Renewable and Sustainable Energy Reviews 193 (2024) 114260

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Examining energy justice: Empirical analysis of clean cooking transition across social groups in India, 2004–2018

Dil Bahadur Rahut [a,*], Jeetendra Prakash Aryal [b], Navneet Manchanda [c], Tetsushi Sonobe [a]

[a] Asian Development Bank Institute (ADBI), Tokyo, Japan

[b] International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates

[c] Consultant, World Bank, New Delhi, India

ARTICLE INFO

Keywords:
Clean fuel
Social group
Caste/ethnicity
Energy justice
India

ABSTRACT

Literature has highlighted the existence of a gap in clean fuel usage between the social groups in most emerging nations across the world, which is detrimental to global efforts to achieve Sustainable Development Goal (SDG) 7 (access to clean energy) and SDG 10 (reducing inequalities) and just energy transition with recognition justice. This paper, assesses the clean fuel gap across social groups in India using three rounds of representative data (2004, 2014, and 2018) by applying the logit model, exogenous switching treatment effect regression (ESTER), and the Blinder–Oaxaca Decomposition Model. Such an analysis is instrumental in identifying the clean energy usage gap and its causes, thereby providing insight to policymakers to design policies to achieve just energy transition and carbon neutrality by 2060. The results show a substantive clean fuel gap between social groups in India, which is a cause of concern for just energy transition. Clean energy utilization gaps among social groups are alarming across geographical locations and consumption quartiles, highlighting the importance of recognition justice for just energy transition. The results show that in rural areas, only 19.6 % of the General Caste households and 14.5 % of the disadvantaged social groups (Scheduled Tribes, Scheduled Castes, and Other Backward Class) in quartile one use clean energy, while in urban areas, the shares are 60.4 % and 46.3 %, respectively. To achieve a just distribution of the benefits of energy transition, energy policies should focus on disadvantaged social groups and simultaneously target General Caste households from a lower economic status and those residing in rural areas, indicating the need for targeting the neglected regions.

Author contribution statement

Dil Bahadur Rahut: Conceptualization of the research idea, data management, data cleaning, analysis, visualization, write-up, editing and structuring, and revision, Jeetendra Prakash Aryal: Conceptualization of the research idea, analysis, write-up, editing and structuring, and revision. Conceptualization, Data sourcing and management, write-up, editing, structuring, and revision. Tetsushi Sonobe: Conceptualization, editing, structuring, revision, and supervision.

1. Introduction

With the increase in clean fuel usage, the issues of energy justice and social equity in its access have dominated the discourse in the development policy debates [1–5]. Access to clean fuel for different socio-ethnic groups, including the marginalized versus dominant social groups, ethnic majorities versus ethnic minorities, Scheduled Castes (SC or Dalits), Scheduled Tribes (ST or Adivasis), and Other Backward Class (OBC), versus General Caste (GC), and also by race, is often uneven. Moreover, recent studies reveal that the concerns of social equity in accessing clean energy for recognition justice are equally crucial in both the developing and developed worlds [6–11], although the severity of the problem is observed more in developing countries. This has raised the importance of the social justice and equity dimensions of clean energy use rather than only the technological aspects related to clean energy production, availability, and distribution [12–14]. In India, where access to clean cooking fuel has been promoted recently, the social justice and equity dimensions are crucial to attaining energy justice [15–17]. This is primarily because ethnicity and caste are fundamental features of society in the Indian sub-continent, where ethnic and caste identities explain several facets of human lives [2,3,18,19]. In this context, the transition to clean energy may produce new inequalities or perpetuate existing inequalities in society [20,21]. The energy justice

* Corresponding author. Asian Development Bank Institute, Kasumigaseki Building, Level 8 3 Chome-2-5 Kasumigaseki, Chiyoda City, Tokyo, 100-6008, Japan.
E-mail address: drahut@adbi.org (D.B. Rahut).

https://doi.org/10.1016/j.rser.2023.114260
Received 5 July 2022; Received in revised form 19 December 2023; Accepted 20 December 2023
Available online 23 January 2024
1364-0321/

Nomenclature

Abbreviations

ST	Scheduled Tribe
SC	Scheduled Caste
OBC	Other Backward Class
GC	General Caste
ST-SC-OBC	Scheduled Tribe, Scheduled Caste, and Other Backward Class
ESTER	Exogenous Switching Treatment Effect Regression
MHH	Male-headed households
FHHs	Female-headed households
LPG	Liquefied petroleum gas

framework, which primarily consists of three basic tenets, including distributive, procedural, and recognition justice, helps in explaining much of the interlinkages between energy use disparity and caste/ethnicity diversity in society [22-] [24]. Distributive justice explains the concerns related to the distribution of benefits and burdens due to the transition to clean energy, procedural justice associates with the inclusive and non-discriminatory aspects of energy transition, and the recognition justice focuses on the sources of injustices that arise owing to inappropriate program design and the ways to understand the needs and vulnerabilities across the diverse groups under diverse circumstance and values [24]. Hence, this paper assesses the relationship between the use of clean energy and caste/ethnicity issues using three rounds of nationally representative health and morbidity data from the National Sample Survey Organization (60th round, 2004); 2014 (71st round, 2014); and (75th round, 2017–18) to examine the situation of energy justice in Indian society using all three tenets of energy justice and contribute to the global effort to achieve carbon neutrality by 2060.[1]

Energy justice has become a leading interdisciplinary energy thematic area in the past decade; especially because this sector lacks a fundamental guiding principle, which is the pervasive integration of justice throughout its operations. This perspective introduces a pragmatic dimension vital to the study of energy justice, specifically focusing on how to apply and actualize it during the ongoing energy transition to ensure a transition that is characterized by fairness, equality, equitability, and inclusivity – in other words, *justice* [25]. Affordability is one of the prime aspects when analysing the association between caste/ethnicity and clean energy from the energy justice perspective [26, 27]. The recent report of NITI Aayog, the apex Planning Commission of India [28], states that the Scheduled Tribe (ST) accounts for 9.4 % of the population of India and is the poorest group in terms of the multidimensional poverty index. More than 83 % of the multidimensionally poor people in India belong to ST, SC, and OBC [29], and have low levels of affordability to clean energy compared to General Caste (GC) households. Using data from India's 68th round of the National Sample Survey Organization, Saxena V, and Bhattacharya PC [30] showed that ST and SC families have limited access to Liquefied petroleum gas (LPG)[2] – considered as a transitional or cleaner alternative to some other high-carbon fuels like coal and traditional biomass, and electricity vis-à-vis higher-caste households. Limited financial means is one of the critical reasons why many households that received subsidized LPG stoves and gas cylinders benefits from the Pradhan Mantri Ujjwala Yojana (PMUY) have not been able to refill LPG cylinders on their own and, thus, have eventually reverted to traditional energy sources for cooking [31,32]. Another reason is a lack of refilling service providers in the village, leading to poor accessibility of such services [32]. Therefore, there is a need to examine the multiple dimensions of energy justice, with regard to income distribution, energy access, and location. In this setting, this paper follows an interdisciplinary perspective with insights from economics, geography, political economy, human rights, distributional justice, energy security, and environmental studies [4,25,27] to examine the issues of energy justice from the ethnic perspective in India.

The income distribution across caste/ethnic groups in India indicates that the deprived caste groups, especially SCs, and STs, earn substantially less than the country's average household income [33,34]. Data from 1961 to 2012 shows that the earnings of SC and ST families are 21 % and 34 % lower, respectively, compared to the national average [33]. Moreover, the All India Debt and Investment Survey (2013) showed that the top 1 % of families hold almost 25 % of the country's total wealth, while the bottom 40 % of the households control only 3.4 % [34]. Although high-caste households hold more wealth compared to other castes/ethnic groups, they also have the highest levels of inequality [34]; hence, the just energy transition policy should also include low-income households from the upper caste (general caste). These economic disparities are deeply intertwined with caste disparities in India and often reinforce each other in a complex web of social and economic dynamics.

In this context, recognition justice, a major component of energy justice, helps conceptualize how wider social networks and trusted intermediaries can play a role in improving distributive justice through appropriate energy policy [1]. Recognition justice contributes to understanding how intermediaries identify and recognise energy-vulnerable households exposed to structural inequalities, reveal ways to correct such inequalities, and strengthen energy justice [1,22, 35,36]. Unequal access to clean energy services, rooted in the broader social landscape characterized by discrimination, is a critical factor contributing to the energy justice dynamic among various caste and ethnic groups in India [3,21,37,38]. "Inequality in energy access is firmly rooted in caste identities and the households' economic status. Poor households and households belonging to lower castes (i.e., Scheduled Castes and Scheduled Tribes) are less likely to have grid connections than affluent, upper castes (i.e., General Castes)" [37]. As the marginalized community lacks equal access to clean energy, energy policy in India needs to reconsider caste/ethnicity-based inequities to achieve clean energy access to all [39] and thereby support the agenda of a just energy transition by 2060. Looking only through the average wealth or income of the caste/ethnic groups without considering the income/wealth inequality within and between groups could lead to sub-optimal policy making. Considering these issues, this paper also controls for the economic and human capital endowments while assessing the relationship between clean energy use and caste/ethnic

[1] Liquefied petroleum gas (LPG) can play a multifaceted role in the journey towards carbon neutrality and addressing climate change. While LPG is a fossil fuel that, when burned, releases carbon dioxide (CO2) emissions, it can be considered a transitional or cleaner alternative to some other high-carbon fuels like coal and traditional biomass. Its role in achieving carbon neutrality depends on how it is produced, distributed, and used. Some efforts are underway to produce LPG from renewable sources, such as bio-LPG or synthetic LPG derived from renewable electricity and carbon capture technologies. These forms of LPG have the potential to be carbon-neutral or even carbon-negative, as they can be produced using sustainable feedstocks and renewable energy sources. However, it is important to note that LPG is not a long-term solution for achieving carbon neutrality on its own. To reach net-zero emissions and true carbon neutrality, there must be a broader transition to renewable and low-carbon energy sources, increased energy efficiency, and comprehensive efforts to reduce emissions across all sectors of the economy. The role of LPG in carbon neutrality is thus contextual and should be considered as part of a broader strategy to reduce emissions and transition to cleaner and more sustainable energy sources.

[2] From the demand/user perspective it is considered as clean fuel as it does not have adverse health and environmental impact at the user end compared to kerosene, coal, and biomass.

status among Indian households.

This study is crucial as India has registered notable progress in adopting cleaner cooking fuels, from nearly 44 % of households using cleaner fuels in 2014–15 to about 60 % in 2019–20 [40]. While this increased utilization of cleaner fuels has been attributed largely to the implementation of the Pradhan Mantri Ujjawal Yojana in 2016, wherein free gas cylinders, pipes, and regulators were distributed to below-poverty-line households, resulting in the dispensation of over 80 million LPG connections by 2019 at subsidized rates [41]. However, despite these advancements, disparities in the adoption of cleaner cooking fuels persist in India. Not only across sectors, but this colossal clean energy use disparity can also be seen across caste/ethnic groups. Some studies have found that even after controlling for various social and economic factors, households from deprived social groups have less access to liquefied petroleum gas (LPG) and electricity usage than upper-caste households [30]. Although several studies have assessed the energy access issue using theoretical and experimental approaches in India, we believe they lack analytical rigor, and the emphasis on social groups is relatively modest [42–45]. In order to bridge this lacuna, this research paper investigates the role of social groups in access to clean fuel using a more rigorous and robust analysis.

The next section deals with recent literature with emphasis on clean energy use and its role in achieving SDGs in India; Section 3 provides background on the social groups in India; Section 4 elucidates the data and empirical approaches; Section 5 explains the results and provides a detailed discussion; and finally, Section 6 summarizes the results and offers policy recommendations.

2. Clean energy and its role in achieving SDGs in India

The use of clean energy is central to realizing various Sustainable Development Goals (SDGs) set by the United Nations. For instance, increasing the use of improved cooking is fundamental to accomplishing several SDGs, primarily the goals related to clean energy, environment, climate action, health, and gender equality [46]. Household Air Pollution (HAP), due to the use of traditional fuels like firewood, kerosene, cow dung, biomass fuels, and coal for household purposes, is one of the most alarming environmental concerns for associated health risks and diseases, especially in developing economies due to inaccessibility or unaffordability of cleaner fuels [47,48]. The decimation of the use of such fuels is central to improving air quality, reducing air pollution, and realizing various Sustainable Development Goals, such as “Good Health and Well-Being (SDG 3), Affordable and Clean Energy (SDG 7), Sustainable Cities and Communities (SDG 11), Sustainable Consumption and Production (SDG 12), and Climate Action (SDG 13)” [49].

Globally, there has been a decline in the population that does not have access to electricity, from 1.2 billion to 0.759 billion between 2010 and 2019, while about 2.6 billion people did not have access to clean fuels in 2019 [50]. Nearly four-fifths of the people who did not have access to clean fuels during 2015–19 reside in 20 developing nations situated predominantly in South Africa, Eastern Asia, and South Asia [50]. With roughly 589 million Indians without clean cooking fuel, India has the largest share (about 22 %) of the world’s population living without clean cooking fuel [50]. Despite rapid growth and development and massive investment in increasing clean energy, only 56 % of Indians have access to clean cooking fuel. This raises concerns about energy justice from multiple dimensions, including energy poverty, energy security, social and distributional aspects of the benefits and burdens of energy systems, and energy consumption [51]. However, access to clean cooking fuel has improved rapidly in India (3.9% points annually between 2015 and 2019) compared with other countries [50]. Although India has shown significant progress in achieving overall SDGs, more effort is still required to achieve the goals set in SDG 7 [52,53], which is crucial to providing access to clean energy to marginalized social groups and poor households, thereby promoting energy justice and also contributing to the global agenda of carbon neutrality by 2060.

Currently, India has the highest energy-deprived population [54], where approximately one in three people are likely to rely on traditional fuels for cooking by 2030, making it nearly impossible for the country to achieve SDG 7 [55]. This is especially worrisome because household air pollution caused by the inefficient burning of solid fuel is the fourth major determinant of the global disease burden, while it is the third major determinant in the case of India [56]. Household air pollution due to cooking biomass consumption in India results in approximately 0.5 million premature deaths per annum in children under five years of age and women [57]. Recent studies show that poor people in India suffer from the double burden of air pollution: smoke from burning dirty energy at home; and disproportionately higher exposure to ambient air pollution caused largely by economically well-off urban families with greater consumption emissions per capita [58,59]. Thus, a transition from dirty to clean energy use calls for a dire need to understand the energy use gap through the lens of energy justice [51,60,61].

Progress in clean fuel for cooking increases the potential of achieving the targets related to climate action (SDG13) and health (SDG3), as it is a significant reason for pollution in India [62]. Hence, a complete switch to clean energy by 2030 is expected to decrease PM2.5 exposure to less than the WHO-defined level for all households [52], which should improve overall health. Such a transition should be just and inclusive, so that marginalized social groups, people living in remote regions of developing countries, and families from lower economic status can benefit equally from the energy transition.

In the case of benefits related to women’s health, understanding differences in women’s perspectives on the use of various types of fuels is crucial to unlocking the cooking fuel transition [63]. Several research papers have found that the household clean energy transition is heavily influenced by economic status [64–66] and the location of the household (rural versus urban) [67,68]. In addition, a recent study by Aklin M et al. [3] in the Jharkhand state of India showed that tribal households are more likely to suffer from lower access to electricity, as their electrification rates are 11% points lower compared with General Caste households. In addition, tribal families own less electrical equipment than the General Caste households, indicating a clear requirement of public policy to ensure energy justice across different caste/ethnic groups in India. Therefore, it is crucial to perform a heterogeneous analysis to understand the energy use gaps across these social groups and to understand how social injustices hinder the achievement of energy justice [36,69–71].

3. India’s social structure

The institution of caste has been in existence in Indian society for ages, which has undeniably kept the division in independent India alive. Although the stringency with which the hierarchical structure of caste is practiced has gradually declined over the last 70 years, it continues to hinder the government’s efforts to achieve social and economic justice. The role of caste affiliations has weakened in contemporary Indian society. Still, caste, with its fluid and dynamic nature, has manifested itself in myriad forms in different social, political, and economic dimensions. Thus, despite attaining independence seven decades back, India continues to be entrapped in the shackles of its exclusionary social structure, which has placed barriers for several groups in accessing key enabling opportunities like schooling, training, health services, and access to cleaner fuel. The caste structure in India is segregated into “Brahmins (priests), Kshatriyas (warriors), Vaishyas (traders), Shudras (menial workers), and Ati Shudras (the former untouchables who did the most menial jobs)” [72]. The bottom-most communities in India’s social hierarchy comprise the earlier “untouchables” now referred to as Scheduled Castes (SCs), and the tribal groups now called Scheduled Tribes (STs) or “Adivasis” – identified by their traditional customs and locations in isolated and distant areas.

Structural inequalities along the lines of caste and ethnicity permeate across all sectors of Indian society. Excluding those in the top-most rung of the caste hierarchy, unequal assignment of rights is pervasive in every caste, but SCs and STs have suffered the most. Historically, SCs have been denied the rights to education, property, and all cultural and religious rights and have also been subjected to social isolation and residential segregation [73]. STs, too, have suffered from "exclusion, neglect, and underdevelopment due to their geographical and cultural isolation-exclusion can take several forms, including the denial of the right to resources around which they live, and displacement induced by economic development" [73]. In this backdrop, along with distributive and procedural aspects of energy justice, the recognition justice helps explain the realities of energy use differences across the caste/ethnic groups in Indian society. Recognition justice is crucial in exploring energy justice as it contributes to how the victims are recognized in the energy system operating in a certain social context [35,36]. Click or tap here to enter text.

According to the latest population census, approximately 9 % is Scheduled Tribes (ST), 17 % is Scheduled Castes (SC), and 44 % is OBCs and only two-thirds of SCs, 59 % of STs, and 65 % of OBCs are literate, while the national average is 74 % [74]. Nevertheless, economic status, place of residence, and literacy levels cumulatively affect the choice of cooking fuels across all caste/ethnic groups. According to the poverty profile of India, 43 % of the STs, 29 % of SCs, and 21 % of OBCs live on less than the nationally defined poverty threshold (BPL) [75]. As a result of recent government policies, the percentage of SC households who use LPG has improved from 12 % in 2015 to 55 % in 2018, while among STs, LPG usage has increased from 8 % to 38 % in the same period, signifying a striking improvement in LPG utilization by marginalized groups [18]. As such, social justice and social equity are relevant issues to achieve energy justice in many cases [38,76]. Affordability is a major constraining factor for clean fuel use in the case of poor households. Studies show that three-fourths of the households without an LPG connection live in houses made of mud and straw (*kutcha*[3] houses), earn less than INR10,000 a month, and cite the cost of recurring refills as the reason for using biomass fuel [77]. Hence, due to unaffordability, a preliminary LPG connection given via the government scheme largely failed to translate into sustained use. The low literacy rate also acts as a barrier to using LPG in households, as there is a general lack of awareness. Perceptions that food cooked in *chulhas*[4] is tastier and healthier than food cooked using LPG are common, especially among deprived social classes.

4. Data and methodology

4.1. Data & sampling

This paper uses unit-level data records from three health and morbidity rounds of the National Sample Survey Organization Schedule 25: 2004 (60th round survey); 2014 (71st round survey); and 2017–18 (75th round survey), which are nationally representative. The survey in 2017–18 collected data from 113,823 families (64,552 and 49,271 from rural and urban households, respectively); in 2014, 65,932 families were surveyed (36,480 from rural and 29,452 from urban locations), while in 2004, 73,868 families were interviewed (47,302 and 26,566 from rural and urban households, respectively). After cleaning the data and dropping the observations with missing information for variables used in the paper, a total of 71,888 households from 2004, 65,318 households from 2014, to 112,352 households from 2018 households were used for the study. Table 1 shows the distribution of the sample used in the study by year, rural-urban location, clean fuel usage, and social group (caste/ethnic).

Table 1
Distribution of sample disaggregated by social group and clean fuel use by year.

	Overall		
	2004	2014	2018
Sample	71,888	65,318	112,351
Clean fuel (yes-1; no-0)	29.1 %	44.8 %	64.0 %
Schedule tribe, caste &other backward class	66.5 %	68.8 %	69.8 %
Other backward class (OBC)	37.4 %	39.3 %	39.5 %
Scheduled caste (SC)	17.2 %	16.7 %	16.9 %
Scheduled tribe (ST)	11.9 %	12.8 %	13.4 %
General caste (GC)	33.5 %	31.2 %	30.2 %
	Rural		
	2004	**2014**	**2018**
Sample	45,895	36,072	64,009
Clean fuel (yes-1; no-0)	9.6 %	20.9 %	44.5 %
Scheduled tribe, caste &other backward class	73.2 %	75.8 %	76.8 %
Other backward class (OBC)	39.3 %	39.5 %	39.5 %
Scheduled caste (SC)	19.1 %	19.1 %	19.6 %
Scheduled tribe (ST)	14.7 %	17.3 %	17.8 %
General caste (GC)	26.8 %	24.2 %	23.2 %
	Urban		
	2004	**2014**	**2018**
Sample	25,993	29,246	48,342
Clean fuel (yes-1; no-0)	63.4 %	74.3 %	89.9 %
Schedule tribe, caste &other backward class	54.6 %	60.1 %	60.5 %
Other backward class	34.0 %	39.1 %	39.5 %
Scheduled caste (SC)	13.7 %	13.8 %	13.3 %
Scheduled tribe (ST)	6.8 %	7.2 %	7.7 %
General caste (GC)	45.4 %	39.9 %	39.5 %

All three rounds have adopted a stratified multi-stage sampling design wherein the census villages in the rural area and Urban Frame Survey (UFS) blocks in the urban area are the First Stage Units (FSUs), and households are the Ultimate Stage Units across sectors (detailed information is available in the national reports of NSS[5]). All the surveys collected detailed information on the household characteristics, socio-economic status of the household (as proxied by MPCE), and sources of energy for cooking.

4.2. Empirical methodology

4.2.1. Logit model

As the dependent variable is discrete and binary (1, if the household [HH] consumes clean fuel for cooking and 0, if the HH uses dirty fuel),[6] we estimated the logit model to understand how large is the gaps between ethnicity or caste groups in terms of use of clean fuel for cooking. The logit model is presented below in equation (1):

$$Proby_i = F\left(X_i^{'}\boldsymbol{\beta} + \varepsilon_i\right), \mathrm{i} = 1, 2, \ldots, \mathrm{N}; \tag{1}$$

$$y_i = \begin{cases} 1 & \textit{if HH use clean cooking fuel} \\ & 0, \textit{otherwise} \end{cases} \tag{2}$$

X_i: independent variable that influences the choice of clean fuel.

[3] Houses made of mud and straw are known as "kutcha" houses; https://timesproperty.com/news/post/kutcha-house-blid2045.

[4] "Chulha" is a conventional stove used for cooking in India (https://www.dsource.in/resource/kitchen-products/stoves/chulha).

[5] National Sample Survey Organization. Social consumption: health - NSS 71st round, 2014 New Delhi: MOSPI, Government of India; 2016. Available at: http://mail.mospi.gov.in/index.php/catalog/161.National Sample Survey Organization. Morbidity, healthcare and the condition of the aged - NSS 60th, 2004 New Delhi: Ministry of Statistics and Programme Implementation, Government of India; 2006. Available at:http://catalog.ihsn.org/index.php/catalog/3230; http://mospi.nic.in/sites/default/files/publication_reports/KI_Health_75th_Final.pdf.

[6] From the available data: LPG, electricity (incl. generated by solar or wind power generators), gobar gas, other biogas, other natural gas are classified as clean sources of energy and coded as 1, while firewood and chips, dung cake, kerosene, coke/coal, charcoal, and others have been classified as dirty fuels and coded as 0.

F is the cumulative standard logistic distribution function.
ε_i: random error term.

4.2.2. Exogenous switching treatment effect regression (ESTER)

To evaluate the consequence of socio-ethnicity on fuel choice, the use of the binary (logit) approach fails to concede the interface between the socio-ethnicity group and other covariates affecting clean cooking fuel choice in the model as "it can only provide the intercept effect (i.e., parallel shift effect or homogenous slope hypothesis), which remains the same irrespective of the value of other covariates" [78–80].

To address this concern, ESTER, in a counterfactual framework, has been employed to estimate the causal effect of the social groups on clean cooking fuel. In this framework, 2 separate equations: for the deprived social group (ST-SC-OBC) and General Caste (GC) were estimated as follows:

$$\begin{cases} y_{st} = x_{st}\beta_{st} + U_{st} \text{ if } st = 1(\text{ST-SC-OBC households}) \\ y_{st} = x_{gc}\beta_{gc} + U_{gc} \text{ if } gc = 1(\text{GC households}) \end{cases} \quad (3)$$

In Equation [3], subscript st and gc represent the deprived social group (ST-SC-OBC) and general caste (GC), respectively; y refers to clean cooking fuel use by groups of households, based on the subscripts.; x is the vector of independent variables; β is the coefficient vector expressing how families from different social groups respond to regressors; and u is an unobservable random error term with zero mean and constant variance.

To assess how social groups determine clean energy use, the counterfactual clean fuel use status of each category is estimated. To be specific, Kassie M. et al. [79] methodology has been adopted wherein the clean cooking fuel status has been estimated in one category of the households (for example, ST-SC-OBC) if the returns (coefficients) to their regressors are assumed to be the same as the coefficients of the other category (for example, General Caste [GC]), and vice versa. More detailed information on ESTER and its application to understand the role of social groups and clean energy use is available from previous studies [70,78,79].

4.2.3. Blinder–Oaxaca Decomposition

To better understand the energy use gap between ST-SC-OBCs and general social groups, this study employs the Blinder–Oaxaca decomposition technique, which considers a separate regression model process for male and female samples and examines the relative contributions of all the measurable characteristics in the model. For linear regression, the standard Blinder–Oaxaca decomposition of the gender gap in the average value of the outcome variable (energy use) Y can be written as:

$$\overline{Y}^M - \overline{Y}^F = \left[\left(\overline{X}^M - \overline{X}^F\right)\widehat{\beta}^M\right] + \left[\overline{X}^F\left(\widehat{\beta}^M - \widehat{\beta}^F\right)\right] \quad (4)$$

where $\overline{X}^J$ is a row vector of average values of the independent variables and $\widehat{\beta}^J$ is a vector of the coefficient of estimate for gender j. However, since our outcome variable of interest is a binary variable, this standard technique cannot be used directly. Following the approach used by Fairlie (1999), the Blinder–Oaxaca decomposition of the gender gap for a logit model can be written as:

$$\overline{Y}^M - \overline{Y}^F = \left[\sum_{i=1}^{N^M}\frac{\boldsymbol{F}\left(X_i^M\widehat{\beta}^M\right)}{N^M} - \sum_{i=1}^{N^F}\frac{\boldsymbol{F}\left(X_i^F\widehat{\beta}^M\right)}{N^F}\right] + \left[\sum_{i=1}^{N^F}\frac{\boldsymbol{F}\left(X_i^F\widehat{\beta}^M\right)}{N^F} - \sum_{i=1}^{N^F}\frac{\boldsymbol{F}\left(X_i^F\widehat{\beta}^F\right)}{N^F}\right] \quad (5)$$

Where N^J is the sample size for gender j, and F is the cumulative standard logistic distribution function. The first term on the right-hand side of equations (4) and (5) captures the difference in the outcome due to observable characteristics X, whereas the second term indicates the different effects in the estimated coefficients.

5. Results and discussion

5.1. Descriptive statistics

Approximately 48.9 % of households relied on clean fuel as their primary cooking source (Table 2). Among these households, about 11.1 % were headed by females (FHHs), and there was no discernible difference in clean fuel usage between households led by males and those by females. Households headed by older members tended to use cleaner fuel than younger ones, likely due to convenience of use and accumulation of wealth. The number of adult males and females was larger among households using clean fuel than those using dirty fuel, while the number of children under 15 years was lower for those using clean fuel. The log per capita consumption expenditure was higher for those using clean cooking fuel, which indicates the importance of income/wealth, highlighting the affordability aspect. Distribution of the sample by the level of education of the household head shows that the family using clean energy for cooking has a higher education level than the family using dirty fuel; this indicates the critical role of awareness of the benefit of clean cooking fuels for health and well-being. Finally, it can be concluded that the households using clean fuel have more wealth, are headed by males, reside in urban locations, and live in socio-economically forward states. The descriptive statistics of the variable used in the study by years is provided in Appendix 1 (Tables 1, 2, and 3).

5.2. Trend analysis

Fig. 1 shows that India has notably increased the use of clean energy sources for cooking. In 2004, the percentage of households using clean fuel as the main source of cooking fuel was 29.1 %, which increased to 44.8 % in 2014 and 64 % in 2018. To assess the equity of this transition and its impact on improving clean energy access for marginalized communities, cooking fuel trends were analysed between the socially disadvantaged groups (ST-SC-OBC) and the general social groups (GC). ST-SC-OBC households using clean energy increased from 20.6 % in 2004 to 58.4 % in 2018, nearly tripling their adoption rate over this period, while GC households started from a higher baseline of 45.9 % in 2004 and increased to 77 % in 2018. This indicates that clean cooking practices have gained traction not only among disadvantaged groups but also in the broader population. While the Government of India has made significant strides in enhancing access to clean energy and narrowing the energy accessibility divide among diverse social demographics, disparities in the adoption rates between social groups still persist, highlighting the need for continued efforts to promote equitable access to clean cooking fuels and technologies for all segments of the population to ensure just energy transition from the distributional perspective.

Fig. 2(a) shows the geographic variation in clean energy usage over time. There is a sizable difference in clean cooking fuel usage between rural and urban households, although the percentage of households using clean energy has increased significantly. Rural households using clean cooking fuel rose from 10 % in 2004 to 44 % in 2018, while urban households using clean cooking fuel rose from 63 % in 2004 to 90 % in 2018. A similar trend is observed among social groups across rural-urban sectors. For example, in 2018, 42 % of ST-SC-OBC families and 54 % of the general social group families in the rural area used clean cooking fuel, while 87 % of ST-SC-OBC families and 95 % of the general social group families in the urban area used clean cooking fuel. The percentage of ST-SC-OBC urban households using clean fuel increased significantly from 52 % in 2004 to 87 % in 2018, while the General Caste urban households showed an increase from 77 % to 95 %. The results clearly show that irrespective of social status, rural households are more clean-energy-deprived than urban households. Therefore, to support energy justice and a just transition, government intervention should target the disadvantaged social groups (ST-SC-OBC) as well as the general social group in rural areas to achieve SDG 7 (access to affordable and clean sources of energy) and SDG 10 (reduced inequality).

Table 2
Descriptive statistics of the variable used in the study for all the years combined (means and standard deviations in parentheses).

	Combined	Clean fuel	Dirty fuel
Clean fuel (yes-1; no-0)	0.489	1.000	–
Demographic			
Female headed HH (FHHs)	0.111	0.111	0.110
Age of household head (yrs)	47.855	48.629	47.115
	(14.006)	(13.837)	(14.127)
If married head	0.857	0.858	0.856
Number of children under 15 years (nos)	1.589	1.346	1.823
	(1.463)	(1.275)	(1.588)
Number of elderly over 65 years (nos)	0.198	0.214	0.182
	(0.476)	(0.498)	(0.454)
Number of adult males (>15 &<65 yrs) (nos)	1.627	1.642	1.612
	(1.021)	(1.002)	(1.038)
Number of adult females (>15 &<65 yrs) Nos)	1.624	1.645	1.604
	(0.912)	(0.913)	(0.910)
Economic status			
Log Monthly per capital expenditure (constant) (log INR)	6.720	7.067	6.388
	(0.634)	(0.576)	(0.493)
Human capital/Education			
No formal schooling (dummy)	0.296	0.162	0.424
Primary & below schooling (dummy)	0.226	0.174	0.275
Middle & below schooling (dummy)	0.157	0.155	0.158
Secondary & below schooling (dummy)	0.215	0.314	0.120
University (dummy)	0.107	0.195	0.023
Location (rural and urban)			
Rural (dummy)	0.585	0.331	0.828
Urban (dummy)	0.415	0.669	0.172
Social groups (Ethnic/Caste)			
Scheduled tribe, caste &other backward class	0.686	0.592	0.775
Other backward class (OBC)	0.389	0.385	0.392
Scheduled caste (SC)	0.169	0.126	0.210
Scheduled tribe (ST)	0.128	0.081	0.173
General caste (GC)	0.314	0.408	0.225
Time/Year			
Year 2004	0.288	0.171	0.400
Year 2014	0.262	0.240	0.283
Year 2018	0.450	0.589	0.317
Location (State)			
Jammu and Kashmir	0.023	0.026	0.021
Himachal Pradesh	0.018	0.014	0.022
Punjab	0.026	0.037	0.015
Chandigarh	0.004	0.007	0.001
Uttaranchal	0.012	0.016	0.008
Haryana	0.022	0.027	0.018
Delhi	0.014	0.028	0.001
Rajasthan	0.045	0.036	0.054
Uttar Pradesh	0.112	0.087	0.135
Bihar	0.048	0.032	0.063
Sikkim	0.007	0.010	0.004
Arunachal Pradesh	0.014	0.013	0.015
Nagaland	0.009	0.009	0.008
Manipur	0.022	0.025	0.020
Mizoram	0.013	0.018	0.009
Tripura	0.018	0.011	0.025
Meghalaya	0.012	0.006	0.017
Assam	0.035	0.028	0.040
West Bengal	0.065	0.049	0.080
Jharkhand	0.026	0.015	0.037
Orissa	0.036	0.018	0.053
Chattisgarh	0.022	0.016	0.029
Madhya Pradesh	0.051	0.042	0.060
Gujarat	0.039	0.045	0.033
Daman Diu	0.002	0.002	0.001
DN Haveli	0.002	0.002	0.002
Maharastra	0.077	0.101	0.055
Andhra Pradesh	0.046	0.054	0.039
Karnataka	0.044	0.051	0.037
Goa	0.003	0.006	0.001
Lakshadweep	0.002	0.001	0.003
Kerala	0.039	0.035	0.042

Table 2 (*continued*)

	Combined	Clean fuel	Dirty fuel
TamilNadu	0.063	0.083	0.044
Pondicherry	0.004	0.007	0.002
AN Islands	0.004	0.005	0.003
Telengana	0.029	0.044	0.008

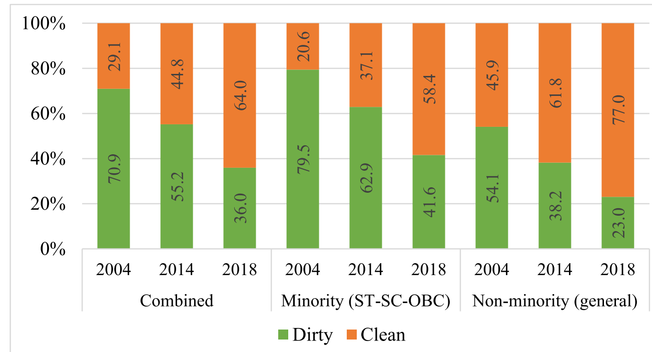

Fig. 1. Trend of households using dirty vs. clean cooking fuel.

Fig. 2(b) reveals that irrespective of the gender of the head of the family, there has been notable progress in access to clean cooking fuel during the last decade. However, the proportion of ST-SC-OBC social groups using clean cooking fuel was lower in families headed by both males and females. Thus, the just energy transition to achieve SDG 7 should target both male and female-headed households from the ST-SC-OBC social groups.

Despite a significant improvement in access to clean cooking fuel, Fig. 2(c) shows a considerable difference between literate and illiterate households, irrespective of social groups. Among illiterate households, in 2018, 44 % of the ST-SC-OBC and 55 % of the general social group used clean cooking fuel, while among literate households, 64 % of ST-SC-OBC and 81 % of the general social group used clean cooking fuel. Therefore, in India, the policy to advance access to clean fuel and ensure energy justice should focus on ST-SC-OBC and the general social group from households headed by illiterate individuals. However, ST-SC-OBCs are more disadvantaged in terms of access to clean energy, irrespective of literacy level; hence, the energy policy should pay special attention to ST-SC-OBCs.

5.3. *Disaggregated descriptive analysis*

Fig. 3 shows the disparity in using clean cooking fuel for ST-SC-OBC vis-à-vis general social groups across all levels of education. Irrespective of the social group, the fraction of households using clean cooking fuel grows with the rise in education levels. About 24.6 % of ST-SC-OBC and 35.2 % of general households with no formal education and 35.2 % and 45.1 % with a primary level of schooling use clean cooking fuel, while 93.2 % of the general social group and 84 % of the ST-SC-OBC social group household with university education use clean cooking fuel. Therefore, just and inclusive clean energy policies should target the disadvantaged social group ST-SC-OBC but should not ignore the general social group with low education, as they also have restricted access to clean cooking fuel.

We further analysed the use of cooking fuel across the level of education for rural and urban households (Appendix 2, Figs. 1 and 2), year (Appendix 2, Figs. 3–5), and gender of the household head (Appendix 2, Figs. 6 and 7), and the result shows there exists a gap between ST-SC-OBC and general groups, but for all social groups, the percentage of households using clean cooking fuel increases with the rise in the education level. In comparing rural and urban households, we find that urban households (irrespective of social group) perform better than

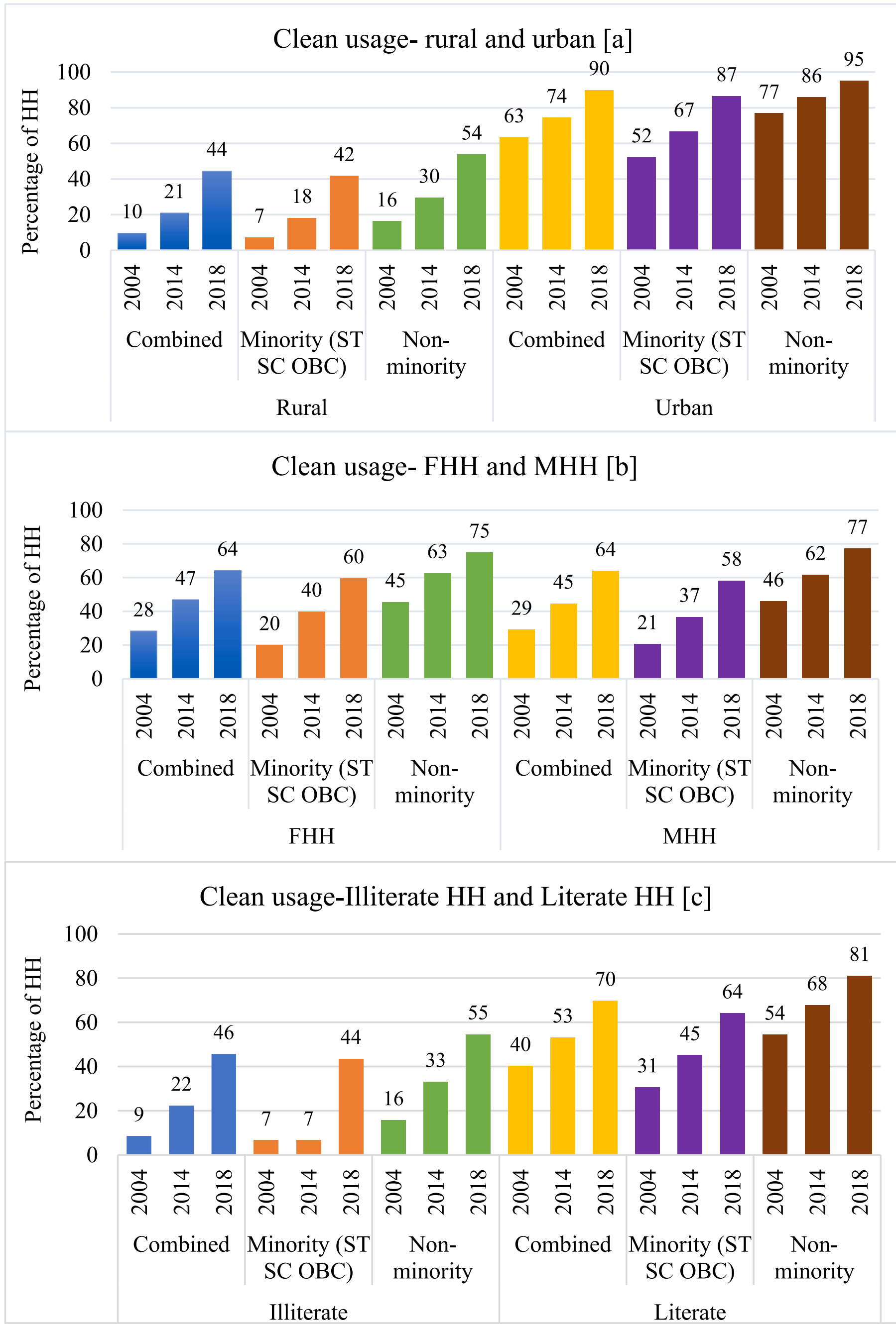

Fig. 2. Percentage of households using clean cooking fuel by location, gender of the head, and literacy.

rural households. In the urban area, 97.9 % of the general social group and 95.3 % of the ST-SC-OBC social group with university-level education use clean cooking fuel. Like any other developing country, India also faces challenges in reducing rural-urban energy disparities to ensure just energy transition and achieve SDG 7. Therefore, besides ST-SC-OBC, the policy to achieve SDG 7 and energy justice should focus on rural households and those with low education levels.

Year-wise analysis of clean cooking fuel usage by education and social groups reveals that the fraction of ST-SC-OBC households using clean cooking fuel was lower than that for the general category, but it increased with the rise in education levels. However, the proportion of households using clean cooking fuel for every level of education has grown over the years, indicating the significant effort of the Government of India to provide access to affordable clean energy, but additional programs, policies, and investments are needed to achieve energy justice and contribute to the global effort of net zero carbon emissions.

Fig. 3(b) shows that 19.6 % of ST-SC-OBC and 28.2 % of the general social group families in consumption quartile 1 use clean cooking fuel, while 77.7 % of ST-SC-OBC and 87.8 % of the general social group in quartile 4 use clean cooking fuel. Clean energy policy should target the disadvantaged social group ST-SC-OBC but should not ignore the poor households from the general social group as they too, have limited access to clean cooking fuel. This means social and economic dimensions are related to the affordability of clean cooking fuel. Thus, addressing economic and social issues is crucial to achieving energy justice in the Indian context.

We also analysed cooking fuel usage across income quartiles for rural and urban households (Appendix 2, Figs. 8 and 9), year (Appendix 2, Figs. 10–12), and gender (Appendix 2, Figs. 13 and 14). The result shows a gap between ST-SC-OBC and general groups, but the percentage of

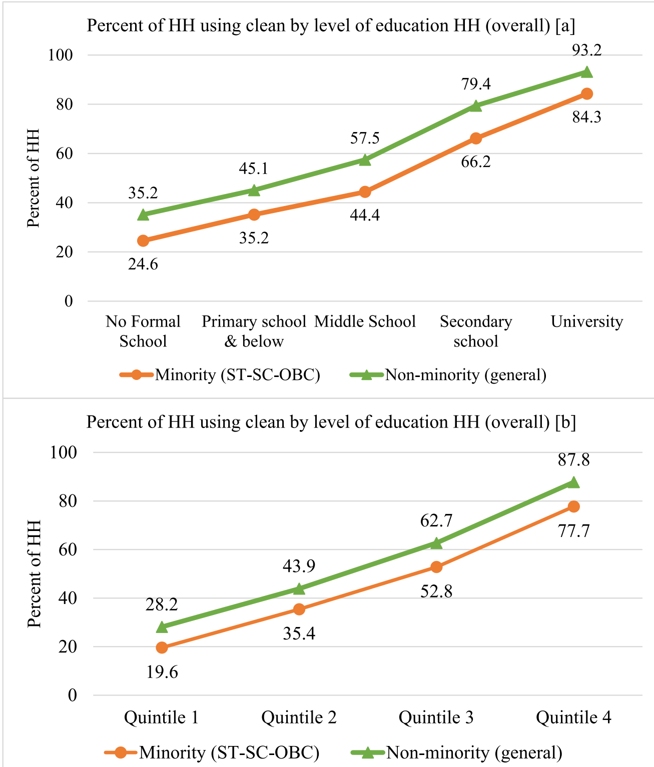

Fig. 3. Percent of HH by education and consumption quartile (for all the years combined).

households increases across the consumption quartile irrespective of social group. In the urban areas, the percentage of ST-SC-OBC and general social group households using clean cooking fuel is higher than in rural areas. For instance, in rural areas, 19.6 % of the general group and 14.5 % of the ST-SC-OBC in quartile 1 use clean energy, while in urban areas, 60.4 % of the general social group and 46.3 % of the ST-SC-OBC in quartile 1 use clean energy.

In quartile 4, 58.1 % of the general social group and 49.4 % of the ST-SC-OBC in the rural areas use clean energy, whereas 94.7 % of the general social group and 88.8 % of the ST-SC-OBC in the urban areas in quartile 4 use clean cooking fuel. Further analysing clean cooking fuel usage by year and income quartiles, we found that the proportion of households using clean fuel increased from year to year, irrespective of the social group across all consumption quartiles, implying a significant improvement in access to clean fuel. Based on the analysis, it can be concluded that the energy policy should focus on the disadvantaged social group, but it should also include low-income families from the general social group in the policy to achieve SDG 7 and just energy transition as energy poverty in India is complex, involving social and economic dimensions.

5.4. *Disaggregated descriptive analysis by state*

Appendix 3, Table 1 shows spatial variation in clean cooking fuel use at the state level across rural and urban locations, Appendix 3, Table 2 shows results over the years; Appendix 3, Table 3 shows variation across consumption quartiles; and Appendix 3, Table 4 shows data across the level of education. First, within social groups (ST-SC-OBC and general), the gap in clean cooking fuel usage is narrow in states with high access to clean fuel. In Chandigarh, Delhi, Goa, Puducherry, and Telangana, roughly 80 % of households use clean cooking fuel. The proportion of ST-SC-OBC and general social group households using clean cooking fuel in these states was high, though it was slightly lower for the ST-SC-OBC groups. Less than 50 % of households use clean fuel as the primary source of energy in Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh, Madhya Pradesh, Odisha, Himachal Pradesh, Kerala, Rajasthan, Tripura, Meghalaya, Assam, Arunachal Pradesh, and West Bengal.

Second, there is a large difference in clean fuel usage between rural and urban areas across states, except for those with high clean cooking fuel penetration rates. In the rural areas of states where the clean cooking fuel penetration rate is low, clean cooking fuel usage is low among all social groups (ST-SC-OBC and general), but there is a significant gap between groups. In the urban areas of most states, the fraction of households that use clean cooking fuel is high; for instance, in the urban areas of 7 states, more than 90 % of the households use clean cooking fuel; and in 15 states, more than 80 % of the households use clean cooking fuel.

We also analysed the distribution of clean fuel usage by state and social groups across consumption quartiles and the household head's level of education. In Chandigarh, Delhi, Goa, Puducherry, and Telangana, only marginal variation in the share of households using clean cooking fuel was observed across the income quintile and education level, mainly because of the high clean energy penetration rate in these states. The clean fuel usage gap between the social groups in the states with high clean energy penetration rates is also low. In poor Indian states, namely Bihar, Odisha, Uttar Pradesh, Assam, Madhya Pradesh, Jharkhand, and Chhattisgarh, wide variation in clean energy usage is observed between poor and rich households and also between social groups. Therefore, the energy justice policy for a just energy transition requires policies that target the marginalized groups and, to some extent, non-marginalized groups from the rural areas of energy-poor states such as Bihar, Odisha, Uttar Pradesh, Assam, Madhya Pradesh, Jharkhand, and Chhattisgarh.

5.5. *Empirical results*

5.5.1. *Factors influencing clean fuel use for cooking (logit model)*

In rural and urban locations, households headed by females tend to use clean cooking fuel (Table 3). Children under 15 years, adults male and female (>15 &<65 years), and the age of the household head have a positive relationship with clean cooking fuel use in urban and rural areas. As expected, the education level of the household head is positive and significant at 1 %, and the marginal effect of education on clean cooking fuel usage increases progressively for both urban and rural households. These findings are similar to existing studies in this context, wherein education seems to play a crucial role in encouraging the adoption of clean energy sources [14,81–85]. As education could help expedite just energy transition, policy contributing to improving literacy on the availability and benefit of clean energy is crucial.

This paper finds that per capita expenditure (in logs) is positive and highly significant, primarily through easing the affordability dimension. Several existing studies have confirmed the crucial role of household income and wealth in the adoption of clean fuel [64,86–89]. Household income and wealth will improve household's capacity to afford clean energy. Based on the current and previous research findings, government energy policy should support the poor and marginalized social groups through price subsidies and cash transfers for clean energy adoption, thereby ensuring distributional energy justice. The coefficient of the rural dummy is −0.238 and significant at 1 %, meaning that rural households have a 23.8 % less likelihood of using clean fuel. Previous studies (Awan et al., 2023 and Timilsina et al., 2023) [90,91] have also highlighted that rural households are largely dependent on biomass for cooking fuel and lack access to clean fuel. Therefore, to improve locational energy justice, the clean energy transition policy must pay special attention to ameliorating accessibility to clean fuel in rural areas through price subsidies to the rural communities and building energy infrastructure in the rural areas. Overall, the gender of the household head, education level, geographical location, and economic status are the crucial drivers of using clean cooking fuel.

As the core aim of this research is to inspect the clean fuel use gap

Table 3
Factor influencing non-solid fuel choice (marginal effect after logit model).

	Location			Gender	
	Combined	Urban	Rural	Male	Female
Demographics					
Female headed HH[a,b]	0.041*** (0.003)	0.043*** (0.004)	0.039*** (0.004)		
Age of household head	0.002*** (0.000)	0.002*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.001*** (0.000)
If married head[a,c]	0.009*** (0.003)	0.016*** (0.004)	0.004 (0.004)	0.006* (0.003)	0.014** (0.007)
Number of children under 15 years	0.002*** (0.001)	0.004*** (0.001)	0.002** (0.001)	0.002*** (0.001)	0.008*** (0.002)
Number of elderlies over 65 years	0.006*** (0.002)	0.008*** (0.003)	0.006** (0.002)	0.004** (0.002)	0.026*** (0.007)
Number of adult male (>15 &<65 yrs)	0.011*** (0.001)	0.012*** (0.001)	0.010*** (0.001)	0.009*** (0.001)	0.025*** (0.002)
Number of adult female (>15 &<65 yrs)	0.019*** (0.001)	0.021*** (0.001)	0.017*** (0.001)	0.016*** (0.001)	0.036*** (0.003)
Education/Education					
Primary school & below education level[a,d]	0.065*** (0.002)	0.091*** (0.004)	0.054*** (0.003)	0.062*** (0.002)	0.093*** (0.006)
Middle school & below education level[a,d]	0.121*** (0.002)	0.154*** (0.004)	0.104*** (0.003)	0.119*** (0.003)	0.147*** (0.009)
Secondary school & below education level	0.207*** (0.002)	0.229*** (0.004)	0.191*** (0.003)	0.204*** (0.003)	0.251*** (0.010)
University[a,d]	0.303*** (0.004)	0.282*** (0.004)	0.304*** (0.006)	0.301*** (0.004)	0.332*** (0.017)
Economic status					
Log Monthly per capital expenditure	0.174*** (0.002)	0.168*** (0.002)	0.168*** (0.002)	0.171*** (0.002)	0.192*** (0.005)
Location					
Rural[a,e]	−0.238*** (0.001)			−0.240*** (0.001)	−0.218*** (0.004)
Social groups					
Scheduled caste[a,f]	−0.076*** (0.002)	−0.087*** (0.003)	−0.066*** (0.003)	−0.074*** (0.002)	−0.085*** (0.007)
Scheduled tribe[a,f]	−0.121*** (0.003)	−0.102*** (0.005)	−0.130*** (0.004)	−0.118*** (0.003)	−0.131*** (0.010)
Oher Backward class[a,f]	−0.043*** (0.002)	−0.044*** (0.003)	−0.036*** (0.003)	−0.041*** (0.002)	−0.047*** (0.006)
States					
Himachal Pradesh[a,g]	−0.075*** (0.007)	−0.036** (0.015)	−0.054*** (0.007)	−0.073*** (0.007)	−0.130*** (0.022)
Punjab[a,g]	0.088*** (0.007)	−0.003 (0.009)	0.139*** (0.009)	0.090*** (0.007)	0.048** (0.024)
Chandigarh[a,g]	0.180*** (0.017)	0.007 (0.015)	0.396*** (0.034)	0.183*** (0.017)	0.119** (0.069)
Uttaranchal[a,g]	0.072*** (0.008)	0.036*** (0.011)	0.091*** (0.011)	0.076*** (0.009)	0.011 (0.026)
Haryana[a,g]	−0.004 (0.007)	−0.041*** (0.010)	0.008 (0.008)	−0.002 (0.007)	−0.042* (0.025)
Delhi[a,g]	0.258*** (0.011)	0.074*** (0.008)	0.599*** (0.032)	0.256*** (0.012)	0.255*** (0.038)
Rajasthan[a,g]	−0.057*** (0.006)	−0.061*** (0.009)	−0.072*** (0.007)	−0.056*** (0.006)	−0.075*** (0.022)
Uttar Pradesh[a,g]	−0.023*** (0.005)	−0.049*** (0.008)	−0.024*** (0.006)	−0.022*** (0.005)	−0.041** (0.020)
Bihar[a,g]	−0.027*** (0.006)	−0.087*** (0.009)	−0.005 (0.007)	−0.022*** (0.006)	−0.094*** (0.024)
Sikkim[a,g]	0.249*** (0.009)	0.088*** (0.013)	0.348*** (0.013)	0.253*** (0.009)	0.184*** (0.028)
Arunachal Pradesh[a,g]	0.067*** (0.008)	0.036*** (0.010)	0.070*** (0.010)	0.071*** (0.008)	0.008 (0.030)
Nagaland[a,g]	0.019** (0.009)	−0.049*** (0.014)	0.054*** (0.012)	0.020** (0.009)	0.005 (0.044)
Manipur[a,g]	0.046*** (0.007)	−0.080*** (0.010)	0.122*** (0.009)	0.044*** (0.007)	0.028 (0.024)
Mizoram[a,g]	0.111*** (0.008)	0.039*** (0.010)	0.121*** (0.012)	0.109*** (0.009)	0.088*** (0.028)
Tripura[a,g]	−0.127*** (0.007)	−0.160*** (0.012)	−0.115*** (0.008)	−0.123*** (0.007)	−0.191*** (0.024)
Meghalaya[a,g]	−0.131*** (0.008)	−0.141*** (0.014)	−0.151*** (0.009)	−0.128*** (0.009)	−0.199*** (0.026)
Assam[a,g]	0.018*** (0.006)	−0.042*** (0.010)	0.044*** (0.007)	0.021*** (0.006)	−0.041* (0.022)
West Bengal[a,g]	−0.114*** (0.005)	−0.184*** (0.008)	−0.089*** (0.006)	−0.110*** (0.005)	−0.175*** (0.020)
Jharkhand[a,g]	−0.120*** (0.007)	−0.222*** (0.010)	−0.074*** (0.008)	−0.118*** (0.007)	−0.156*** (0.025)
Orissa[a,g]	−0.098*** (0.006)	−0.179*** (0.010)	−0.066*** (0.007)	−0.090*** (0.006)	−0.187*** (0.023)
Chhattisgarh[a,g]	−0.024*** (0.007)	−0.109*** (0.010)	0.012 (0.009)	−0.020*** (0.007)	−0.077*** (0.025)
Madhya Pradesh[a,g]	−0.015*** (0.006)	−0.054*** (0.008)	−0.019*** (0.007)	−0.013** (0.006)	−0.033 (0.022)
Gujarat[a,g]	0.018*** (0.006)	−0.069*** (0.009)	0.059*** (0.008)	0.024*** (0.006)	−0.050** (0.023)
Daman & Diu[a,g]	0.152*** (0.019)	−0.016 (0.024)	0.255*** (0.028)	0.157*** (0.021)	0.104** (0.048)
D & N Haveli[a,g]	0.021 (0.019)	−0.112*** (0.025)	0.102*** (0.029)	0.023 (0.019)	−0.001 (0.094)
Maharastra[a,g]	0.072*** (0.005)	−0.023*** (0.008)	0.118*** (0.007)	0.075*** (0.005)	0.035* (0.021)
Andhra Pradesh[a,g]	0.147*** (0.006)	−0.003 (0.008)	0.234*** (0.008)	0.155*** (0.006)	0.067*** (0.021)
Karnataka[a,g]	0.072*** (0.006)	−0.047*** (0.008)	0.137*** (0.008)	0.081*** (0.006)	−0.011 (0.021)
Goa[a,g]	0.189*** (0.016)	−0.012 (0.018)	0.362*** (0.027)	0.174*** (0.018)	0.187*** (0.038)
Lakshadweep[a,g]	−0.163*** (0.015)	−0.268*** (0.024)	−0.117*** (0.022)	−0.175*** (0.018)	−0.212*** (0.033)
Kerala[a,g]	−0.140*** (0.006)	−0.301*** (0.009)	−0.051*** (0.007)	−0.127*** (0.006)	−0.241*** (0.020)
Tamil Nadu[a,g]	0.127*** (0.006)	−0.041*** (0.008)	0.243*** (0.007)	0.137*** (0.006)	0.037* (0.020)
Pondicherry[a,g]	0.133*** (0.014)	−0.025* (0.014)	0.333*** (0.028)	0.148*** (0.016)	0.031 (0.035)
A & N Islands[a,g]	−0.030*** (0.012)	−0.164*** (0.019)	0.041*** (0.016)	−0.026** (0.012)	−0.089*** (0.035)
Telangana[a,g]	0.278*** (0.007)	0.058*** (0.009)	0.400*** (0.010)	0.282*** (0.007)	0.230*** (0.024)
Year					
2014[a,h]	0.057*** (0.002)	0.054*** (0.003)	0.058*** (0.003)	0.056*** (0.002)	0.066*** (0.006)
2018[a,h]	0.197*** (0.002)	0.144*** (0.003)	0.233*** (0.003)	0.197*** (0.002)	0.189*** (0.006)
Number of obs	249,466	103,544	145,922	221,863	27,597
LR chi2 (53)	153,455	37,009	53,260	138,417	15,521
Prob > chi2	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.444	0.346	0.309	0.450	0.406
Log likelihood	−96131	−34946	−59465	−84519	−11365

Note: ***, **, * significant at 1 %, 5 %, and 10 %.
[a] Dummy variable.
[b] Base category: male-headed household.
[c] Base category: single head household (not-married, divorced, widow).
[d] Base category: illiterate household head.
[e] Base category: urban.
[f] Base category: General Caste (GC) household.
[g] Base category: Jammu & Kashmir.
[h] Base category: Survey year 2004.

among social groups, we divided the households into 4 social dummies, namely, scheduled caste (SC), scheduled tribe (ST), other backward class (OBC), and general caste (GC) category; in our analysis, general caste (GC) is used as the base. Across the country, we find that compared to the GC, ST are 12.1 % less likely to use clean cooking fuel, while the SC and OBC are 7.6 % and 4.3 % less likely, respectively, to use clean cooking fuel. We also find a similar result in the urban and rural areas, i.e., compared to the GC social group, the SC, ST, and OBC are less likely to use clean fuel, and the ST is the most deprived group.

We estimated the marginal effect of the interaction between social groups, economic status (per capita consumption quartile), and level of education after logit regression, as provided in Table 4. The result shows that the minority social group (ST-SC-OBC) has a lower likelihood of using clean cooking fuel. However, families with low education levels and economic status are less likely to use clean cooking fuel irrespective of the social group (GC or ST-SC-OBC). Therefore, government policy should certainly focus on minority social groups (ST-SC-OBC), but should not ignore the non-minority social groups (GC) in the lower socio-economic categories.

To examine the heterogeneity, we estimated the logit model separately for different states (Appendix 4, Tables 1 & 3–9), different levels of education (Appendix 4, Tables 2 and 10), different income quartiles (Appendix 4, Tables 2 and 11), and different years (Appendix 4, Tables 2 and 12). As expected, we find that STs were most deprived of clean cooking fuel usage. State-level analysis shows that ST, SC, and OBC had a lower likelihood of using clean cooking fuel, but it varies across states, and the education of the household head and wealth positively impact clean cooking fuel use. The logit model at a different education level and consumption quartile shows that ST-SC-OBC had a lower likelihood of using clean cooking fuel compared to the general social group. Given the complexity of Indian society, this analysis clearly highlights the need to target households in the disadvantaged social group (i.e., ST-SC-OBC) and also families from the general social group with a lower economic status) to achieve SDG 7 and a just energy transition by 2060. Thus, the energy policy in India should be nimble and agile enough to ensure energy justice.

Table 4
Marginal Effect of the interaction between social group, economic status (per capita consumption quartile), and level of education after logistic regression.

		Quartile 1	Quartile 2	Quartile 3	Quartile 4
		Non-minority (GC)			
		(A)	(B)	(C)	(D)
No formal schooling	(1)	0.221*** (0.008)	0.299*** (0.008)	0.434*** (0.010)	0.582*** (0.013)
Primary school & below education level	(2)	0.284*** (0.010)	0.417*** (0.010)	0.554*** (0.010)	0.746*** (0.009)
Middle school & below education level	(3)	0.396*** (0.014)	0.537*** (0.011)	0.680*** (0.009)	0.823*** (0.007)
Secondary school & below education level	(4)	0.541*** (0.014)	0.668*** (0.009)	0.804*** (0.006)	0.920*** (0.003)
University	(5)	0.706*** (0.025)	0.812*** (0.013)	0.884*** (0.007)	0.966*** (0.002)
		Minority (ST-SC-OBC)			
		(A)	**(B)**	**(C)**	**(D)**
No formal schooling	(1)	0.146*** (0.003)	0.229*** (0.004)	0.303*** (0.005)	0.429*** (0.010)
Primary school & below education level	(2)	0.222*** (0.005)	0.322*** (0.005)	0.451*** (0.006)	0.606*** (0.009)
Middle school & below education level	(3)	0.285*** (0.007)	0.404*** (0.007)	0.543*** (0.007)	0.731*** (0.008)
Secondary school & below education level	(4)	0.398*** (0.008)	0.540*** (0.007)	0.685*** (0.006)	0.861*** (0.004)***
University	(5)	0.511*** (0.019)	0.698*** (0.013)	0.816*** (0.009)	0.934*** (0.004)

5.5.2. Ethnicity and the use of clean energy sources for cooking: exogenous switching treatment effect regression (ESTER)

ST-SC-OBCs are generally less likely to use clean cooking fuel compared to the GC social group (Table 3 and Appendix 4). Further, we estimate the conditional expected probability of clean energy use and treatment effects of social groups using the estimated coefficients from ESTER. A large fraction of the ST-SC-OBC social groups would use clean cooking fuel if they had the same observed resources and characteristics as the general social group. Still, the gap between ST-SC-OBC and GC would not be zero even if these observed differences were accounted for, as the unobservable social differences would have caused the ST-SC-OBC social group to use less clean cooking fuel than the general social category. Such a finding is crucial to ensuring a just energy transition and energy justice by 2060 in developing countries. Recognizing socio-cultural complexities in energy policy in India is a significant step toward achieving SDG 7, 10 and 5 and energy justice.

In Table 5, the data showing actual and counterfactual clean cooking fuel use is given in cells (a) and (c), and (b), and (d), respectively. The difference between cells (a) and (b) in Table 5 represents the observed clean cooking fuel usage gap between ST-SC-OBC and GC (i.e., the social group clean energy gap), which is 21.2 %. The analysis shows that this clean energy use gap could decline by 6.1 % if the ST-SC-OBC were GC (difference between cells [c] and [b], Table 5). Such a disparity can be explained by applying the recognition justice (i.e., how society acknowledges the social position of each caste/ethnic group and how their roles and access are facilitated and/or inhibited due to their caste/ethnic identity) aspects of the energy justice in a society deep-rooted with caste/ethnic differences. Hence, government policy should attempt to close the social energy inequality gap by devising apposite opportunities for marginalized social groups to enhance their human capital, partake in non-farm employment, and improve their economic status. More importantly, if the ST-SC-OBC had the same level of returns on their resources as their GC counterparts, the clean energy use gap could be reduced but still remain due to unobserved heterogeneity. Energy policy should aim to make clean energy accessible and affordable to marginalized groups (ST-SC-OBC) by building clean energy infrastructure and making it affordable through price support. Such policy would improve the adoption of clean cooking fuels and reduce energy inequity, thereby

Table 5
Non-solid fuel use, treatment, and heterogeneity effects by social group (Exogenous switching treatment effect regression [ESTER]).

Social Group	Social Group		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.422 [a] (0.001)	0.574 [c] (0.001)	0.151*** (0.001)
Non-minority (GC)	0.484 [d] (0.001)	0.635 [b] (0.001)	−0.150*** (0.002)
Heterogeneity effect	−0.062*** (0.001)	−0.061*** (0.002)	−0.212*** (0.001)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste.
SC-Schedule caste.
OBC-Other backward class.

contributing to just energy transition and attaining the SDG 7 target.

In Table 6, we compared ST, SC, and OBC with each other and found that ST is the most underprivileged social group, which indicates that from among the marginalized groups, the scheduled tribe (ST) needs more support to attain SDG7 and energy equity. Cell (c) of Table 6 signifies the counterfactual condition for ST, i.e., if the observed characteristics of ST had the same returns as of SC-OBC, what would be ST's clean cooking fuel use status? The difference between cells (a) and (b) in Table 6 (section A) shows the observed clean cooking fuel use gap between ST and SC-OBC, which is 13.9 %. The results show that this clean energy use gap would remain at 5.4 % even if the ST had the same return to their resources as SC-OBC (Difference between cells [c] and [b], Table 6, section A). It indicates that distributive justice aspects of energy justice is also crucial to address the clean energy use gap in a social set up where recognition is associated with access to economic resources. Thus, unless the government puts forth effective strategies to close the social energy gap by expanding opportunities for STs to enhance their human capital, partake in non-farm activities, and increase their economic status, achieving energy justice will be a distant dream.

The observed difference between SC and ST-OBC is −7.6 %, significant at a 1 % significance level, while the gap between ST and SC-OBC is −13.9 % (see Table 6, Section B). This result shows that within ST-SC-OBC, there are differences in access and usage of clean cooking fuel, and hence, effective energy policies should be designed to uplift the most marginalized groups rather than a blanket policy. The clean cooking fuel gap between OBC and ST-SC is 14.3 % (Table 6, Section C), confirming that the policy should focus on STs followed by SCs and OBCs to achieve SDG 7 with the aim of providing clean and affordable energy by 2030. This section concludes that energy policy for just energy transition and distributional justice should be more granular, and the level of incentives and support should be needs-based and differentiated by less segregation of the social groups. It also reflects why recognition justice within the tenets of energy justice can be a guiding principle in designing future energy policy in India.

Table 6
Non-solid fuel use, treatment, and heterogeneity effects by social group (within the minority)- Exogenous switching treatment effect regression (ESTER).

Social Group	Social Group (Scheduled tribe versus scheduled caste and Other backward class) [A]		
	Minority (ST)	Other minorities (SC-OBC)	Treatment effect
Minority (ST)	0.310 [a] (0.002)	0.395 [c] (0.001)	0.085*** (0.001)
Minority (SC-OBC)	0.382 [d] (0.002)	0.448 [b] (0.001)	−0.066*** (0.002)
Heterogeneity effect	−0.072*** (0.003)	−0.054*** (0.001)	−0.139*** (0.002)
Social Group	**Social Group (Schedule caste versus schedule tribe and Other backward class) [B]**		
	Minority (SC)	Other minorities (ST-OBC)	Treatment effect
Minority (SC)	0.365 [a] (0.002)	0.435 [c] (0.001)	0.069*** (0.002)
Minority (ST-OBC)	0.389 [d] (0.002)	0.441 [b] (0.001)	−0.052*** (0.002)
Heterogeneity effect	−0.024*** (0.002)	−0.007*** (0.001)	−0.076*** (0.002)
Social Group	**Social Group (Other backward class versus Scheduled tribe and scheduled caste) [C]**		
	Minority (OBC)	Minority (ST-SC)	Treatment effect
Minority (OBC)	0.485 [a] (0.001)	0.385 [c] (0.001)	0.099*** (0.002)
Minority (ST-SC)	0.430 [d] (0.001)	0.341 [b] (0.001)	0.089*** (0.002)
Heterogeneity effect	0.055*** (0.002)	0.044*** (0.002)	−0.143*** (0.002)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste.
SC-Schedule caste.
OBC-Other backward class.

5.5.3. Heterogeneity analysis by gender: ethnicity and the use of clean energy sources for cooking using exogenous switching treatment effect regression (ESTER)

In Table 7, we compared the ST-SC-OBC with the GC by gender of the household head. The variance between cells (a) and (b) in Table 7 indicates the observed clean cooking fuel use gap between the ST-SC-OBC and GC, which is 21.4 % for male-headed households (MHHs) and 19.5 % for female-headed households (FHHs). Our analysis suggests that the clean cooking fuel use gap would still remain at 6.7 % and 5.9 % for FHHs and MHHs, respectively, if the ST-SC-OBC were GC social group (Difference between cells [c] and [b], Table 7). The effects due to unobserved heterogeneity remain crucial even if both groups of households have similar returns to their capital resources, implying that the clean energy use gap between these two categories of households would persist over time. The analysis suggests that ST-SC-OBC, irrespective of the gender of the household head, faces a disadvantage in access to clean energy and, thus, support for marginalized groups is critical for just transition and accomplishing SDG 7. However, it is crucial to note that FHHs from the ST-SC-OBC group are more disadvantaged, and hence, FHHs need more support for just energy transition.

In Table 8, we compared the ST-SC-OBC group with the GC social group by rural-urban location of the households. The observed clean cooking fuel use gap among the ST-SC-OBC and GC is 9.6 % for rural and 14.6 % for urban households. Our results show that the clean cooking fuel use gap would remain at 6.1 % and 5.1 % for rural and urban households, respectively, if the ST-SC-OBC were the GC social group. For rural and urban households, if the ST-SC-OBC were the GC social group, the clean energy use gap would decline by 3.5 % and 8.1 % for rural and urban households, respectively. The ST-SC-OBC group lacks access to clean cooking fuel compared to GC in rural and urban locations; thus, regardless of the location, the energy justice program should target ST-SC-OBC so that no one is left behind during the transition. However, ST-SC-OBC living in rural areas are more clean energy deprived and need more support in the form of subsidies and accessibility through

Table 7
Non-solid fuel use, treatment, and heterogeneity effects by social group and gender of the household head (FHH and MHH)- Exogenous switching treatment effect regression (ESTER).

Social Group	FEMALE-HEADED HOUSEHOLDS		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.432 [a] (0.002)	0.561 [c] (0.004)	0.128*** (0.001)
Non-minority (GC)	0.474 [d] (0.002)	0.627 [b] (0.004)	−0.153*** (0.004)
Heterogeneity effect	−0.042*** (0.003)	−0.067*** (0.002)	−0.195*** (0.004)
Social Group	**MALE-HEADED HOUSEHOLDS**		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.421 [a] (0.001)	0.576 [c] −0.001	0.155*** (0.002)
Non-minority (GC)	0.485 [d] (0.001)	0.635 [b] (0.001)	0.151*** (0.002)
Heterogeneity effect	−0.063*** (0.002)	−0.059*** (0.001)	−0.214*** (0.001)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste.
SC-Schedule caste.
OBC-Other backward class.

Table 8
Non-solid fuel use, treatment, and heterogeneity effects by social group and location (Rural and Urban)- Exogenous switching treatment effect regression (ESTER).

Social Group	RURAL HOUSEHOLDS		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.253 [a] (0.001)	0.288 [c] (0.001)	0.035*** (0.002)
Non-minority (GC)	0.327 [d] (0.001)	0.349 [b] (0.001)	−0.022*** (0.002)
Heterogeneity effect	−0.074*** (0.001)	−0.061*** (0.002)	−0.096*** (0.002)
Social Group	**URBAN HOUSEHOLDS**		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.728 [a] (0.001)	0.823 [c] (0.001)	0.095*** (0.002)
Non-minority (GC)	0.794 [d] (0.001)	0.875 [b] (0.001)	−0.081*** (0.001)
Heterogeneity effect	−0.066*** (0.001)	−0.051*** (0.001)	0.146*** (0.001)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste.
SC-Schedule caste.
OBC-Other backward class.

infrastructure.

The results presented in Table 8 illustrate that the likelihood of using clean cooking fuel for the general social group is 40.4 % in rural areas, while the likelihood of using clean cooking fuel for ST-SC-OBC in urban areas is 77.3 %. Therefore, the clean energy policy should not only focus on ST- SC-OBC but also target the GC social group in rural areas to ensure a fair energy transition.

Table 9 compares the clean energy usage gap between ST-SC-OBC and the GC social group across per capita consumption quartile. The observed clean cooking fuel use gap between the ST-SC-OBC and GC social groups is 8.5 %, 8.5 %, 9.9 %, and 10 % (significant at 1 %) for quartiles 1, 2, 3, and 4, respectively. The results show that the clean cooking fuel use gap would still remain at 6.5 %, 6.7 %, 7.4 %, and 3.4 % (significant at 1 %) for quartiles 1, 2, 3, and 4, respectively, if ST-SC-OBC were GC social group.

The probability of using clean cooking fuel for the GC social group is 38.1 % in quartile 1, and 43.9 % for quartile 2, while the likelihood of using clean cooking fuel for the ST-SC-OBC social group in quartiles 3 and 4 is 52.8 % and 77.7 %, respectively (Table 9). Just energy transition policy must be designed in a way that it is not one-size-fits-all for the ST-SC-OBC; rather, it should target the ST-SC-OBC in quartiles 1 and 2, followed by the GC social group in quartiles 1 and 2.

In Table 10, we compare the ST-SC-OBC with the GC social group by the literacy of the household head. 10.3 % is the observed clean cooking fuel use gap between the ST-SC-OBC and GC for households with illiterate heads and 18.8 % for households with literate heads. The results show that the clean cooking fuel use gap would remain at 6.6 % and 7.6 % (significant at 1 %) for illiterate and literate households, respectively, if the ST-SC-OBC were GC social group. Thus, a clean energy policy should be designed to provide financial and infrastructural support to ST-SC-OBC with illiterate household heads to contribute to just energy transition.

In Table 11, we compare the ST-SC-OBC with the GC social group by the education level of the head of the family. The observed clean cooking fuel use gap between the ST-SC-OBC and GC social groups is 10.6 %, 9.9 %, 13 %, 13.3 %, and 8.9 % (significant at 1 %) for households headed by a head without formal school, with a primary level of schooling, with middle level of schooling, with a secondary level of schooling and university level of schooling, respectively. The results show that the clean cooking fuel use gap would still remain at 6.7 %, 6.3 %, 6.3 %, 5.8 %, and 3 % (significant at 1 %) for households headed by a head without formal school, with a primary level of schooling, with middle level of schooling, with secondary and university education, respectively if the ST-SC-OBC had a similar level of endowments as a general social group. Interestingly, if the return on resources for ST-SC-OBC had been similar to their GC counterpart, this clean energy use gap would have been lowered to 3.9 %, 3.6 %, 6 %, 7.4 %, and 5.9 % for households headed by head without formal school, with a primary, with middle, with a secondary and university education, respectively.

Table 9
Non-solid fuel use, treatment, and heterogeneity effects by social group (across consumption quartile)- Exogenous switching treatment effect regression (ESTER).

Social Group	HOUSEHOLDS IN CONSUMPTION QUARTILE 1		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.196 [a] (0.001)	0.215 [c] (0.001)	0.020*** (0.002)
Non-minority (GC)	0.273 [d] (0.001)	0.281 [b] (0.001)	−0.008*** (0.003)
Heterogeneity effect	−0.077*** (0.003)	−0.065*** (0.001)	−0.085*** (0.002)
Social Group	**HOUSEHOLDS IN CONSUMPTION QUARTILE 2**		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.354 [a] (0.001)	0.372 [c] (0.001)	0.018*** (0.003)
Non-minority (GC)	0.432 [d] (0.001)	0.439 [b] (0.001)	−0.007*** (0.003)
Heterogeneity effect	−0.077*** (0.002)	−0.067*** (0.003)	−0.085*** (0.003)
Social Group	**HOUSEHOLDS IN CONSUMPTION QUARTILE 3**		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.528 [a] (0.001)	0.553 [c] (0.001)	0.024*** (0.003)
Non-minority (GC)	0.605 [d] (0.001)	0.627 [b] (0.001)	−0.022*** (0.003)
Heterogeneity effect	−0.077*** (0.002)	−0.074*** (0.003)	−0.099*** (0.003)
Social Group	**HOUSEHOLDS IN CONSUMPTION QUARTILE 4**		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.777 [a] (0.001)	0.843 [c] (0.001)	0.066*** (0.002)
Non-minority (GC)	0.821 [d] (0.001)	0.878 [b] (0.001)	−0.057*** (0.002)
Heterogeneity effect	−0.044*** (0.002)	−0.034*** (0.002)	−0.100*** (0.002)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste.
SC-Schedule caste.
OBC-Other backward class.

Further, the possibility of using clean cooking fuel for the GC social is 35.1 % in households with no formal education, 45.1 % for households with primary schooling, and 57.4 % for households with middle school education, while the likelihood of using clean cooking fuel for ST-SC-OBC with secondary schooling is 66.1 % and 84.2 % for those with university education. Therefore, the government's just energy transition policy should aim to increase awareness through campaigns and the provision of support for education to ST-SC-OBC. India already has a reservation system for university education and government jobs, but it seems to benefit ST-SC-OBC from a higher economic status. Hence, a complex matrix based on a combination of social group and economic status should be used to identify the target group. The results suggest targeting the GC social group, whose household heads have no or low levels of education.

Table 10
Non-solid fuel use, treatment and heterogeneity effects by social group by literacy.

Social Group	HOUSEHOLDS WITH ILLITERATE HEAD		
	Minority ((ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.243 [a] (0.001)	0.280 [c] (0.002)	0.037*** (0.003)
Non-minority (GC)	0.309 [d] (0.001)	0.346 [b] (0.003)	−0.037*** (0.003)
Heterogeneity effect	−0.066*** (0.002)	−0.066*** (0.004)	−0.103*** (0.003)
Social Group	HOUSEHOLDS WITH LITERATE HEAD		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.510 [a] (0.001)	0.622 [c] (0.001)	0.112*** (0.002)
Non-minority (GC)	0.594 [d] (0.001)	0.698 [b] (0.001)	−0.104*** (0.002)
Heterogeneity effect	−0.084*** (0.001)	−0.076*** (0.002)	−0.188*** (0.002)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste.
SC-Schedule caste.
OBC-Other backward class.

Table 12 compares the ST-SC-OBC with the GC social group by survey year. The observed clean cooking fuel use gap between the ST-SC-OBC and GC social groups was 25.3 % in 2004, 24.6 % in 2014, and 18.5 % (significant at 1 %) in 2018. The results show that the clean cooking fuel use gap would still remain at 4.6 % in 2004, 6.7 % in 2014, and 6.7 % in 2018 if the ST-SC-OBC were GC social group (calculated as the difference between cells [c] and [b] of Table 12). Though the clean cooking fuel gap declined over time, the gap persists, which calls for additional support to ST-SC-OBC for a just energy transition. Further, this should be complemented by building infrastructure for the distribution of clean fuel.

We also estimated the clean cooking fuel use gap by state. The analysis indicates the existence of a clean cooking fuel use gap among ST-SC-OBC and the GC social group in India (Appendix 5, Tables 1–32). However, it is essential to remember that there is likely a wide variation in the use of clean cooking fuels between ST-SC-OBC and the GC social group. For instance, in Rajasthan, Uttar Pradesh, Jharkhand, Odisha, Chhattisgarh, Madhya Pradesh, Gujarat, Dadra & Nagar Haveli, the clean cooking fuel observed gap [(a)-(b)] between the social group is more than 20 %. In Jammu & Kashmir, Punjab, Haryana, Bihar, Manipur, Tripura, Meghalaya, West Bengal, and Maharashtra, the clean cooking fuel observed gap [(a)-(b)] between the social groups is more than 15 %. In contrast, the clean cooking fuel observed gap [(a)-(b)] between the social groups is around 10 % in Himachal Pradesh, Arunachal Pradesh, Nagaland, Andhra Pradesh, Kerala; and less than 7 % in Chandigarh, Uttaranchal, Delhi, Assam, Daman & Diu, Karnataka, Goa, Tamil Nadu, Andaman & Nicobar Islands, and Telangana. In some states such as Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh, Bihar, Arunachal Pradesh, Tripura, Meghalaya, Assam, West Bengal, Odisha, and Kerala, the likelihood of using clean cooking fuel is low for both ST-SC-OBC and GC social groups. Thus, the central government and state governments of the energy-poor states should work closely to improve the affordability of the poor and socially marginalized groups further by heavy investment to improve the accessibility and supply of clean energy.

5.5.4. Robustness check using the Blinder–Oaxaca model

To examine the robustness of the ESTER results, we estimate the Blinder–Oaxaca model, and the results show that the clean fuel use gap between the ST-SC-OBC and GC social groups is 20.6 %. While 14.2 % is due to the endowment, 8.6 % is due to the coefficient, and the interaction term reduces the gap by 2.3 % (Table 13). Further, the clean fuel gap between ST and SC-OBC is 18 %, 11.3 % due to endowments, 12.6 % due to the coefficient, and the interaction reduces the gap by 5.2 %. The gap between SC and ST-OBC is 7.0 %, and 6.9 % is due to the endowment effect, 2.1 % is due to the coefficient effect, and the interaction has a reducing effect of 2.0 %. The gap between OBC and ST-SC is −16.9 %, with −9.7 % due to the endowment effect and −6.1 % due to the coefficient effect. This confirms that ST-SC-OBC are disadvantaged in clean cooking fuel usage, but ST is worse off among them, followed by SC and OBC. Thus, the just energy transition should pay more attention to ST and SC as these social groups are the most disadvantaged in terms of access to clean cooking fuel, which is crucial for health and well-being.

Table 11
Non-solid fuel use, treatment and heterogeneity effects by social group and level of schooling- Exogenous switching treatment effect regression (ESTER).

Social Group	HOUSEHOLDS HEAD WITH NO FORMAL SCHOOL		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority ((ST-SC-OBC)	0.246 [a] (0.001)	0.285 [c] (0.001)	0.039*** (0.002)
Non-minority (GC)	0.314 [d] (0.001)	0.351 [b] (0.001)	−0.038*** (0.003)
Heterogeneity effect	−0.068*** (0.002)	−0.067*** (0.003)	−0.106*** (0.003)
Social Group	HOUSEHOLDS HEAD WITH PRIMARY SCHOOL &BELOW		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.352 [a] (0.001)	0.388 [c] (0.003)	0.036*** (0.002)
Non-minority (GC)	0.415 [d] (0.002)	0.451 [b] (0.003)	−0.036*** (0.003)
Heterogeneity effect	−0.064*** (0.002)	−0.063*** (0.004)	−0.099*** (0.003)
Social Group	HOUSEHOLDS HEAD WITH MIDDLE SCHOOL		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.444 [a] (0.002)	0.504 [c] (0.003)	0.060*** (0.003)
Non-minority (GC)	0.513 [d] (0.002)	0.574 [b] (0.003)	−0.061*** (0.003)
Heterogeneity effect	−0.064*** (0.003)	−0.063*** (0.004)	−0.130*** (0.003)
Social Group	HOUSEHOLDS HEAD WITH SECONDARY SCHOOL		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.661 [a] (0.002)	0.736 [c] (0.002)	0.074*** (0.003)
Non-minority (GC)	0.733 [d] (0.002)	0.794 [b] (0.002)	−0.061*** (0.002)
Heterogeneity effect	−0.072*** (0.002)	−0.058*** (0.003)	−0.133*** (0.002)
Social Group	HOUSEHOLDS HEAD WITH UNIVERSITY AND ABOVE		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.842 [a] (0.002)	0.901 [c] (0.001)	0.059*** (0.002)
Non-minority (GC)	0.883 [d] (0.002)	0.931 [b] (0.001)	−0.048*** (0.002)
Heterogeneity effect	−0.041*** (0.003)	−0.030*** (0.002)	−0.089*** (0.002)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively.
Standard errors are in parentheses.
ST-Schedule caste; SC-Schedule caste; OBC-Other backward class.

6. Conclusion and policy recommendations

The UN's SDG 7 strives to realize access to clean and affordable energy sources for all by 2030. Delivery of clean and reasonably priced

Table 12
Non-solid fuel use, treatment, and heterogeneity effects by social group and year - Exogenous switching treatment effect regression (ESTER).

Social Group	HOUSEHOLD WITH THE YEAR 2004		
	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.205 [a] (0.001)	0.413 [c] (0.002)	0.207*** (0.002)
Non-minority (GC)	0.240 [d] (0.001)	0.459 [b] (0.002)	−0.219*** (0.003)
Heterogeneity effect	−0.034*** (0.002)	−0.046*** (0.003)	−0.253*** (0.003)
	HOUSEHOLD WITH THE YEAR 2014		
Social Group	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.371 [a] (0.002)	0.551 [c] (0.002)	0.179*** (0.003)
Non-minority (GC)	0.434 [d] (0.002)	0.617 [b] (0.002)	−0.183*** (0.003)
Heterogeneity effect	−0.063*** (0.002)	−0.067*** (0.003)	−0.246*** (0.003)
	HOUSEHOLD WITH THE YEAR 2018		
Social Group	Minority (ST-SC-OBC)	Non-minority (GC)	Treatment effect
Minority (ST-SC-OBC)	0.584 [a] (0.001)	0.716 [c] (0.002)	0.132*** (0.002)
Non-minority (GC)	0.673 [d] (0.001)	0.769 [b] (0.001)	−0.096*** (0.002)
Heterogeneity effect	−0.063*** (0.002)	−0.067*** (0.002)	−0.185*** (0.002)

***, **, * implies significance at less than 1 %, 5 % and 10 %, respectively. Standard errors are in parentheses.
ST-Schedule caste; SC-Schedule caste; OBC-Other backward class.

Table 13
Non-solid fuel use gap by social group and year using Blinder Oaxaca model.

	Group 1: General Group 2: (ST-SC-OBC)	Group 1: SC-OBC Group 2: ST	Group 1: ST-OBC Group 2: SC	Group 1: OBC Group 2: ST-SC
Group 1	0.713*** (0.002)	0.542*** (0.002)	0.523*** (0.002)	0.410*** (−0.002)
Group 2	0.506*** (0.001)	0.355*** (0.003)	0.453*** (0.003)	0.579*** (0.002)
Difference	0.206*** (0.002)	0.187*** (0.003)	0.070*** (0.003)	−0.169*** (0.003)
Endowments	0.142*** (0.002)	0.113*** (0.007)	0.069*** (0.004)	−0.097*** (0.006)
Coefficients	0.086*** (0.004)	0.126*** (0.009)	0.021*** (0.003)	−0.061*** (0.003)
Interaction	−0.023*** (0.004)	−0.052*** (0.011)	−0.020*** (0.004)	−0.011** (0.006)

fuel at the household level would not only improve the well-being of the household but also contribute to reducing global greenhouse gas (GHG) emissions, thereby helping to achieve the global pursuit of carbon neutrality. However, according to the World Energy Outlook Special Report, 2017 roughly 2.5 billion individuals globally bank on biomass as a cooking fuel [92]. For energy justice and a just energy transition, it is crucial to support the energy-poor individuals to switch from dirty fuel to clean fuel. The Government of India has laid down numerous policies and programs to expand access to clean and reasonably priced energy sources. However, in India, a significant proportion of 1.429 billion people do not have access to clean cooking fuel sources, which poses a crucial question on energy justice and a just energy transition.

Furthermore, socially disadvantaged households, including Scheduled Tribes (ST), Scheduled Castes (SC), and Other Backward Class (OBC), often have lower asset endowments, making it difficult for them to afford clean fuel access. This socio-economic disparity hinders the equitable distribution of the benefits of modern energy systems, thereby aggravating the vision of "just energy transition" in India. Rural households also face greater challenges in accessing clean fuel compared to their urban counterparts, irrespective of their caste or ethnic status, mainly due to affordability and accessibility.

To comprehensively understand the existing gap in clean cooking energy access among various social and economic groups and devise strategies to promote energy justice, this study utilizes unit-level data records from three health and morbidity rounds of the National Sample Survey Organization Schedule 25: 2004 (60th round survey); 2014 (71st round survey); and 2017–18 (75th round survey).

The findings reveal a significant clean cooking fuel adoption gap between social groups in India, emphasizing the need for policies that facilitate just energy transition and support the achievement of SDG 7 by 2030. Among disadvantaged social groups, Scheduled Tribes (ST) face the most significant deprivation, followed by Scheduled Castes (SC) and Other Backward Class (OBC). Therefore, clean energy policies that aim to ensure energy justice and just transition from the distributional or equity perspective should target these marginalized and disadvantaged communities. Additionally, the analysis highlights that in rural areas, together with marginalized social groups, the General Caste (GC) households also face challenges in adopting clean cooking fuels, regardless of their social status, indicating the importance of improving accessibility and affordability of rural households for clean energy through price subsidies in rural areas, and building clean energy infrastructure to connect rural families to clean and affordable sources of energy.

Besides, the findings show that the gender of the head, education, and economic status also emerged as critical determinants of the adoption of clean cooking fuel irrespective of the social groups. As female-headed households have limited endowment, their affordability for clean energy is limited; hence, the policy for just energy transition should support female-headed households through energy price subsidies, progressive energy pricing, and cash transfers, which would enable the female-headed households to overcome the barrier of availing clean energy. Educating households on the benefits of clean energy on the health and well-being of the family members, particularly the female, and children, would go a long way in nudging the household on the use of clean cooking fuel and hence support the endeavour of just energy transition. Irrespective of social status, low-income households are disadvantaged in using clean cooking fuel, particularly due to affordability, calling for a just energy transition policy to support low-income families to ensure distributional justice and equity.

Finally, the paper concludes that the clean energy policy should consider both Scheduled Tribes, Scheduled Castes, and Other Backward Class, as well as General Caste households, particularly those with low economic status, female-headed households, household heads with limited education levels, and those residing in rural areas and disadvantaged states, such as Bihar, Jharkhand, Madhya Pradesh, Himachal Pradesh, Chhattisgarh, Rajasthan, Uttar Pradesh Tripura, Meghalaya, West Bengal and Orissa (Odhisa), to ensure social equity, promote energy justice, and facilitate a just energy transition in India.

From the just energy policy perspective, it is not only critical to strengthen the implementation of targeted subsidy programs to make clean cooking fuels, such as LPG (liquefied petroleum gas), more affordable and accessible for socially disadvantaged groups like Scheduled Tribes (ST), Scheduled Castes (SC), and Other Backward Class (OBC) but also to invest in launching awareness and education campaigns aimed at both rural and urban households, with a focus on low-income families, female-headed households and disadvantaged communities. These campaigns should highlight the benefits of clean cooking fuels, such as better health and well-being of the female members who are engaged in cooking and the environmental impact of switching to cleaner options. Additionally, a campaign to create awareness of gadgets complementary to clean fuel sources could induce the adoption of clean cooking fuel.

Financial incentives, such as progressive pricing, cash transfer, and subsidies to indigenous communities, low-income families, and rural households, could significantly improve their affordability to purchase and use clean cooking fuel. Thus, such a financial policy for energy justice would ease the financial constraints of socially, economically, and locationally disadvantaged households and ensure equity by enabling them to benefit equally from the transition.

Our results, thus, indicate a need for acknowledging all three tenets of energy justice, including distribution, procedural, and recognition justices, while making policies to address energy justice in a society where recognition is a critical issue. The just energy policy should not only focus on improving the affordability of families to clean energy but also pay critical attention to the clean energy infrastructure as it is crucial for enhancing accessibility and reducing spatial energy inequity (or spatial energy injustice). Policy for energy infrastructure to reduce spatial energy injustice includes investing in electricity grids connecting rural and remote communities and setting up micro-LPG dealers and mobile LPG suppliers in rural areas. Additionally, for improving access to clean energy in remote areas where connecting to electric grids and LPG dealers is expensive and challenging, it may be imperative to provide financial incentives or grants for installing clean cooking technologies, such as biogas plants and solar panels, to marginalized social groups and low-income households in rural areas. These incentives can help reduce the upfront costs and promote the use of environmentally friendly cooking solutions. Future research on energy justice could go beyond choice to examining the intensity of clean fuel consumption by different social groups, use long-term panel data, and conduct games and experiments or randomized controlled trials.

Acknowledgments and Funding

This work was supported by the Asian Development Bank Institute (ADBI). We thank the National Sample Survey Office(NSSO), Ministry of Statistics and Programme Implementation, Government of India for providing the data. We would also like to thank Adam Majoe for helping with the editing and Jeongwon Seo for assisting with the graphical abstract. The views expressed here are those of the authors and do not necessarily reflect the views of the authors' institutions and shall not be used for advertising purposes. The usual disclaimer applies.

Declaration of competing interest

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

Data availability

The authors do not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2023.114260.

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