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Evidence of multidimensional gender inequality in energy services from a large-scale household survey in India

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Energy access delivers broad socio-economic benefits, but few studies have examined how benefits are allocated within the household. Here we conduct a large-scale survey with 4,624 respondents across six Indian states to provide results on intra-household differences across multiple outcome dimensions of energy service, including knowledge, satisfaction, utilization and opinion. Using a Women's Empowerment Index (WEI) to measure household-level gender equality, we find that women in low-WEI households are less aware of energy services and use less electricity than their spouses. This awareness gap manifests in differences in satisfaction, as women in higher-WEI households show more concern with energy services and fuel sources. Overall, these results signify that the 'one-size-fits-all' approach of providing energy access may not effectively meet the goal of sustainable energy for all. Bridging the gender gap through targeted information and learning campaigns that empower and educate women could unlock additional support for sustainable energy policies.

Energy access is broadly accepted as beneficial to economic development, but few studies have examined how benefits are allocated within the household, especially in the Global South. An extensive literature has shown that access to clean energy delivers broad socio-economic benefits, such as increasing per capita income, reducing poverty, promoting children's educational attainment, lowering health risks from household air pollution and increasing media access[1–6]. Women, in particular, stand to reap large benefits from clean electricity and cooking energy in terms of time use, access to information and intra-household relations[7–14]. But the gains are highly context specific and not universal[15]. Little is known about how intra-household dynamics contribute to the heterogeneous relationship between gender and energy access across studies. A better understanding of the gender gap in energy access and use could unlock additional support for sustainable energy policies.

To study the gender gap in energy access and use in the Global South, we conduct a large-scale survey with 4,624 respondents across 58 districts and six states in India to provide results on intra-household differences across multiple outcome dimensions of energy service, including knowledge, satisfaction, utilization and opinion. Home to 17% of the world's population, India has made remarkable progress towards universal electricity access in recent years. But substantial gaps remain in women's economic participation and health[16]. The six sample states, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Rajasthan and Uttar Pradesh, are among those with the lowest socio-economic conditions and highest health burdens from household air pollution. As such, our findings could provide new insights on making sustainable energy policies more inclusive in the Global South.

Because households may differ in many unobserved characteristics affecting both energy access and gender-specific outcomes, a naive comparison between males and females across households in the cross section is likely to yield biased estimates for the gender gap in energy access and use. To address this challenge, we survey women and their spouses in the same household, thus allowing for intra-household comparisons while minimizing the influence of time-invariant unobservables at the household level. To understand how existing power dynamics between men and women in the household affect gender disparities, we build upon existing global instruments[16–20] to create a Women's Empowerment Index (WEI) to measure the level of gender equality within households in our sample.

We find evidence of multidimensional gender inequality in energy services within Indian households. Women in low-empowerment households are significantly less likely to have heard about energy services. The gap in awareness manifests in differences in satisfaction. Women in higher-empowerment households tend to be more unsatisfied with energy services, such as home and community lighting, compared with their husbands. Moreover, we find that the overall progress in electricity access does not eliminate the gender gaps in usage. Women in low-empowerment households are less likely to use electricity during most of the day except in the morning between 6 a.m. and 12 p.m. This echoes prior findings that access to electricity tends to favour men in the household over women[21,22]. Power dynamics between husbands and wives is an important mechanism behind the gender inequality in awareness and usage, as women in high-empowerment households have the smallest gap. Differences in awareness, usage and satisfaction also generate divergence in preference and opinion. Less-empowered women show stronger preferences for government subsidies in grid electricity over kerosene and solar home systems. Empowering women has the potential to unlock additional support for sustainable energy policies by raising awareness and agency.

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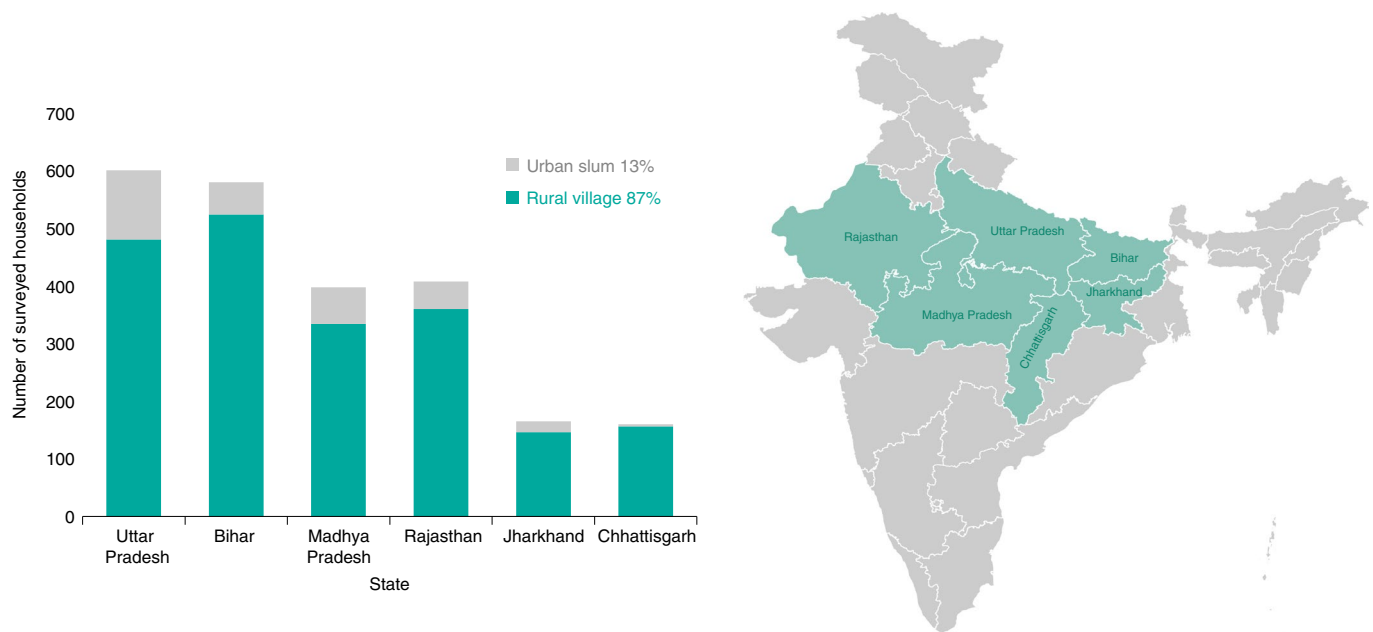
Fig. 1 | Geographic coverage and key statistics of the Gender Perception Survey for Energy Access and Use. We conducted a large-scale 45-minute survey using a stratified multistage probability sampling design. The survey encompasses 2,312 rural and urban slum households (4,624 individuals) across six Indian states, 58 districts, 506 rural villages and 79 urban slums. The states—Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Rajasthan and Uttar Pradesh—are among those with the lowest socio-economic conditions and highest health burdens from household air pollution in India. In each household, we surveyed the primary cook and their spouse to analyse within-household gender differences in the awareness, satisfaction, usage and opinion of energy services. Data for administrative boundaries adapted by Anuj Tiwari and publicly available on GitHub.

Energy access and gender equality

To build a more sustainable and just world, the United Nations adopted the 2030 Agenda for Sustainable Development in 2015 and developed 17 Sustainable Development Goals (SDGs) to end extreme poverty, reduce inequality and protect the planet from irreversible climatic change[23]. The SDGs gained broad consensus amid rising tensions between economic growth and environmental degradation at both global and local scales. They became important report cards to achieve the triple bottom lines of economic development, environmental sustainability and social inclusion[24]. Among them, gender equality (SDG 5) and affordable and clean energy (SDG 7) are crucial measures of the progress towards inclusive and sustainable economic development.

Against this backdrop, India has made remarkable progress towards universal electricity access in recent years. Since 2000, more than 900 million citizens have received electricity connections[25] thanks to ambitious government programmes such as Saubhagya. Nearly 97% of households are now connected to the grid, and the average daily supply is 20.6 h (ref. [26]). Despite near-universal access, considerable challenges remain for achieving the SDG 7 goals of reliability, affordability and sustainability. Unanticipated outages and billing/metering issues are common in rural areas due to high transaction costs[26]. In addition, 80% of the current energy demand is still being met by coal, oil and solid biomass, and more than 300 million Indians rely on solid fuels for cooking[25,27]. These statistics highlight the need to improve our understanding of effective government policies for accelerating the transition towards more sustainable energy sources.

Gender inequality remains one of the greatest challenges to unlock the full potential for human development. Progress has slowed in recent years[28], and based on current trends, it would take 257 years to close the gender gap in economic participation[29]. In India, women's empowerment has lagged behind the progress in economic development[25]. The 2021 Global Gender Gap Index[16]

ranks India 140 out of 156 countries and identifies substantial economic participation and health gaps. The economic gender gap, in particular, has widened over recent years. This could have important implications for the energy sector through reductions in appliance demand, clean cooking access and affordability and women's health outcomes[25,30]. SDG 5 recognizes that economic development cannot be sustainable if one-half of humanity continues to be denied their full human rights and opportunities.

Improved energy access has been shown to deliver broad benefits to women who spend more time on paid work, engage less in labour-intensive tasks and have more flexible housework schedules[2,7–12,31–33]. Increased energy access also challenges gender norms when women have the opportunity to work in non-traditional roles outside the home, such as solar engineers[34]. In addition, modern appliances give women access to the media and information[13]. These benefits, however, are not guaranteed and depend on the types of opportunity that emerge[34–36]. For instance, electricity connections in rural South Africa increased women's employment while reducing their relative earnings compared with men[2]. On the contrary, in India, electrification was shown to benefit those engaged in paid work the most[37,38]. Little is known about how intra-household dynamics contribute to these observed differences in the interconnection between gender and energy access across studies.

WEI

To understand the interconnections between gender equality and energy access, we designed, conducted, and analysed a large-scale 45-minute survey[39] with 2,312 rural and urban slum households (4,624 individuals) across six Indian states: Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Rajasthan and Uttar Pradesh. The survey includes modules on electricity, lighting and cooking. In each household, we surveyed the primary cook and their spouse to analyse within-household gender differences in the awareness, satisfaction, usage and opinion of energy services. Figure 1 depicts the

geographic coverage of the survey and key statistics. Supplementary Note 1 provides the survey design.

We create a WEI to measure the level of gender equality within households in our sample. Following Kabeer[40], we broadly define empowerment as the ability to make choices. Drawing on existing instruments for measuring the gender gap[16–20] and their visualizations[41], our index encompasses six dimensions on knowledge, social norm, work, time, money and power (Fig. 2a). While the dimensions in our index are similar to the Gender Equality Index[17], it is not directly comparable because the latter is for country-level comparisons. We contribute to the literature by providing a direct measure of individual empowerment in rural and urban slum areas in India. This echoes recent efforts by the United Nations Entity for Gender Equality and the Empowerment of Women (UN Women) and United Nations Children's Fund (UNICEF) to develop a women's empowerment index for Kenya[42]. Some of the domains we choose, especially time, money and knowledge, are also identified in prior work as important measures of empowerment[43]. But unlike our WEI, which measures within-household gender equality, the W+ Standard by WOCAN[43] is a fee-based certification programme that measures and evaluates the impact of climate and development projects on women's empowerment. Our approach to survey both women and men within the same household draws a parallel to the Women's Empowerment in Agriculture Index[19,20]. Building upon the Women's Empowerment in Agriculture Index, our index goes beyond the agriculture sector to encompass more indicators, such as social norm and knowledge, in an effort to construct a more inclusive and thorough measure of women's empowerment within the Indian context.

Kabeer[40] conceptualizes empowerment in terms of *resources* (pre-conditions), *agency* (process) and *achievements* (outcomes). The design of our index is inspired by this conceptualization. We consider the different dimensions as interdependent and not easily separable in determining the validity of the empowerment index. In other words, it is important to triangulate between dimensions and not evaluate them in isolation to avoid interpretative bias. For each indicator, households are ranked as low (1), medium (2) or high (3) empowerment based on their survey responses. Methods and Supplementary Note 3 provide the rationale behind each dimension. Supplementary Table 8 shows the cut-offs used for each indicator. Fig. 2b compares the empowerment scores across indicators for low, medium and high-WEI households. While more-empowered households tend to score higher on all dimensions, they still have considerable gender gaps in power, money and work. Supplementary Tables 3–6 show survey summary statistics. On average, less than 12% of female respondents have a non-farm labour job, and the majority (78%) of them engage in unpaid housework. The lack of a paying jobs and financial independence hinder women's agency. Less than 50% of women reported making decisions about their health, family visits or children's education.

Across-household gender inequality in energy services
We find descriptive evidence of inter-household gender differences in the cross-sectional data. Figure 3a shows that female respondents tend to be less aware of energy services across the board, even those that are targeted towards women, such as the *Pradhan Mantri Ujjwala Yojana* (PMUY) scheme. PMUY was launched by Prime Minister Narendra Modi in May 2016 with the goal of safeguarding women and children's health by providing them with liquefied petroleum gas (LPG), which is a flammable mixture of hydrocarbon gases used as heating and cooking fuel. LPG produces less particulate matter and is considered a cleaner cooking fuel compared to solid fuels. Under the scheme, 50 million LPG connections have been issued to women in households below the poverty line[44]. Women tend to be more satisfied with community lighting and home electricity and less so with LPG and primary fuel availability

(Fig. 3b). They have a stronger preference for government subsidies on grid electricity at home. Consistent with prior findings on the gender disparity in household electricity usage[22], women in our sample tend to use electricity at different times of the day and for different appliances than men. In particular, we identify TVs, fans and chargers as female-intensive appliances. These initial observations suggest that even though 94% of households (Supplementary Table 3) in our sample are connected to the grid, basic access may not translate into gender-balanced awareness, satisfaction, usage or opinion of these energy services.

Within-household gender inequality in energy services
Our analysis aims to investigate within-household gender inequality in energy services along the dimensions of awareness, satisfaction, usage and preference/opinion. The corresponding survey questions are: Awareness—Are respondents knowledgeable about energy services? Satisfaction—Are respondents satisfied with energy services? Usage—During what time of the day do respondents use electricity, and what appliances do they use? Preference—Which energy services do respondents prefer the government to subsidize? Opinion—Do respondents consider cookstove smoke harmful for health?

Comparing outcomes between men and women across households in the cross section could result in biased estimates for the gender gap[45]. For instance, observed usage gaps between men and women in the cross section could reflect unobserved social status or family wealth. Our research design improves upon previous work and addresses this empirical challenge by surveying the primary cook, of which 99.8% are females, and their spouses in the same household. This allows us to consider within-household variations and control for time-invariant household-level confounders through fixed effects. We estimate linear probability models shown in Methods equation (3) that includes the gender dummy and interaction variables of gender and the WEI.

In Fig. 4 and Supplementary Tables 9–14, we find significant gender disparities within the household across four outcome categories: awareness (Fig. 4a), satisfaction (Fig. 4b), time and appliance use (Fig. 4c,d), preference for government subsidy and opinion on the harmful effects of smoke (Fig. 4e,f). It shows the differences in outcomes, that is, marginal effects, between females and males (treated as the baseline) within the same household and controls for household-level confounders through fixed effects. Each colour represents a different outcome variable for a given panel, and the coefficients and 95% confidence intervals are shown.

Women are less aware of common energy services (Fig. 4a), even those that are targeted towards women, such as PMUY. Women in low-WEI households are significantly less likely to have heard about microgrids, PMUY, solar home systems and the *Pradhan Mantri Sahaj Bijli Har Ghar Yojana* (Saubhagya) scheme. Saubhagya was launched by Modi in September 2017. Under the scheme, all un-electrified rural households and poor urban households without electricity can receive free or subsidized last-mile connections. The goal is to achieve power for all households by December 2018. As of 2019, all 'willing' households in India have been electrified[26,46]. While women in higher-WEI households tend to be more knowledgeable, the gender gap is still evident. The gap in awareness manifests in differences in satisfaction (Fig. 4b). While less-empowered women tend to be more satisfied with community lighting, home electricity, primary fuel and LPG than their husbands, more-empowered women tend to show a greater level of concern with these energy services and fuel sources. This indicates that women with more agency and bargaining power may have higher expectations for their household energy situation.

Next, we turn to gender differences in the time use of home electricity and the usage of appliances. The vast majority (94%) of households in our sample have grid electricity. The average household
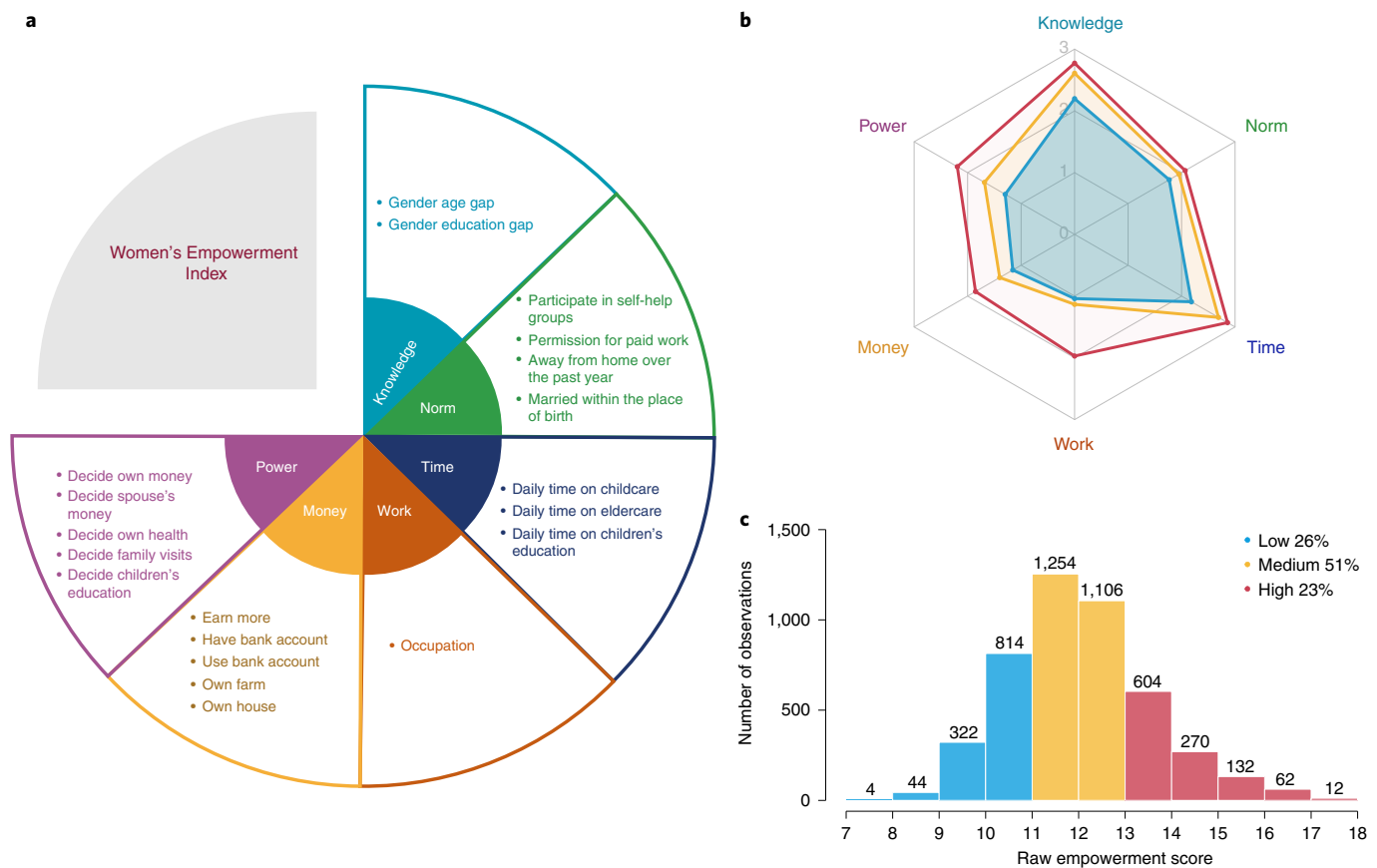
a

Women's Empowerment Index

- Gender age gap
- Gender education gap

Knowledge

Norm
- Participate in self-help groups
- Permission for paid work
- Away from home over the past year
- Married within the place of birth

Power

Time
- Daily time on childcare
- Daily time on eldercare
- Daily time on children's education

Money
- Decide own money
- Decide spouse's money
- Decide own health
- Decide family visits
- Decide children's education

Work
- Occupation

- Earn more
- Have bank account
- Use bank account
- Own farm
- Own house

b

c

Fig. 2 | Women's Empowerment Index (WEI). a, Indicators used to create the WEI are grouped under six dimensions on knowledge, work, time, money, power and social norm. For each indicator, households are ranked as low (1), medium (2) or high (3) empowerment based on their survey responses. We then aggregate across all six indicators to create a composite index that corresponds to low, medium and high women's empowerment. **b**, Spider graph showing the empowerment score for households with low, medium and high WEI against the six dimensions. **c**, Distribution of the raw empowerment scores that range from 7 to 18. Bar height represents the number of observations with the corresponding raw empowerment score, i.e. 1,254 respondents have empowerment scores of 11. There are 592 households ($n = 1,184$) or 26% of respondents in the low-empowerment category (raw score ≤ 10), 1,180 households ($n = 2,360$) or 51% of respondents in the medium-empowerment category ($11 \leq$ raw score ≤ 12) and 540 households ($n = 1,080$) or 23% of respondents in the high-empowerment category ($13 \leq$ raw score ≤ 18). Supplementary Table 8 shows detailed breakdowns of the key indicators and their assigned levels.

has been connected for nine years and has electricity available 19 h per day (Supplementary Table 3). This progress in energy access, however, does not eliminate the gender gaps in usage. We find that women in low- and medium-WEI households are less likely to use electricity than their spouses during most of the day except in the mornings between 6 a.m. and 12 p.m. (Fig. 4c). Electricity use in the morning is particularly pronounced for women in low-income, rural and newly connected households (Supplementary Tables 33–41). We define a new grid user as a household that has been connected to the grid for five years or less. This echoes prior findings that providing electricity access per se may not overcome the existing gender imbalance in consumption within the household[21,22]. Power dynamics between husbands and wives is an important mechanism behind the gender inequality in usage, as women in high-WEI households have the smallest gap in time use.

In addition to time use, we find gender differences in the usage of specific household appliances. We identify TVs, fans and charging devices as female intensive in usage (Fig. 4d). 'Female intensive' means women are more likely to use grid electricity for these appliances. This should not be interpreted as duration or frequency of usage, as we do not know how often they use a specific appliance. As 97% of female respondents are primarily housewives who spend a considerable amount of time around the house, this implies

that any power outage would affect women more than men. These results expand on previous findings[22] to shed new light on the gender differences in appliance use. They also highlight the importance of accounting for household-level unobservables such as economic and social status that could affect appliance adoption and ownership. Having a much larger sample size and household fixed effects allow us to identify a different set of appliances as female intensive.

To investigate if gender inequality in awareness, time use and satisfaction generate divergence in preference and opinion, we examine preferences for government subsidy and opinion on the harmful health effects of smoke. As a clean cooking fuel, LPG is very popular among both genders with 91% of women supporting a subsidy. In low-WEI households, however, women's preference for a LPG subsidy is slightly lower than that of men. This implies that less-empowered women may have lower opportunity costs for biomass collection. In contrast, in the absence of a cheap alternative to electricity, women tend to favour subsidies for grid electricity more than their spouses (Fig. 4e). Perhaps due to the lack of awareness (Fig. 4a), women in low-WEI households put the least emphasis on subsidizing solar home systems. To the extent that knowledge and understanding induce adoption and usage, raising awareness may help generate more support for renewable energy sources. These results highlight that women stand to
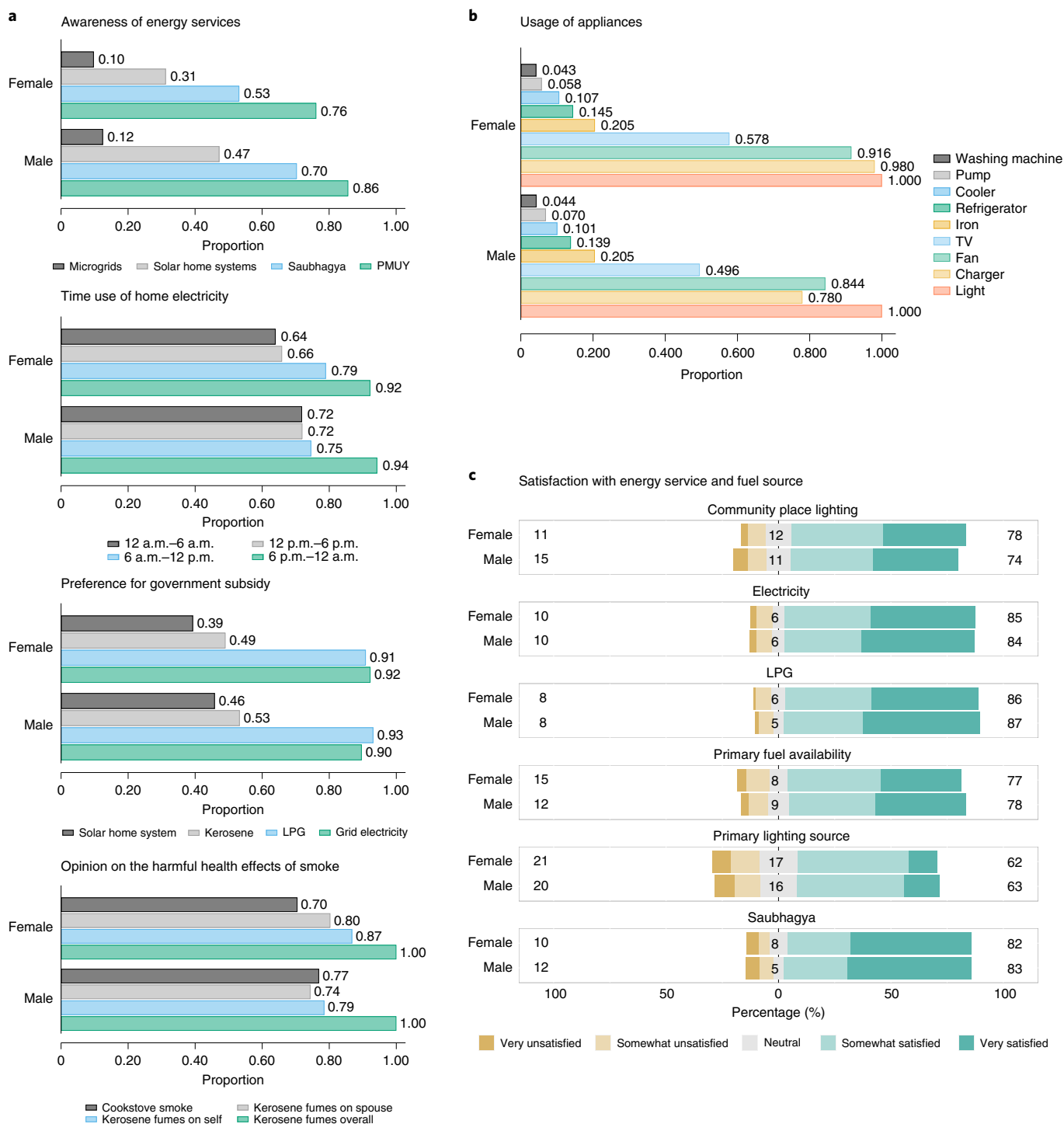
Fig. 3 | Across-household gender inequality in energy services. a,b,c, This figure shows descriptive evidence of inter-household gender differences. The number on each bar shows the proportion or percentage of females and males who report each outcome. For instance, 86 percent of male respondents are aware of PMUY, in contrast to 76 percent of female respondents. Female respondents tend to be less aware of energy services across the board (**a**). Women in our sample tend to use electricity at different times of the day and for different appliances than men (**b**). In particular, we identify TVs, fans and chargers as female-intensive appliances. Women tend to be more satisfied with community lighting and electricity and less so with LPG and primary fuel availability (**c**). They have a stronger preference for government subsidies on grid electricity at home.

reap major benefits from improved accessibility and affordability of home electricity. The reliance on home energy services also implies that women would bear higher burdens from inadequate access and use.

As more than 99% of female respondents are the primary cook, lack of access to clean fuels and cookstoves has important implications for their health[47,48]. We find that for both men and women, smoke from cooking is an important consideration. For house-
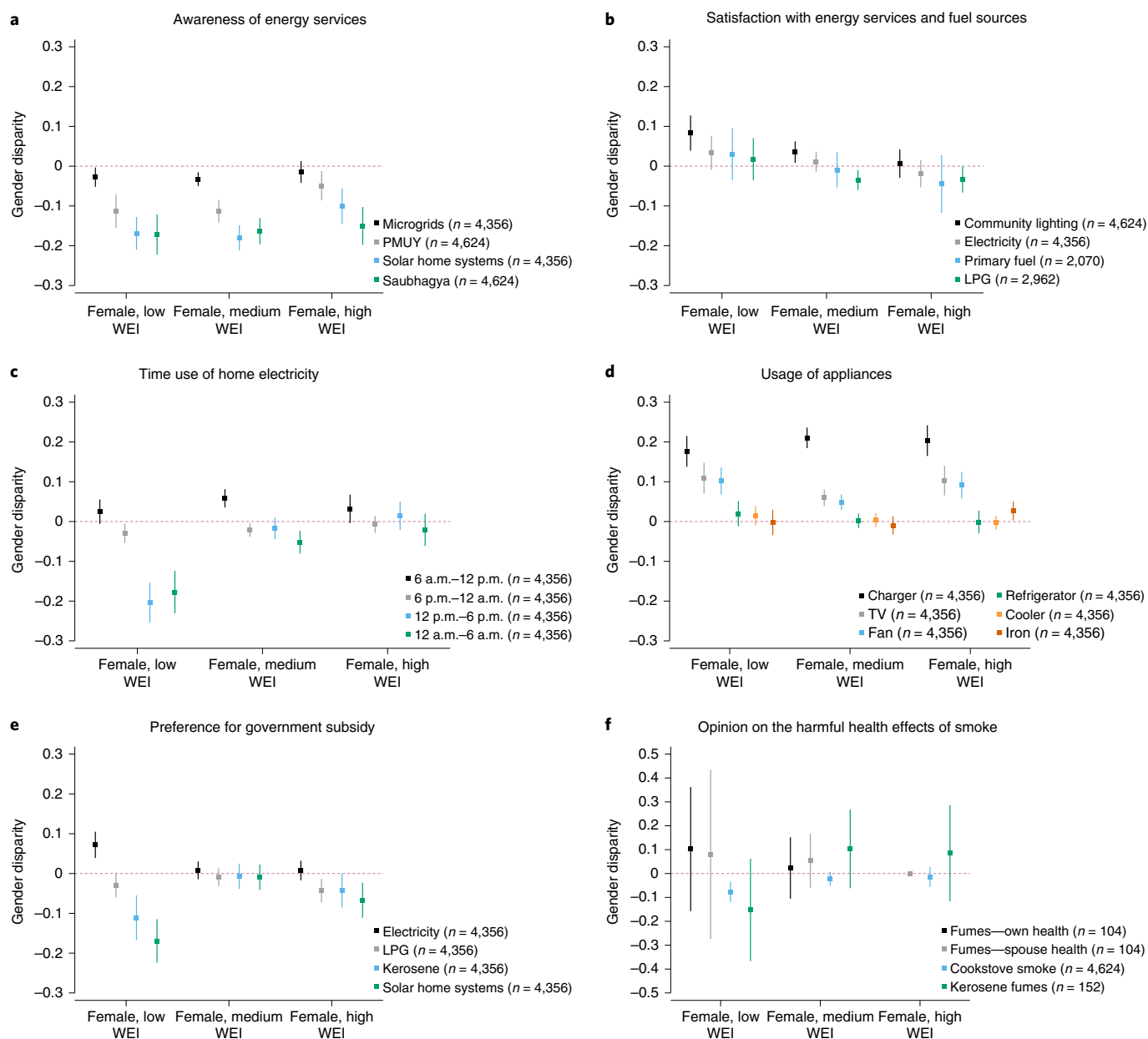
Fig. 4 | Within-household gender inequality in energy services. This figure shows the marginal effects of gender by the household-level WEI. In other words, it shows the difference in outcomes between females and males (treated as the baseline) in low-, medium- and high-WEI households after removing household-level confounders through household fixed effects. For a given panel, each colour represents a different dependent variable shown in the legend. Solid squares represent the coefficient estimates, and vertical lines are the 95% confidence intervals. Full model specifications are available in the Methods section. Standard errors are robust to heteroskedasticity and are clustered at the household level. **a–f**, We find significant gender disparities within the household across four outcome categories: awareness (**a**), satisfaction (**b**), time and appliance use (**c,d**) and preference for government subsidy and opinion on the harmful effects of smoke (**e,f**).

holds without LPG as the primary fuel ($n = 1,176$), 86% of respondents think the primary cooking arrangement produces excessive smoke. On the contrary, for families with LPG as the primary fuel ($n = 1,277$), more than 90% of respondents are satisfied with LPG stove's reduced level of smoke. Despite this universal concern with smoke, however, women put less priority on health when choosing a stove. Indeed, 60% of women put 'health and safety' as the top factor in choosing cookstoves, compared with 63% for men. In contrast, 17% of women are most concerned with connection and recurring costs compared with 14% among men.

These broad patterns in the data are further corroborated by the regression model. Compared with their spouses, women are sig-

nificantly less likely to believe that cookstove smoke is harmful for health (Fig. 4f). Perhaps due to differences in educational attainment, women in higher-WEI households tend to be more concerned with the harmful health effects of cookstove smoke. The coefficients on kerosene fumes are imprecise because few households use kerosene for lighting. Despite the availability of clean cooking fuels, women with different levels of empowerment may hold diverging views that make them hesitant to adopt LPG. Considering the rich literature on the negative health impacts of household air pollution in the Global South[47], this gender gap points to the importance of information campaigns to raise awareness on the dangers of cookstove smoke. It also supports prior research on the benefits

of peer-learning initiatives between solid fuel and LPG users to promote the transition to cleaner fuels[49,50]. Overall, these regression results on the gender inequality in awareness, satisfaction, usage and opinion validate our visual comparisons (Fig. 3) with the cross section data by minimizing household-level unobservables.

Limitations

Our cross-sectional, within-household survey has several limitations. First, it does not capture the causal relationship between women's empowerment and energy access and use. To answer such questions, longitudinal surveys and experimental approaches will be necessary to achieve causal identification and avoid endogeneity or reverse causality issues. Second, the WEI is a simplification of a complex social situation. While our findings are robust to variations in the index, refining ways to measure and collect longitudinal data on women's empowerment is an important direction for future research. Similarly, our design does not allow us to explore the causal effect of household characteristics on within-household gender differences in outcomes. Third, we do not extensively explore the relationship between clean energy and women's empowerment, as few households in our sample use sources such as distributed solar power. Exploring this relationship will further improve our understanding of the gender–energy nexus in sustainable development. Such research could also generate policy recommendations by exploring how energy access and women's empowerment initiatives produce positive spillovers. Finally, our data from six northern Indian states may have limited generalizability across India and other countries.

Discussion

Our findings highlight the importance of intra-household dynamics in explaining the interconnection between sustainable energy policy (SDG 7) and gender equality (SDG 5). Despite a 94% connectivity rate to grid electricity in our sample, women in low-empowerment households are significantly less aware of energy services and use less electricity during the day. By relaxing the assumption that households are single decision-making agents with one set of preferences[51–53], we provide evidence for multidimensional gender imbalances in awareness, satisfaction, usage and opinion of energy services within Indian households. This study fills a key gap in the literature and demonstrates that intra-household dynamics between husbands and wives are important determinants of the realized benefits from energy access.

For policymakers, these results signify that goals for affordable clean energy need to be inclusive and realistic about the context of implementation[54,55]. To the extent that household dynamics affect resource allocation, policymakers should consider a targeted approach that accounts for existing gender imbalances. In particular, to increase the adoption of PMUY and LPG, outreach programmes could target women in low-income and urban slum households as they show the largest awareness gap. Power companies could consider gender-specific plans to increase consumer satisfaction because a gender-neutral approach is unlikely to capture the whole picture. To sustain and enhance consumer satisfaction, they should improve service quality, especially among women in urban slum households. Subsidizing energy-efficient fans and TVs (female-intensive appliances) may achieve a greater uptake among women, who are more concerned with the cost of electricity.

In addition, a better understanding of the gender gap in energy services could unlock additional support for sustainable energy policy. Low empowerment could be a hindrance to clean energy adoption[56]. As primary cooks, women stand to benefit the most from the adoption of clean cooking fuels and stoves. But they may not have the decision-making power. As such, educating and empowering women could create a positive feedback loop through which more-empowered women demand cleaner and more sustainable

cooking energy, which further frees up their time to engage in paid work and reduces their health burdens from household air pollution.

More broadly, our research design of surveying the primary cook and their spouses in the same household provides a valuable framework for future empirical studies on women's empowerment. Future work could build upon these results to analyse how specific government interventions, such as the provision of clean, affordable and accessible cooking fuels, affect household members differently. While our study focuses on one time period and cannot speak to changes in household dynamics over time, collecting and analysing longitudinal data within the household would be a fruitful area of future research to unpack the linkages between SDGs.

Methods

Gender Perception Survey for Energy Access and Use. To study gender differences in energy access and use in the Global South, we conducted a large-scale survey in India to provide results on intra-household differences in knowledge, satisfaction, utilization and opinion of energy services between male and female adult household members. The Gender Perception Survey for Energy Access and Use was conducted by the Council on Energy, Environment and Water (CEEW) in collaboration with the Initiative for Sustainable Energy Policy at Johns Hopkins University in 2019–2020. The study was funded by the MacArthur Foundation. The survey covered 2,312 households in rural areas and urban slums across six states in India (Fig. 1): Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Rajasthan and Uttar Pradesh. These are among the states with the lowest socio-economic conditions and highest health burdens from household air pollution. Because households may differ in many unobserved characteristics that affect both energy access and gender-specific outcomes, a naive comparison between males and females in a sample is likely to yield biased results. To address this, we surveyed both the primary cook and their spouse in each household, that is, 50% of respondents are males and 50% are females, resulting in 4,624 individual responses.

Sampling strategy. We used a stratified multistage probability sampling design. For each of the six states, we assigned districts (d) in proportion to the state population while ensuring a minimum of four and a maximum of 16 districts. To sample districts within each state, we first arranged all districts in descending order of household population, forming $d/2$ strata such that each strata had comparable population and then sampled two districts from each strata using probability proportional to size without replacement[39].

For within-district sampling, we formed rural and urban strata which comprised rural villages and urban slums in the district as per Census 2011. A sample of 48 households was allocated between urban and rural stratum in proportion to the urban and rural household population in the district, as per Census 2011. Overall, 1–5 urban slums and 6–10 villages were sampled from each district. From each slum and village, eight and four households, respectively, were sampled, using the random walk procedure. At the household level, we conducted surveys with a heterosexual couple comprising the primary cook and his/her spouse. Thus, only households where both members were at home and willing to participate in the survey were considered for this study. See Supplementary Note 1 for further details on sampling strategy.

Data collection. We designed the survey questionnaire to capture details about the household socio-economic condition, intra-household differences in decision-making and perceptions, preferences, usage, satisfaction and willingness to pay for household energy sources (electricity, lighting and cooking). To validate responses concerning perceptions, certain key questions were asked in different ways. Supplementary Note 9 contains the questionnaire. The questionnaire administration typically took 30–45 minutes and was piloted in two urban and rural locations before the survey rollout.

A team of trained enumerators from Market Xcel Data Matrix Private Ltd. conducted in-person surveys using handheld tablets. The application SurveyToGo was used for data collection as it allowed robust and real-time monitoring. All enumerators attended three days of training comprising classroom discussions, role plays and dry runs. In view of power dynamics, enumerators were directed to ensure that respondents from the same household were in separate rooms during the survey collection so that their responses were not influenced by each other. To facilitate this, the survey team comprised equal numbers of male and female enumerators. To avoid collection of duplicate data, some of the factual questions on the socio-economic condition of the household (such as ownership of household assets) were asked to primary cooks only. Thorough data quality checks were conducted to identify and address any gaps. This was complemented by multiple field visits by CEEW researchers to observe the survey administration, take corrective measures and better understand the context for survey responses.

Sample representativeness. Supplementary Tables 6 and 7 show how demographics and socio-economic conditions compare across the six states both in our survey and in the census. The survey was conducted along with the India Residential Energy Survey (IRES) 2020, which was a nationally representative sample of Indian households. While we have used a stratified multistage probability sample design and have incorporated survey weights throughout the analysis, we do not have representative data across all sub-populations. In particular, the urban sample for Chhattisgarh was incomplete due to COVID-19 lockdowns and does not fully represent all the slum households in the state.

Our sample consists of more rural and Hindu households (Supplementary Table 6) compared with the census (Supplementary Table 7). For energy access, our sample generally accords with the nationally representative National Family Health Survey (NFHS-5). Chhattisgarh, Madhya Pradesh and Rajasthan have the highest electrification rates in NFHS-5. In our sample, households in these states have the longest electricity availability per day. On the other hand, Uttar Pradesh, Jharkhand and Bihar have the lowest electrification rates. Our sampled households in these states have the shortest daily availability for electricity.

Variables and measurement levels. We consider gender disparities across four outcome categories: (1) awareness, (2) satisfaction, (3) time and appliance use and (4) preference and opinion. Supplementary Tables 3–6 show summary statistics for the sample. The average respondent age is 38 years old and the average educational attainment is seven years. Below, we list the survey questions and response options for each outcome category.

Awareness:
"Are you aware (have you heard) of [microgrids/PMUY/solar home systems/Saubhagya]?" The response options are: Yes (1) or No (0).

Satisfaction:
"Generally, how satisfied are you with [community lighting/home electricity/ availability of primary fuel/LPG]?" The response options are: Very Unsatisfied (1), Somewhat Unsatisfied (2), Neutral (3), Somewhat Satisfied (4), Very Satisfied (5). We recode these into binary variables: Unsatisfied (1–3) and Satisfied (4–5) for two reasons. First, multinomial logit models may not be the most appropriate in our case because some of the satisfaction categories, such as 'very unsatisfied,' have very few observations. Second, using our preferred specification and the ordinal dependent variables on satisfaction produces very similar results qualitatively. As such, we use binary dependent variables for consistency and ease of comparison across outcome categories.

Usage:
"At what times of the day do you use electricity at home?" The response options are: 6 a.m.–12 p.m., 12 p.m.–6 p.m., 6 p.m.–12 a.m., 12 a.m.–6 a.m. "What do you use grid electricity for?" The response options are: a list of 16 household appliances. See survey questionnaire for details.

Preference/opinion:
"In your opinion, should the government subsidize households on [grid electricity/LPG/kerosene/solar home systems]?" The response options are: Yes (1) or No (0).
"In your opinion, is [smoke from cookstoves/kerosene fumes] harmful for health?" The response options are: Yes (1) or No (0).

In addition to respondent's gender, the main independent variable is a household-level WEI, which accounts for the underlying gender imbalance within the household. Drawing on existing global instruments for measuring the gender gap, our index encompasses six dimensions on knowledge, social norm, work, time, money and power (Fig. 2a). We use a two-step procedure when computing the WEI[19]. First, for each indicator, households are ranked as low (1), medium (2) or high (3) empowerment based on their survey responses. For example, households are assigned a score of 3 on 'power' if women make more than 80% of the household decisions, whereas they are assigned 1 if women make no decisions at all. Unless otherwise specified, the indicators are derived from women's responses in the questionnaire. We then sum across indicators for each dimension to compute a summary score S_d for dimension d (equation (1)). We use cut-offs to convert the raw score S_d into categories of low (1), medium (2) or high (3) empowerment and obtain $\hat{S}_d$. Lastly, we sum across all six dimensions and calculate an aggregate empowerment score E (equation (2)). The same WEI score applies to the entire household.

$$S_d = I_1 + I_2 + \dots + I_k \tag{1}$$

$$E = \sum_{d=1}^{6} \hat{S}_d \tag{2}$$

Drawing on existing women's empowerment indices[19,20], the cut-off for low empowerment is around the 20th percentile and that for high empowerment is around the 80th percentile for each indicator. This ensures a reasonable distribution of the empowerment index for comparison across the three sub-groups. The raw empowerment scores E range from 7 to 18, and the

distribution is shown in Fig. 2c. On the basis of the distribution of the aggregate score E, the 20th percentile corresponds to 10, and the 80th percentile corresponds to 13. As such, we use 10 as the cut-off for low empowerment and 13 as the cut-off for high empowerment. Overall, 592 households are in the low-empowerment category ($E \leq 10$), 1,180 in the medium-empowerment category ($11 \leq E \leq 12$) and 540 in the high-empowerment category ($13 \leq E \leq 18$). Supplementary Table 8 provides further details on the indicators and cut-offs.

Empowerment, as an ongoing and intrinsic process, is challenging to define and measure[40,57]. The WEI measure we construct is not without shortcomings. Because we survey each household once, we cannot measure how women's status evolves in response to improvements in energy access. This could be a source of reverse causality and is a limitation of our study. Our results should therefore be interpreted with the caveat that the level of empowerment is assumed to be fixed at the time of survey. We use the WEI as a way to proxy for women's bargaining power, defined as their ability to make choices. Our focus here is on providing evidence for heterogeneous gender differences by levels of empowerment within households. As such, we do not attempt to provide an all-encompassing measure or definition of empowerment—a term that could have different meanings under different contexts and require normative judgements[40,58].

Statistical methods and model specification. To understand how existing power dynamics between men and women in the household affect gender disparities in energy access and use, we estimate the model below and interact gender and the WEI:

$$Y_{ih} = \alpha_h + \beta \text{Female}_{ih} + \gamma \text{Female}_{ih} \times \text{EmpowermentIndex}_h + \varepsilon_{ih}, \tag{3}$$

where i denotes individuals and h households. Y_{ih} are binary (Yes/No) dependent variables of interest with Yes = 1. α_h is the household fixed effect, accounting for any confounding factors across households, such as family wealth and social status, that may bias our results. As such, we consider variations only *within* the household between husbands and wives. Female_{ih} is a binary variable that is 0 for males and 1 for females. To understand the heterogeneity in observed gender differences between women and their spouses, we include interactions between Female_{ih} and $\text{EmpowermentIndex}_h$, which is the household-level WEI measured on a 1 (low) to 3 (high) scale. We do not include individual-level controls in our main specification in equation (3) for two reasons. First, due to strong positive assortative matching among spouses in India, there is little variation in religion and caste within most households. Second, the WEI accounts for individual-level differences between spouses, such as gaps in age, education, employment and bargaining power.

When interpreting results, it is important to recognize the benefits and limitations of our research design. By surveying women and their spouses, we minimize the influence of time-invariant unobservables at the household level. But household fixed effects do not eliminate other sources of endogeneity that could arise due to omitted variables or measurement error[59]. In particular, unobserved factors could affect women's empowerment levels over time. Because our survey is conducted only once and empowerment is an evolving measure by definition, we are not able to evaluate the causal impact of women's empowerment on outcomes. This represents a source of omitted variable bias and is a major limitation of our study. In addition, empowerment, as it is experienced intrinsically by individuals, is challenging to measure[40]. Our WEI measure is, at best, a proxy for the actual level of gender equality within the household at the time of survey.

With these caveats in mind, β is the coefficient on the gender dummy and provides descriptive evidence of gender inequalities in outcomes for low-WEI households. γ is the coefficient on the interaction between gender and the household-level WEI. It represents the heterogeneity in gender gaps for a medium- or high-WEI household, compared with a low-WEI household. Standard errors are robust to heteroskedasticity and are clustered at the household level. Sampling weights are included in all regressions. We do not cluster at the primary sampling unit (district) level because the conventional approach of 'clustering at too aggregate a level is not innocuous, and can lead to standard errors that are unnecessarily conservative, even in large samples'[60]. Instead, we choose household as the level of clustering because our WEI measure is fixed at the household level, and there may be unobserved within-household correlations of the residuals and regressors. In Supplementary Tables 27–32, we explore the robustness of the results by clustering at the district, which is our primary sampling unit (PSU), and village or slum levels. With 58 districts, clustering at the PSU level leads to more conservative standard errors[60], but the results are generally robust and consistent with our preferred model specification that clusters at the household level.

We estimate parameters in equation (3) using the linear probability model, which is more preferable than logit/probit models because the coefficients are easier to interpret and it handles fixed effects better[61]. In addition, because we focus on the sign and significance of the coefficients rather than the magnitude, the linear probability and logit models give qualitatively similar results[59]. Previous research has demonstrated that the P values from both models are nearly identical[62]. To demonstrate the importance of considering household-level unobservables, we estimate across-household logit regressions in Supplementary Tables 15–20. Even after controlling for a comprehensive set of covariates, including age, education, religion, household type and household monthly income, the inter-household logit results tend to be noisier and much harder to interpret.

Robustness and heterogeneity. Our main results are robust to multiple hypothesis tests against false rejections. In Supplementary Tables 21–26, we compare *P* values from linear probability models with binary dependent variables and two methods for correcting multiple hypothesis tests: sharpened False Discovery Rate (FDR) *q*-values and Westfall–Young stepdown adjusted *P* values[63–66]. The FDR gives the proportion of false rejections (type I errors), whereas the Westfall–Young method controls for the probability of making any type I error, that is, familywise error rate. While the two methods give similar qualitative results, we find that the FDR-sharpened *q*-values are closer to the original *P* values, whereas the familywise error rate *P* values are substantially larger, more conservative and have less power. As such, we favour the FDR approach for its balance between reducing false rejection and maintaining power.

To understand how the gender gap varies across sub-populations, we conduct sub-sample analysis of key outcomes in satisfaction, awareness, usage and preference by sampled state, household type (rural versus urban slum), religion (Hindu versus Muslim), monthly income (low versus high) and electricity connection (new user versus existing user) in Supplementary Tables 33–42. These results show that government policies that promote energy access and usage need to be targeted and context specific. Effective policy interventions should account for intra-household dynamics and implement information campaigns that empower and educate women.

Ethics. We communicated the survey objectives, approximate duration and question types to all respondents and obtained their informed consent. Any information collected during the survey that might permit the identification of respondents or their households, such as respondent details, addresses and phone numbers, are held by the survey company for verification purposes only and kept confidential. Respondents were not compensated. This study's protocol was approved by Johns Hopkins University's Institutional Review Board (study number HIRB00009724, 29 September 2019, exempt status) and the CMS Institutional Review Board of India (study number IRB00006230). The study complied with all other relevant ethical regulations.

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The survey questionnaire and technical documentation are available in Supplementary Notes 1 and 9. The survey data are anonymous and publicly available on Harvard Dataverse[39] at https://doi.org/10.7910/DVN/GV85BL. Fig. 1 uses India administrative boundary shape files by Anuj Tiwari, publicly available on GitHub. Supplementary Table 7 uses NFHS data for summary statistics, available at https://www.iipsindia.ac.in/content/nfhs-project.

Code availability

Code for replicating results in this article is publicly available[67] on Zenodo at https://doi.org/10.5281/zenodo.6511986.

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Author contributions

A.T.Z. conceived and designed survey, contributed to data collection and verification, performed data analysis and wrote the paper. S.P. contributed to survey design and led data collection and verification. S.J. contributed to survey design and contributed to data collection and verification. S.A. contributed to survey design and conducted survey sampling. C.F.G. contributed to survey design and verification. J.U. conceived the survey and oversaw the administration of the project. All authors read and approved the manuscript.

Competing interests

The authors declare no competing interests.

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Software and code

Policy information about availability of computer code

Data collection	A team of trained enumerators from Market Xcel Data Matrix Private Ltd. conducted in-person surveys using handheld tablets. The application SurveyToGo was used for data collection as it allowed robust and real-time monitoring. The survey company converted the raw data into CSV files and shared with researchers for analysis.
Data analysis	The survey data was cleaned, analyzed, and visualized in Stata MP 15 and R Studio (Version 1.4.1106). Maps were created in QGIS. Survey infographics were created in Microsoft Powerpoint. Layout of composite figures were arranged in Adobe Illustrator.

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The survey questionnaire and technical documentation are available in the Supplementary Information. The anonymized survey data is publicly available on Harvard Dataverse at https://doi.org/10.7910/DVN/GV85BL. Supplementary Table 7 uses NFHS data for summary statistics, available at https://www.iipsindia.ac.in/content/nfhs-project.

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Behavioural & social sciences study design

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Study description	We conduct a large-scale survey with 4,624 respondents across six Indian states to provide results on intra-household differences across multiple outcome dimensions of energy service, including knowledge, satisfaction, utilization, and opinion. Since households may differ in many unobserved characteristics affecting both energy access and gender-specific outcomes, a naive comparison between males and females across households in the cross-section is likely to yield biased estimates for the gender gap in energy access and use. To address this challenge, we survey two members (primary cook and their spouse) of the same household and use fixed effects regression models to control for potential household-level unobserved confounding variables.
Research sample	The Gender Perception Survey for Energy Access and Use consists of 2,312 rural and urban slum households (4,624 individuals) across 6 Indian states: Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Rajasthan, and Uttar Pradesh. In each household, we surveyed the primary cook and their spouses, i.e. 50% of respondents are males and 50% are females, to allow for within-household comparison. The average respondent age is 38 years old and the average educational attainment is 7 years. The six sample states are among those with the lowest socioeconomic condition and highest health burdens from indoor air pollution. These states also have the highest percentage of households covered under Pradhan Mantri Ujjwala Yojana (PMUY) – the flagship clean cooking energy program by the Government of India. The focus on six Hindi speaking states helped us focus on one language (and translation) and ensure comparability across the states surveyed. To ensure representativeness, we create sampling weights per Census 2011 demographics (see below) and include these weights in all analysis.
Sampling strategy	We used a stratified multi-stage probability sampling design. For each of the six states, we assigned districts (d) in proportion to the state population while ensuring a minimum of 4 and a maximum of 16 districts. To sample districts within each state, we first arranged all districts in descending order of household population, forming (d/2) strata such that each strata had comparable population, and then sampled 2 districts from each strata using probability proportional to size without replacement. For within district sampling, we formed rural and urban strata which comprised rural villages and urban slums in the district as per Census 2011. A sample of 48 households was allocated between urban and rural stratum in proportion to the urban and rural household population in the district, as per Census 2011. Overall, 1-5 urban slums and 6-10 villages were sampled from each district. From each slum and village, eight and four households, respectively, were sampled, using the random walk procedure. At the household level, we conducted surveys with a heterosexual couple comprising the primary cook and his/her spouse. Thus, only households where both members were at home and willing to participate in the survey were considered for this study.
Data collection	A team of trained enumerators from Market Xcel Data Matrix Private Ltd. conducted in-person surveys using handheld tablets. The application SurveyToGo was used for data collection as it allowed robust and real-time monitoring. All enumerators were given three-day long training comprising classroom discussions, role plays, and dry-runs. In view of power dynamics, enumerators were directed to ensure that respondents from the same household were in separate rooms during the survey conduct so that their responses were not influenced by each other. To facilitate this, the survey team comprised equal number of male and female enumerators. To avoid collection of duplicate data, some of the factual questions on the socio-economic condition of the household (such as ownership of household assets) were asked to primary cooks only. Thorough data quality checks were conducted to identify and address any gaps. This was complemented by multiple field-visits by CEEW researchers to observe the survey conduct and take corrective measures and better understand the context for survey responses. Each enumerator was given a survey kit, which included a questionnaire with detailed instructions, show cards to be used during select questions, and the authorization letter from CEEW. Enumerators contacted the sampled household at least thrice to maximize the response rate. The questionnaire administration typically took 30-45 minutes, and was piloted in two urban and rural locations before the survey roll out. Enumerator were not aware of the study hypothesis.
Timing	The survey was conducted between November 2019 and March 2020, with the majority of data collection concentrated between the months of December, January and February.
Data exclusions	Observations from 34 households were excluded due to data quality issues. In these households, the enumerators covered only one respondent – either primary cook or spouse – because the other one was not available. The enumerators were not able to revisit these households due to pandemic related issues.
Non-participation	The survey had an overall participation rate of 76 percent. For our research design, presence of the primary cook and their spouse at the same time was imperative because it allows us to control for household fixed effects. Absence of even one of these members necessitates dropping of that household. The majority (34 percent) of non-responses, both in urban slums and rural households, were due to the absence of the primary cooks or their spouses.
Randomization	Not applicable. Comparing outcomes between men and women across households in the cross-section could result in biased estimates for the gender gap. Our research design improves upon previous work and addresses this empirical challenge by surveying the primary cook, of which 99.8% are females, and their spouses in the same household. This allows us to consider within-household variations and control for time-invariant household-level confounders through fixed effects.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☐	☒ Human research participants
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics	See above.
Recruitment	We communicated the survey objectives, approximate duration, and question types to all respondents and obtained their informed consent. Any information collected during the survey that might permit the identification of respondents or their households, such as respondent details, address, and phone numbers, is held by the survey company for verification purposes only and kept confidential. Respondents were not compensated.
Ethics oversight	This study's protocol was approved by Johns Hopkins University's Institutional Review Board (study no. HIRB00009724, 9/29/2019, exempt status) and the CMS Institutional Review Board of India (study no. IRB00006230). The study complied with all other relevant ethical regulations.

Note that full information on the approval of the study protocol must also be provided in the manuscript.