionally disadvantaged groups, or whether structural barriers identified here have attenuated their effectiveness for the most deprived households. This study has also not considered inequities based on religion, or the consideration of Other Backward Castes beyond the Scheduled Castes and Tribes in India and previous works in other fields have shown that these factors may also influence outcomes. There could also be regional and local variation that has not be accounted for here. Lastly, it would be imperative to examine the causal mechanisms and qualitative work in this area can contribute to improving our understanding of how intersectionality affects behavior and lived experiences of the energy poor.

Data Availability Statement

The data used in this study are from the Indian Human Development Survey (IHDS-II, 2011-12), which is publicly available through the Inter-university Consortium for Political and Social Research (ICPSR) at https://doi.org/10.3886/ICPSR36151.v6. The National Sample Survey (NSS) Round-66 data are available from the Ministry of Statistics and Programme Implementation, Government of India.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Information

Supplementary Information is available for this paper, including:

SI Table S1: Axes of deprivation and definitions used in this study

SI Table S2: Full results of ordered logit regression analysis

SI Table S3: Fuel collection time tiers

SI Fig. S1: Distribution of households across intersectional deprivations in IHDS

SI Fig. S2: Intersectionality observed in privileged households

SI Fig. S3a-b: Additive deprivation effects across dimensions (electricity and cooking fuels)

SI Fig. S4: Fuel stacking behavior across income deciles

SI Fig. S5: Distribution of households across energy poverty tiers for electricity by income

SI Fig. S6: Distribution of households across energy poverty tiers for cooking fuels by income

SI Fig. S7: Lorenz curve for electricity consumption inequality

SI Fig. S8a-b: Lorenz curves for cooking fuel consumption inequality (all fuels and LPG only)

SI Fig. S9: Fuel collection time distribution by intersectional category