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Evidence of gender inequality in energy use from a mixed-methods study in India

Meital Rosenberg[1], Daniel Erian Armanios[2*], Michaël Aklin[3] and Paulina Jaramillo[2,4,5]

Prior studies suggest that women particularly stand to benefit from increased electricity access. Yet, few have empirically tested this implicit linkage between energy access (SDG 7) and gender equality (SDG 5). More specifically, few explore how female household members use electricity once it is made accessible. Using India as an illustrative case, we conduct a mixed-methods study. We first inductively assess household appliance use by gender in Gujarat ($n = 31$). We then assess the generalizability of the use patterns identified through a representative six-state household survey (Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh and West Bengal, $n = 8{,}563$). In including use, we find that women are neither the sole nor primary beneficiaries of electricity access, even when appliances that would particularly benefit them are affordable. While energy access could improve gender equity, our study highlights intra-household power dynamics as an important boundary condition on realizing more equitable energy access.

While many studies argue that women should particularly benefit from electricity access, our results suggest that power dynamics within the household are an important boundary condition to these benefits. When looking inside the household, we find that even basic electricity access does not necessarily result in more equitable use. In analysing electricity use, our study finds that women are not necessarily benefiting from electricity access as much as men. We argue that this unequal distribution of benefits could be occurring because, while economic affordability and public policy could drive access, existing power relationships within the household seem to drive use patterns. When electrification interacts with intra-household power relationships, these dynamics do not necessarily benefit women. This observation highlights the complex interactions between two sustainable development goals (SDGs): gender equality (SDG 5) and access to clean and affordable energy (SDG 7). Providing electricity connections could improve access. However, doing so without taking social factors into account could attenuate the benefits of such access on gender equality and even reinforce inequality within the household.

With the aims of advancing a more sustainable world, the United Nations established 17 sustainable development goals (SDGs). While many studies analyse progress on these SDGs independently, there is an acknowledged dearth of studies looking at the interdependencies between goals and whether the pursuit of one SDG may reinforce (or undermine) the pursuit of another[1]. Even those studies that seek to better map the linkages between SDGs predominantly do so for resource-based SDGs (for example, food, water, energy, land and materials: SDGs 2,6,7,11–15)[2]. This focus neglects linkages between resource-based SDGs and socially oriented SDGs.

An example that serves as the basis for this study is the implied linkage between access to clean and affordable energy (SDG 7) and gender equality (SDG 5). Energy research in the Global South suggests that women receive unique benefits from heightened electricity access[3–8]. These studies argue that household electrification reduces time spent on women-dominated, time-intensive tasks (such as water or fuel collection and cooking)[9–11], as well as increases their labour participation[4,6,12–14]. These benefits are argued to accrue even at more basic electricity access tiers, defined as tiers 1–3 according to the World Bank's multi-tier definition of electricity access[15]. The common perception then is that improving electricity access should uniquely benefit women, which should help enhance gender equality.

While improving energy access can clearly better the lives of women, how exactly these linkages between energy access and gender equality manifest within the household has received less attention. Households are not unitary and efficient actors. Instead, resources are allocated though a bargaining process shaped by the social context (norms)[16] and the relative bargaining power[17] of the different household members. For instance, a study in China shows that stronger bargaining power for males is associated with higher consumption of male-preferred goods[18]. Conversely, a programme in India making marriage conditional on better private sanitation infrastructure substantially improved conditions for women[19]. Thus, in male- (female-)dominated households, resources tend to be overly allocated based on male (female) preferences. If household dynamics can asymmetrically channel consumption of goods to certain household members, then such dynamics could also plausibly affect energy use beyond access. Analysing use patterns then may help us ascertain whether electrification benefits are universally realized for both men and women across the entire household. The results of such analysis can help determiine whether electricity access enhances or undermines gender equality.

To understand electricity use patterns after electrification in the Global South, we study the case of India and use a mixed-methods approach[20]. To first ascertain whether distinguishing electricity use patterns from access is a consequential distinction, we conduct a detailed inductive study of a sample of women in Gujarat ($n = 31$), which has one of the highest rates to reliable electricity access in India. In documenting every electrical appliance in each of our respondents' households and who uses it, we identify unequal patterns of electricity use as related to gender. To assess the generalizability of our results from this initial inductive study to other parts of

[1]Hirsch & Associates, San Francisco, CA, USA. [2]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA. [3]Department of Political Science, University of Pittsburgh, Pittsburgh, PA, USA. [4]Green Design Institute, Carnegie Mellon University, Pittsburgh, PA, USA. [5]Kigali Collaborative Research Center, Carnegie Mellon University African Campus, Kigali, Rwanda. *e-mail: darmanios@cmu.edu

India, we then evaluate data from an existing representative survey of six states in Northeast India (Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh and West Bengal; $n=8{,}563$ households across 714 districts)[21]. Overall, in distinguishing use from access, we hope our study helps overcome the lack of sociological and mixed qualitative and quantitative insights that have limited how we analyse SDGs as they pertain to energy and development[22,23].

Empirical context and site justification

According to the International Energy Agency (IEA), of the approximately 1.1 billion people in the world without electricity access in 2016, about 239.2 million lived in India, which makes it the country with the largest unelectrified population in the world[24]. These low percentages of electricity access are reflective of increasing urban–rural inequality in India. On the basis of the aforementioned IEA report data and World Bank population estimates from 2016, approximately 95% of those in India without electricity access reside in rural areas, which closely mirrors urban–rural disparities found in earlier studies of the country[25]. Such a large rural–urban divide in electricity stems from India's post-independence focus on urban electrification for industrial development. India's rural electrification policies only began focusing on extending electricity grids to rural households in the 1970s (Supplementary Table 1). Moreover, such electrification efforts primarily focused on centralized grid expansion. Centralized grid extension requires sizable initial investments and more intensive maintenance due to the remoteness of rural areas. Additionally, because rural consumers tend to belong to lower income brackets, revenue generation to economically sustain such systems is minimal[26]. A persistent lack of incentives to extend service to the rural poor has thus limited the success of India's rural electrification efforts.

Despite these pervasive barriers, some Indian states have been more successful than others in expanding electricity access to rural communities. Supplementary Fig. 1 provides a map of Indian states by percentage of electrified rural households. For our initial inductive study, we focus on the state of Gujarat (green outlined state, Supplementary Fig. 1), where 62% of the population lives in rural areas and 52% of the total workforce depends on agriculture for their livelihood[27]. This state is hailed not only for extending electricity access to its rural areas but also for providing a higher amount of continuous quality power supply than most Indian states[28]. Such success is often attributed to the state's flagship energy programme, the Jyotigram Yojana Scheme (JGY). Before 2003, Gujarat's electricity supply to agricultural, residential, industrial and commercial customers ran through a single feeder. That year, the JGY bifurcated the feeders so that electricity needed for agriculture ran through a feeder separated from the power required for non-agriculture uses. By 2006, the JGY covered over 90% of Gujarat's 18,000 villages[29] and the programme has been celebrated for providing agricultural activities with eight uninterrupted hours of supply per day as well as providing constant power supply for non-agricultural uses[27]. Due to JGY, household access to low levels of electricity and the duration of such access increased and transmission and distribution losses also decreased[27].

While prior work has documented the number and quality of electrical connections in Guajarat, there is limited knowledge of how improved electrification could have varying effects for men and women. Given the importance of women in development, understanding the effect of electrification on their daily lives is particularly important. A roundtable organized by the Prayas Energy Group specifically identified the need to study issues of gender and electricity in Gujarat, given it is considered a successful case of village electrification[11]. While prior studies surmise that Gujarat's increase in rural access to electricity could help enhance gender equality through increased labour participation of women[30], it remains unclear whether gender equity improvements also occur within the household. This study aims to fill this knowledge gap. Additionally, we relied on data from a previously conducted survey[21] in states with markedly lower electrification levels compared to that of Gujarat to evaluate the generalizability of the findings from the initial inductive study. Those states are Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh and West Bengal (red outlined states, Supplementary Fig. 1).

Access to electricity is only one dimension of energy access. Because electricity access has been shown to increase economic activity that can particularly benefit women[30,31], we focus on this dimension of energy poverty and exclude others, such as access to clean cooking fuels. While excluding access to clean cooking alternatives ignores the potential to improve women's health via reduced air pollution[32], efforts to improve access to clean cooking options have usually operated separately from electrification efforts. That said, we believe the approach that we advance here to assess linkages between SDG goals can later be expanded to include these other neglected dimensions, as we propose in the Discussion.

Results

Inductive analysis—grounded study of appliance use in Gujarat. Figure 1 classifies appliance use on the basis of the gender of the household members that most use the appliance of interest. Figure 1a categorizes more male-used appliances whereby women report that their male counterparts use these appliances more than themselves. These appliances are the television, non-kitchen fans and mobile phones. Figure 1b categorizes gender-neutral appliances whereby women report that they and their male counterparts equally use these appliances. These appliances are non-kitchen bulbs, water pumps and refrigerators. Finally, Fig. 1c categorizes more female-used appliances whereby women report that they use these appliances more than their male counterparts. These appliances are the kitchen light, kitchen fan, iron, mixer, sewing machine and grinder. These insights did not seem to change if males were present during these interviews with female respondents, which suggests there is agreement across the entire household regarding these gender distinctions in appliance use (Supplementary Table 2).

When comparing appliance access in terms of ownership (left-hand side of each panel in the figure) to the gender distinctions around appliance use patterns (right-hand side of each panel), Fig. 1 shows households in our inductive study sample own more male-used appliances than female-used appliances. Gender-neutral and more female-used appliances tend to be specialized appliances (for example, grinders, sewing machines, irons, mixers, refrigerators and water pumps), which prior studies note are more affordable for those of a higher socioeconomic status[33–35]. In our study, we distinguish socioeconomic status across several indicators: payment problems versus no payment problems, landowner versus not a landowner, high versus not high castes, children versus no children. Averaging across these indicators, about 57% of the higher socioeconomic status households (no payment problems, landowner, high castes and/or have children) have gender-neutral and female-used appliances. Only about 26% of the lower socioeconomic status households (payment problems, not a landowner, not high castes and/or no children) have these appliances. Thus, there may be an association between economic affordability and the observed distinctions between access and use patterns.

Yet, electricity use patterns and access distinctions seem to persist even when we focus on those appliances that seem affordable across all households. While households across socioeconomic status levels have a mean of 3–5 fans and 3–6 bulbs in their homes (Fig. 1), only 48% of households have a kitchen light and just 13% have a kitchen fan. That so many households have multiple bulbs and fans suggests they are affordable. Furthermore, while most women remarked on the desirability of light bulbs in completing housework (respondents 2, 3, 4, 5, 6, 7, 9, 10, 16, 26 and 28), most households

a

More male-used appliances

	Appliance access						Appliance usage					
	Has appliance			Average points of use			Female usage			Male usage		
	TV	Non-kitchen fan	Mobile	TV	Non-kitchen fan	Mobile	TV	Non-kitchen fan	Mobile	TV	Non-kitchen fan	Mobile
Payment problems (*n* = 22)	82%	100%	95%	0.86	3.73	2.55	72%	91%	62%	100%	100%	100%
No payment problems (*n* = 8)	75%	88%	88%	0.75	2.63	1.25	33%	63%	43%	100%	100%	100%
Land owner (*n* = 8)	100%	100%	100%	1.00	4.75	3.38	88%	88%	75%	100%	100%	100%
Not a land owner (*n* = 23)	70%	91%	91%	0.74	2.83	1.74	50%	82%	52%	100%	100%	100%
Kids (*n* = 19)	79%	95%	89%	0.84	3.21	2.16	73%	89%	59%	100%	100%	100%
No kids (*n* = 12)	75%	92%	100%	0.75	3.50	2.17	44%	73%	58%	100%	100%	100%
High caste (*n* = 7)	100%	100%	100%	1.00	4.43	2.86	71%	71%	71%	100%	100%	100%
Not high caste (*n* = 24)	71%	92%	92%	0.75	3.00	1.96	59%	87%	55%	100%	100%	100%
All households (n = 31)	*77%*	*94%*	*94%*	*0.81*	*3.32*	*2.16*	*83%*	*90%*	*66%*	*100%*	*100%*	*100%*

b

Gender-neutral appliances (both female and male usage)

	Appliance access						Appliance usage					
	Has appliance			Average points of use			Female usage			Male usage		
	Non-kitchen bulb	Water pump	Refrigerator	Non-kitchen bulb	Water pump	Refrigerator	Non-kitchen bulb	Water pump	Refrigerator	Non-kitchen bulb	Water pump	Refrigerator
Payment problems (*n* = 22)	100%	64%	64%	4.91	0.64	0.64	100%	93%	100%	100%	100%	100%
No payment problems (*n* = 8)	100%	25%	25%	3.13	0.25	0.25	100%	100%	100%	100%	100%	100%
Land owner (*n* = 8)	100%	88%	75%	5.88	0.88	0.75	100%	86%	100%	100%	100%	100%
Not a land owner (*n* = 23)	96%	39%	43%	3.74	0.39	0.43	100%	100%	100%	100%	100%	100%
kids (*n* = 19)	100%	53%	53%	3.84	0.53	0.53	100%	90%	100%	100%	100%	100%
No kids (*n* = 12)	92%	50%	50%	5.00	0.50	0.50	100%	100%	100%	100%	100%	100%
High caste (*n* = 7)	100%	86%	71%	6.00	0.86	0.71	100%	83%	100%	100%	100%	100%
Not high caste (*n* = 24)	96%	42%	46%	3.79	0.42	0.46	100%	100%	100%	100%	100%	100%
All households (n = 31)	*97%*	*52%*	*52%*	*4.29*	*0.52*	*0.52*	*100%*	*94%*	*100%*	*100%*	*100%*	*100%*

c

More female-used appliances

	Appliance access						Appliance usage											
	Average points of use						Female usage						Male usage					
	Iron	Kitchen light	Kitchen fan	Mixer	Sewing machine	Grinder	Iron	Kitchen light	Kitchen fan	Mixer	Sewing machine	Grinder	Iron	Kitchen light	Kitchen fan	Mixer	Sewing machine	Grinder
Payment problems (*n* = 22)	0.50	0.64	0.18	0.59	0.27	0.23	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	17%	0%
No payment problems (*n* = 8)	0.38	0.13	0.00	0.00	0.00	0.00	100%	100%	NA	NA	NA	NA	0%	0%	NA	NA	NA	NA
Land owner (*n* = 8)	1.00	1.00	0.25	0.88	0.63	0.38	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	20%	0%
Not a land owner (*n* = 23)	0.26	0.30	0.09	0.30	0.04	0.09	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
kids (*n* = 19)	0.53	0.58	0.05	0.47	0.26	0.21	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	20%	0%
No kids (*n* = 12)	0.33	0.33	0.25	0.42	0.08	0.08	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
High caste (*n* = 7)	0.86	0.86	0.29	0.71	0.43	0.14	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	33%	0%
Not high caste (*n* = 24)	0.33	0.38	0.08	0.38	0.13	0.17	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%
All households (n = 31)	*0.45*	*0.48*	*0.13*	*0.45*	*0.19*	*0.13*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*0%*	*0%*	*0%*	*0%*	*17%*	*0%*

Fig. 1 | Household matrices of appliance ownership and use. a–c, Those devices that are more male-used (**a**), those appliances that are gender-neutral (**b**) and those appliances that are more female-used (**c**). To enhance readability, **c** does not include the percentage of households with the specific device, as households surveyed only own one of each of these appliances so these values are the same as the average points of use. For the inductive study, we measure appliance ownership as either percentage of households with the appliance of interest or average points of use of each device of interest. Similarly, we classify appliance use on the basis of the gender of the household members that most use the appliance of interest. Darker green indicates more use or ownership; darker red suggests less use or ownership. For the 'has appliance', 'female usage' and 'male usage' columns, darkest red represents 0%, darkest green represents 100%, and 50% is the midpoint. For the 'average points of use' column, darkest red represents 0, darkest green represents the maximum value for all of the appliances in the panel, and 0.5 is the midpoint. In both instances, the midpoint value represents the cut-off above which a majority possess or use the appliance of interest. NA signifies those households without the appliance, therefore use cannot be ascertained for these appliances. These households, namely those with payment problems ($n=8$) without these appliances, are distributed within the other categorizations. Supplementary Table 2 explores whether the presence of the male head of household affected the responses reported here and we find the responses to be qualitatively similar.

did not have any light bulbs, or fans, in the kitchen area. As with prior studies[4,33,36], we observed women were the ones predominantly using the kitchen area, so the lack of appliances in this space disproportionally affects them.

Our other inductive questionnaire results suggest that women have increased ability to work at night, which may allow them to reallocate their time budgets so as to use daytime hours to enjoy more leisurely activities or to access information more easily.

For example, 96% of respondents suggested that access to electricity makes it easier to engage in their work and 91% reported being able to work longer into the night. Furthermore, 57% of women in this study reported spending less time on household work; 65% said electrification allows them to engage in leisurely activities; and 70% reported having access to more information sources. Such flexibility in how women use their time implies that electrification gives women more autonomy over their daily routines.

However, our inductive questionnaire results, as well as our interviews and ethnographic observations, also suggest that women in our sample do not perceive having such autonomy and even perceive their male counterparts as benefitting more from electrification than they do themselves. Thus, electricity access does not seem to change the underlying patriarchal social structure in these households. Males seem still to dictate heavily household affairs and, in turn, female electricity use. Only 26% of respondents felt they have more ability to do what they want. For example, one respondent said, 'life is easier but still women are always busy with household work—not as free as men. Now I am just always working' (respondent 9). While most women reported using the television or fans, they typically stated men were the primary users. Multiple respondents said: 'I don't use the fan, that is for my children and husband' (respondent 24, 25 and 28). Others noted that their 'husband[s] use electricity the most, constantly using the fan and the television' (respondent 2, 3, 4 and 17).

We even directly observed such asymmetric male–female power dynamics as we administered our questionnaire. While power dynamics do not seem to influence what respondents say (Supplementary Table 2), it does seem influence if women choose to speak. For example, one respondent stopped answering our questions when her husband returned home towards the end of the interview (respondent 16), highlighting first-hand how these intra-household dynamics play out. These power dynamics also seem to transcend socioeconomic status. Another woman noted that despite having higher socioeconomic status, this very gathering to answer our questions would not be possible if a male was present. Moreover, she is not allowed to leave the home unaccompanied and has to send her children to buy things from outside (respondent 10). These questionnaire results, interviews and ethnographic observations all suggest that electricity access has not changed existing power relationships that heavily favour males over females.

Overall then, while women do experience benefits from electrification such as improved ease of performing household activities, these benefits seem largely restricted to activities that align with traditionally sanctioned gender roles in the local social context. The most telling observation in this regard was that, despite electricity access, most respondents felt less able to do what they wanted. This was noted in questionnaire responses, directly stated in interviews and ethnographically observed in household behaviour.

More generally, these findings suggest that household power dynamics are an understudied mechanism through which energy access (SDG 7) is linked to gender equality (SDG 5). As with seminal work in the Global North[37], the insights from our inductive study suggest that without accompanying changes to social structure, patriarchy and gender roles, even basic electricity access will do little to empower women. If these findings are valid, then our inductive observations imply the following proposition, which we will test in our subsequent generalizability analysis: electricity access is more associated with the ownership of appliances more frequently used by those with more power in the household. On the basis of the insights of our inductive study, we expected that this proposition holds even for basic electricity access. This proposition leads to the following testable hypotheses that are more specific to the patriarchal social structure that we observed in our Indian context. First, we posit that households will be associated with more male-used than female-used appliances (hypothesis 1). Second, even for more affordable appliances that depend less on socioeconomic status (light bulbs and fans), we posit that these appliances will be more associated with those locations that are more frequented by males than females (non-kitchen locations; hypothesis 2). If these trends are based on intra-household power dynamics, then we would expect that female-led households may be a key boundary condition. In these households, males do not have the same power over females in how electricity is consumed within the household.

Generalizability analysis—six-state quantitative survey study. Table 1 reports associations between more male- and female-used appliance counts and household electrification (panel a, grid electricity availability—yes/no; panel b, duration of grid electricity availability—years; panel c, any electricity connection—grids, micro-grids, diesel generator or solar system—yes/no). As corroborated through Wald tests across these models, electricity access is associated with significantly higher ownership of male-used than female-used appliances. These significant associations start after the household has received grid electricity for just 1 yr and persist even after having grid electricity for 10 yr or more (Fig. 2 and Supplementary Table 3 reports the full regression models that generated this figure). Bayesian approaches produce similar results (Supplementary Fig. 2). As with our inductive study, these results suggest that from the onset of acquiring electricity access, households seem to prioritize ownership of male-used over female-used appliances. This lends support to hypothesis 1.

One could argue that male-used appliances are often cheaper than female-used appliances and that this cost differential drives the observed prevalence of more male-used appliances. We try to mitigate for concerns of economic affordability by assessing the interaction between a respondent's gender and the availability of a kitchen on the total number of lights and fans in the household. Assessing this interaction allows us to ascertain whether we see such male–female appliance disparities even at lower tiers of electricity access. For this analysis, we restrict the main analysis to electrified households as those are the only households with electricity inputs for appliances ($n = 5{,}953$ households). Supplementary analyses where we incorporate the full sample (include non-electrified households without appliances) yield consistent results (Supplementary Table 4). As with our inductive study, most households own multiple lights and fans, which suggests that these appliances fit the budget of most families (~90% of electrified households in this survey own at least two lights, fans or some combination thereof). We infer the availability of a kitchen if the respondent noted that they cook indoors. Table 2 shows that when the house has a kitchen, male respondents are associated with significantly more reporting of bulbs and fans than female respondents (panel a). When we restrict to households with schoolchildren, these associations are even more robust (panel b). Given our inductive study and prior studies that show males are less likely to use the kitchen than females[4,33,36], these results suggest that bulbs and fans are more associated with non-kitchen locations that males frequent more than females. This lends support to hypothesis 2.

As Table 2 shows, these results do not hold for female-led households (panels c and d). If anything, these results lend some support to the idea that female respondents in female-headed households are associated with reporting more lights and fans when the house has a kitchen. As expected then, female-led households are a key boundary condition as males in these households cannot exert the same power over females in how the household consumes electricity.

In Methods, we detail a series of checks we conducted to gauge the robustness of our results. In these analyses, we explore various transformations of the dependent variables, use a wider set of controls, as well as assess the potential for omitted variable biases (Supplementary Tables 5–22). These additional analyses yielded largely consistent results with these different dependent variable

Table 1 | Linear regression models showing the effect of electrification on more male- and female-used appliance counts by household electrification

	SD cluster		D cluster		SD FE		D FE	
	Male	Female	Male	Female	Male	Female	Male	Female
Panel a: Grid availability (yes/no)								
	1.70****	0.25****	1.70****	0.25****	1.80****	0.25****	1.77****	0.25****
	(0.04)	(0.02)	(0.08)	(0.04)	(0.05)	(0.02)	(0.08)	(0.03)
Fixed effects	No	No	No	No	Yes	Yes	Yes	Yes
n	8,563	8,563	8,563	8,563	8,563	8,563	8,563	8,563
Adjusted-R^2	0.33	0.06	0.33	0.06	0.40	0.21	0.38	0.20
Wald test (χ^2) (male $\neq$ female)	1,966.90****		633.10****		1,810.32****		641.44****	
Panel b: Grid availability (yr)								
	0.08****	0.02****	0.08****	0.02****	0.08****	0.02****	0.08****	0.02****
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Fixed effects	No	No	No	No	Yes	Yes	Yes	Yes
n	8,038	8,038	8,038	8,038	8,038	8,038	8,038	8,038
Adjusted-R^2	0.20	0.08	0.20	0.08	0.28	0.23	0.25	0.22
Wald test (χ^2) (male $\neq$ female)	466.00****		225.45****		344.99****		173.75****	
Panel c: Any electricity (yes/no)								
	1.83****	0.24****	1.83****	0.24****	1.88****	0.24****	1.86****	0.23****
	(0.04)	(0.02)	(0.07)	(0.04)	(0.04)	(0.02)	(0.07)	(0.03)
Fixed effects	No	No	No	No	Yes	Yes	Yes	Yes
n	8,563	8,563	8,563	8,563	8,563	8,563	8,563	8,563
Adjusted-R^2	0.36	0.05	0.36	0.05	0.43	0.21	0.41	0.20
Wald test (χ^2) (male $\neq$ female)	3,981.93****		1,263.14****		2,616.95****		921.96****	

Significance reported via two-tailed tests with robust standard errors reported in parentheses: $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$, $^{****}p<0.001$. SD, subdistrict; D, district; cluster, errors clustered at subdistrict or district; FE, errors clustered and fixed effects included at subdistrict or district level; male, more male-used appliances; female, more female-used appliances. Pooled regression models not shown yield robust results. Missing values for grid availability (yr) analysis ($n=8{,}038$) are because the respondent either did not know or remember when they received grid electricity ($n=320$) or the house already had grid electricity before the respondent moved in ($n=205$).

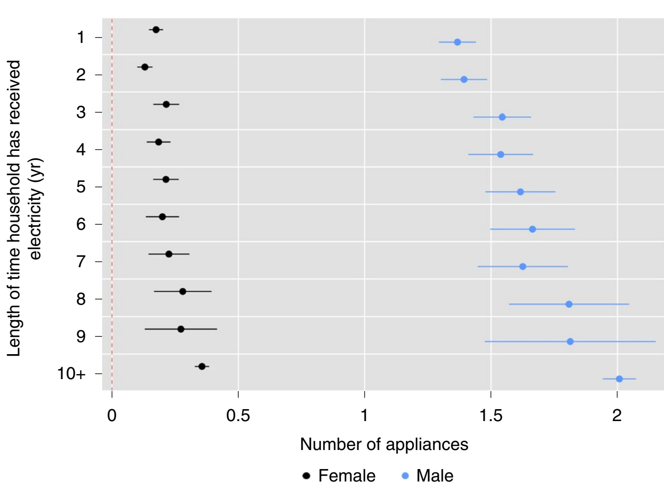

Fig. 2 | Effects of grid electricity on ownership of male- versus female-used appliances. The black dots and black error bar lines are the average counts and standard errors of more female-used appliance, respectively. The blue dots and blue error bar lines are the average counts and standard errors of more male-used appliance, respectively. These results visualize those results presented in Supplementary Table 3.

transformations and additional controls, as well as suggesting that omitted variable biases are less of a concern.

Discussion

Our study highlights the need to analyse empirically linkages between SDGs, rather than analysing them in isolation. More specifically, it identifies and tests male–female power relationships inside the household as one understudied linkage between energy access (SDG 7) and gender equality (SDG 5). In so doing, our study suggests that even basic electricity access, defined as tiers 1–3 in the World Bank's multi-tier framework[15], may not lead to more gender-balanced electricity consumption across the household. This should be a key component of overall gender equity and one that is inadequately considered in the prior literature[3–7,9–11,38]. As such, we find advancing electricity access may not overcome persistent and asymmetric power dynamics within the household and those dynamics could be detrimental to overall gender equity. Economic affordability does not seem to fully explain these results. Even though most households have multiple lights and fans, few households place them in the kitchen where women would more greatly benefit, regardless of socioeconomic level.

From a policy standpoint, our study suggests the need to accompany electricity access with measures of gender equality in electricity consumption. According to the quantitative survey used in our

Table 2 | Total fan and light bulb counts by gender and by cooking location

	SD cluster	D cluster	SD FE	D FE
Panel a: All respondents distinguished by respondent's gender				
Female (yes/no)	−0.01	−0.01	−0.44***	−0.48***
	(0.15)	(0.19)	(0.14)	(0.14)
Kitchen	0.02	0.02	0.69****	0.67***(
	(0.12)	(0.16)	(0.11)	(0.14)
Female × Kitchen	−0.45**	−0.45**	−0.20	−0.15
	(0.19)	(0.19)	(0.20)	(0.19)
Fixed effects	No	No	Yes	Yes
n	5,953	5,953	5,953	5,953
Adjusted-R^2	0.00	0.00	0.18	0.14
Panel b: Subset of respondents from households with children in school				
Female (yes/no)	−0.06	−0.06	−0.24	−0.38**
	(0.18)	(0.21)	(0.18)	(0.15)
Kitchen	0.03	0.03	0.78****	0.74****
	(0.12)	(0.16)	(0.14)	(0.14)
Female × Kitchen	−0.45**	−0.45**	−0.50**	−0.26
	(0.22)	(0.21)	(0.24)	(0.20)
Fixed effects	No	No	Yes	Yes
n	4,208	4,208	4,208	4,208
Adjusted-R^2	0.00	0.00	0.19	0.15
Panel c: All respondents distinguished by whether woman is head of household				
Woman head (yes/no)	−0.08	−0.08	−0.35	−0.27
	(0.23)	(0.19)	(0.22)	(0.18)
Kitchen	−0.06	−0.06	0.66****	0.65****
	(0.11)	(0.16)	(0.11)	(0.13)
Woman × Kitchen	0.30	0.30	0.25	0.20
	(0.31)	(0.32)	(0.30)	(0.33)
Fixed effects	No	No	Yes	Yes
n	5,953	5,953	5,953	5,953
Adjusted-R^2	−0.00	−0.00	0.17	0.14
Panel d: Subset of respondents from households with children in school				
Woman head (yes/no)	−0.40*	−0.40*	−0.50**	−0.45**
	(0.24)	(0.22)	(0.25)	(0.20)
Kitchen	−0.08	−0.08	0.68****	0.67****
	(0.12)	(0.16)	(0.13)	(0.14)
Woman × Kitchen	1.00***	1.00**	0.64*	0.70
	(0.37)	(0.41)	(0.38)	(0.43)
Fixed effects	No	No	Yes	Yes
n	4,208	4,208	4,208	4,208
Adjusted-R^2	0.00	0.00	0.19	0.15

These linear regression models show the effects on total household lights and fans of a kitchen (for example, cook indoors), respondent's gender (male/female), respondent's head of household (male/female) and their interactions. We report results based on respondent's gender (panel a) and subset to those households with school-aged children (panel b). We also report results based on whether the respondent is in a female- or male-led household (panel c) and subset to those households with school-aged children (panel d). Significance reported via two-tailed tests with robust standard errors reported in parentheses: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$, ****$p < 0.001$. SD, subdistrict; D, district; cluster, errors clustered at subdistrict or district; FE, errors clustered and fixed effects included at subdistrict or district level; male, more male-used appliances; female, more female-used appliances. Pooled regression models not shown yield robust results. Analysis restricted to households with electricity for appliances ($n = 5,953$).

generalizability analysis, about 78% of household decisions in India are made by the male head[21]. Hence, this study invites us all to consider a more use-sensitive electricity policy. For example, such an approach could inform policies that assess the impact of encouraging more equitable location-sensitive appliance placement across the household (for example, inside and outside the kitchen). Such a strategy could more equitably distribute energy resources across all household members.

That said, policymakers must also be mindful of the risks when using such a use-sensitive policy and must craft mitigation strategies. For example, similar efforts in other Global South contexts have led to severe backlash to the point that men physically abused women who were seeking to participate in such programmes[39]. In the event that future work tests, and subsequently shows, the benefits of a use-sensitive programmatic approach, such efforts require an accompanying communication strategy to increase local buy-in that conveys the benefits of doing these efforts for the entire household (for example, when conditions improve for women, everyone benefits)[40]. We believe that such a framing can help mitigate the risk of backlash. In so doing, we hope this study can better inform rural electrification policy that can both ensure greater electricity access and that the benefits of such access are more evenly distributed across the entire household.

Regardless of the particular strategy used to reduce inequality in the benefits gleaned from electricity access, our study highlights a more complex relationship between SDG 5 (gender equality) and SDG 7 (access to clean energy) than previously understood. It suggests that even basic electricity access (SDG 7) might not advance, and might even hinder, more balanced power dynamics within the household, which we argue is a key component of gender equality (SDG 5). While prior studies note clear synergies whereby better energy access tangibly improves gender equity[3–7,9–11], our study suggests that intra-household power dynamics present an understudied boundary condition that could countervail, or at the least caveat, these positive linkages between these two SDGs[1].

Our study's approach to focus on interdependencies also more generally suggests that to reach our SDG targets, we need more empirical analyses that help to identify and test factors that link different SDGs together. For example, air pollution is linked to female health[32], which suggests another linkage between good health and wellbeing (SDG 3) and gender inequality (SDG 5). Using our approach, future studies could test the linkages between these two goals through analysing and crafting interventions around other female-dominated household tasks (such as cooking) that influence pollution exposure. Our overall aim in this study, and hopefully in future studies, is to push for greater attention to be paid to local social context and the reinforcing (and counteracting) linkages it could reveal between SDG targets.

Methods

To understand electricity use patterns beyond electricity access in the Global South, a distinction that has not been adequately explored in prior research, we use a mixed-methods approach in India, an illustrative Global South case study[20]. The inductive study seeks to identify whether electricity use patterns lead to asymmetric benefits from access. We then attempt to generalize these findings through an analysis of a previous quantitative survey in a six-state region of northeast India with markedly lower rural electrification than the state used in the inductive study[21]. This follow-on quantitative analysis affords us useful variation within India for which to test the generalizability of the findings from our initial inductive study.

Inductive study. To ascertain whether there are notable distinctions between electricity access and use, particularly amongst women in rural areas, we relied on qualitative methods[41–43]. Our sample includes 31 women in 13 villages and two districts (15 or 16 women per district); no women refused to answer our questionnaire. Our small sample size for this initial inductive study was a conscious choice to trade-off depth for scale. We were concerned that discussing household decisions with potential ramifications on intra-household family dynamics was a sensitive one. Such sensitivities can increase the risk of respondent bias, whereby respondents feel pressured to provide socially acceptable answers. Biased responses that conform to social norms would therefore obscure the role of social context on electricity use. Our approach to alleviate these potential sources of bias was to triangulate questionnaire data with ethnographic observation to confirm that questionnaire responses matched observed behaviours. Triangulating these multiple sources of household data in remote communities is a difficult, time-intensive and expensive task that requires building trust with respondents. Therefore, we had to conduct our methods on-site inside the house, which limited our ability to collect data on a larger sample of households.

This small sample size is less of a concern as our inductive study aims to build rather than test theory because the dimensions for disentangling electricity use from access have not been widely explored empirically in the prior literature, especially in ways that account for gender[38]. As prescribed in qualitative social science research methods[44], our inductive study sought to maximize the variation across our cases to better facilitate such theory-building. We subsequently performed a follow-on generalizability analysis for which we could test our resulting theoretical assertions from this initial study. We performed such a generalizability analysis using an existing, more representative and larger scale survey dataset[21].

The core data for the inductive study was a detailed, 36 question, appliance questionnaire that asked respondents about the availability of electrical appliances, their location within the home and who uses them (appliance questionnaire in Supplementary Information). We used a variety of measures to ensure that our results were consistent across different markers of socioeconomic status. To distinguish between those with or without problems with payment, we asked respondents whether they are able to pay their electricity bill regularly (question 23). To distinguish between those who are landowners and those who aren't, we asked respondents if their family owns land (question 7). To distinguish between high and non-high castes, we asked the respondent's social group using contextually appropriate classifications (scheduled tribe, scheduled caste, other backward classes, nomadic tribes and denotified tribes, general and other—question 6). Any classifications other than 'general' are considered socially disadvantaged and thus marked as not high castes. To distinguish between households with children and without, we asked if they had any children under 18 (question 3). To determine the appliance percentages and point-of-use noted in Fig. 1, we asked which appliances they had in the home (question 17). To gauge use, we triangulated three sources of information. We asked for the primary user of each appliance (questions 25–29). We also asked which appliances the respondent operated on their own (question 30). If the household owned the appliance but the respondent did not operate it on their own, we made the reasonable assumption that the primary user was their partner. As a final confirmatory check, we also leveraged comments during the deployment of the questionnaire where the respondent noted particular appliances that they or their partners use in the household.

Given that these household surveys were administered on-site, we could use other qualitative techniques in tandem with this appliance questionnaire. The first technique was documenting ethnographic observations of the household as the questionnaire was administered (for example, household layout and interactions between female respondents and male partners). Second, we also used more semi-structured and unstructured clarifying questions to better understand questionnaire responses (for example, why do these differences exist? for which appliances are these differences most prominent?). Integrating questionnaires with ethnographic observation and more semi-structured and unstructured interviewing techniques helps clarify responses and better triangulate questionnaire findings with other observational and less codifiable interview response data. As with any inductive study, what characteristics are important to capture around an understudied phenomenon such as electricity use is not necessarily clear before the study's onset. We felt this more integrated inductive approach was particularly important to make sure we captured the phenomena as comprehensively and as accurately as possible.

We worked with the Gujarat Institute of Development Research to ensure survey clarity and accuracy. A local women's empowerment organization based in the state of Gujarat (ANANDI) then reviewed the survey to ensure it was culturally sensitive to the local context. Finally, we piloted the study with a translator to ensure respondents could accurately understand the survey in the local language.

Gujarati social networks were observed to be atomistic, whereby individuals tend only to trust close kin, which can bias typical respondent-driven sampling approaches. In these instances, site-based sampling is a less biased approach[45]. In this approach, data are collected through sampling a key location that the population of interest is known to frequent. Such a site can be a key local organization that provides important goods or services that the local population is known to need. As a result, site-based sampling is likely to be more representative as respondents across kinship ties are more likely to be sampled with this approach than with respondent-driven sampling.

Using this site-based sampling approach, we deployed our questionnaires through ANANDI's subsidiary organization, Mahila Swaraj Munch (MSM), which operates in the Bhavnagar district of Gujarat. MSM served as a useful site for sampling because it provides key services that most local households use, such as accessing and facilitating participation in government initiatives. MSM chose the specific villages for the study based on their familiarity with locals who use their services and their ability to access the village. Villages were also selected to ensure that the study represented a broad range of demographics and locations. These factors led to the decision to locate the study in a set of villages located near the towns of Sihor and Umrala. Using MSM contacts in the community, we first talked to women whom they assisted. We then also approached neighbouring women at random once in the village. As is typical for such grounded methodological approaches[42], this additional step allowed us to address gaps in our data collection. For example, one gap we discovered as we collected information was the lack of data along different household castes, which we were able to correct for in real-time through this additional data collection step. We primarily relied on women because they tend to spend more time in the house and are often responsible for all domestic work, so they arguably have the best understanding of household appliance use patterns.

While we were primarily interested in female responses, seven questionnaires were conducted in the presence of males. These took place when the males were at home when we arrived to do the interview. The males did not disagree with the female responses, nor were the responses substantively different from the responses other women provided without the presence of males (see Supplementary Table 2). While there is a risk that answers are affected by the presence of males, given responses with and without males remain consistent, we believe that this suggests that these responses are commonly agreed on and therefore likely to be accurate. Thus, while females were the primary focus of this inductive study, we are confident responses do reflect the views of both males and females regarding household electricity access and use. Even if the presence of males does not influence questionnaire responses, this does not preclude our ethnographic observations of the asymmetric male–female power dynamics within the household, which we document in the body of the manuscript.

All women were individually contacted through the phone or in person to explain the study and to ask for their consent in participation. Surveys were conducted in person verbally through a translator and in the presence of M.R. (the study's first author). For feasibility reasons, a female translator was not always available. To ensure the male-translated interviews did not create social sensitivity issues or reluctance, we compared the information gathered by the male- and female-translated interviews and found no systematic differences. Women were only contacted and visited once for the interview, which was typically conducted in their homes and lasted on average 20–40 min. Interviews began with fact-based questions before shifting towards more open-ended perspective questions, which is shown to be an effective approach to mitigate recall bias[46].

Finally, in addition to the women sampled, and to enhance the external validity of our findings, we also actively sought the views of other stakeholders in the area. We conducted interviews with local government officials and electrical engineers and triangulated our survey and interview results from our female respondents with these additional interviews. We also shared our results with our non-governmental organization (NGO) partners to confirm that these results reflect their observations. Overall, this iterative approach of using questionnaires, ethnographic observation and interviews in conjunction with external sources helps to ensure adequate rigour in an inductive study[42,43].

Generalizability analysis—six-state quantitative survey study. Aklin et al. previously described the details and representativeness of the survey underlying our generalizability analysis[21]. Overall, 8,563 households in six Indian states were interviewed over several weeks. As discussed previously, the six states are among those most affected by energy poverty and have lower household electrification levels than the location of our initial inductive study (Gujarat). As such, these sites afford us useful variation within India to assess the generalizability of our qualitative findings.

Beyond the opportunity to see how our inductive study scales to other parts of India with a larger household sample, evaluating the responses from this more extensive survey also helps to address limitations in our inductive study. First, this dataset has both male and female respondents. While the presence of males did not seem to substantially affect responses (Supplementary Table 2), the inductive study nonetheless has only female respondents. Second, this dataset allows us to better isolate the effects children may have on appliance use, especially since prior studies suggest school-aged children predominantly use electricity for nightly studies[47]. While 83% of participants in the inductive study noted that increased access to electricity allowed their children to study longer, we could not specifically ascertain how children affected appliance use. To capture these dynamics around children, we additionally subset respondents in this dataset with at least one child in school to determine whether this has any impact on gender-based appliance use. Third, this dataset has both male- and female-led households. In our inductive study, except one household led by a female widow, all other households were male-led. To capture the dynamics around women-led households, we additionally code for women-led households in this dataset to determine whether there is any differential impact.

To ensure that the large-scale quantitative survey dataset that we use for this generalizability analysis is comparable to our inductive study, we first sought to confirm the gender distinctions around appliance use observed in the initial inductive study. As in the inductive study, we use total televisions and mobile phones in the household as more male-used appliances and total refrigerators and water pumps as gender-neutral appliances. For females, we did not have separate categories for sewing machines, grinders and mixers. The reason is that rural residents in this six-state area have less electricity access, so these appliances were considered too high-end for this area. For example, only 69 out of 8,563 (0.81%) respondents reported having a grinder. As such, for females, we used appliances with an equivalent gender distinction to those in our inductive study but more commonly available in the six states. On the basis of our inductive study findings and prior studies[7], this led us to define an equivalent set of more female-used appliances for the generalizability analysis as total irons, washing machines and stoves.

The main text reports linear models, which are all separately estimated as pooled (not shown), as clustered errors at both the district and subdistrict level, and finally as including subdistrict or district-level fixed effects. They all have the form:

$$\text{Number of appliances}_i = \alpha_j + \beta\text{Grid}_i + \varepsilon_i$$
$$\text{Number of appliances}_i = \alpha_j + \beta_1\text{Gender}_i + \beta_2\text{Kitchen}_i + \beta_2\text{Gender}_i \times \text{Kitchen}_i + \varepsilon$$

where the number of appliances is defined above and is separately computed for male and female appliances for Table 1 and for total fans and lights for Table 2. For those analyses with the head of household, we replace gender (female coded as "1") with head (female-led household coded as "1"). The outcome varies by household respondent i; α is an intercept for each subdistrict j (or district depending on the analysis); and ε is an error term. The parameters are estimated with least squares. Whenever our models include subdistrict intercepts, we are looking at the within-subdistrict variation. In some models, the standard errors are clustered by subdistrict, which relaxes the assumption that the errors are uncorrelated within these units. To ensure the robustness of our findings, we also run the main linear models based on the district rather than subdistrict level.

We also estimate Bayesian hierarchical versions of our main models. Hierarchical Bayesian models are useful where the data are structured in groups containing a small number of observations as estimating many fixed effects can greatly reduce degrees of freedom[48]. This allowed us to conduct our analysis at the village level, which is more granular than the subdistrict level. In a Bayesian framework, we model unknown parameters by combining prior beliefs about their value and the data. By 'parameters', we mean the effect of electricity access on male and female appliances as well as geographic effects (for example, β and the other parameters above). We start with a prior distribution for each parameter which represents our ex-ante belief. Here, the priors we used were conservatively distributed as Normal with a mean of zero and a standard deviation scaled by the outcome variable. Then, the dataset is used to update these prior beliefs. The result is a posterior distribution that presents our best guess as to the true value of a parameter. The results (Supplementary Fig. 2) are similar to our main findings.

Generalizability analysis—robustness checks. To further assess the robustness of the results reported in Tables 1 and 2, we conducted a series of checks. First, given that our main estimates rely on variation within districts or subdistricts, we control for additional potential confounders: total rooms in the house, total adults, total children, total school-aged children, monthly household expenditures and education level. This helps to include household size and composition effects that could lead to spurious findings. Second, we re-ran our models with logarithmic and inverse hyperbolic sine-transformations of our dependent variable to ensure a more continuous outcome variable. These models all mostly gave consistent results (Supplementary Tables 5–14).

Finally, we checked for the possibility of omitted variable bias. We take two approaches to gain insight into this. Our first approach recognizes that knowing or collecting all potential omitted variables is impossible but that we can possibly gain insight into how strong such an omitted variable would need to be to generate concern. This can be done as follows: we can imagine how strongly correlated a hypothetical omitted variable is with our dependent and independent variable of interest. Then, we can estimate what would happen to our point estimates if such a variable would be added to our statistical models; this process uses the sensemakr package in R[49]. Using household expenditures to illustrate this approach, we find that our results would remain similar. Even adding an omitted variable three times as important as our current household expenditure data would not qualitatively change our main findings (Supplementary Table 15).

Our second approach probes into concerns of omitted variables by exploring whether a variable not in our models is correlated with our dependent and our independent variable. This approach is also more appropriate for our models with interaction terms. To do this, we take each of our model residuals and assess their correlation both to our model's predicted values as well as to its controls. When we do this analysis with two control variables of importance—household expenditures and education—none of our plots suggests high correlations (Supplementary Tables 16–22). This is the case when we correlate residuals from models that either include or exclude these controls. While we cannot rule out all possible sources of omitted variable bias, we can at least ascertain that such a variable would need to be more than three times as important as household expenditure, one of our more consequential control variables, for it to be a cause of concern. Even when we exclude this control and education level from our analysis, the model residuals have little correlation with our predicted values. We believe the likelihood that our models omit an important variable is low and we remain confident that omitted variables are not a major threat to our analysis.

Ethics. In interviewing the women for this study, we obtained informed consent from all participants. The study's protocol was approved by the University of Pittsburgh's Institutional Review Board (study no. PRO15129236, 5/19/2016, exempt status) and complied with all other additional relevant ethical regulations.

Data availability

The data for the generalizability study conducted in six Indian states are publicly available at Harvard Dataverse (https://dataverse.harvard.edu/dataverse/IndiaAccess).

Code availability

The code used to generate the results is also made available here: https://doi.org/10.7910/DVN/DRVBZY. The data for the inductive study in Gujarat (questionnaire data, interview data and ethnographic observations) are available from the corresponding author on reasonable request.

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Author contributions

M.R. developed the initial concept for the overall study and designed, executed and contributed to the writing of the inductive portion of the study. D.E.A. contributed to the research design and the data analysis for the inductive study, to the research design and the data analysis for the generalizability study, and to the overall writing of the paper. M.A. contributed to the research design and data analysis of the generalizability study, as well as to the overall writing of the entire paper. P.J. contributed to the research design for the inductive study and contributed to the overall writing of the paper.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to D.E.A.