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Residential Consumer's Willingness to Pay for Renewable Energy: Evidence from a Double-Bounded Dichotomous Choice Survey from India

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A B S T R A C T

Despite the falling costs of Renewable Energy (RE), RE adoption in Indian residential households is still at tepid growth rates. With the onset of retail electricity market deregulation in India, the introduction of "green tariffs" for residential households can be effective in resolving the issue of low RE adoption. This study investigates the willingness to pay for green tariffs/renewable energy-based electricity contracts using the contingent valuation method. Data collected from 476 Indian residential households are analyzed by the Double-Bounded Dichotomous Choice technique. The results of the conducted maximum Likelihood Estimation (MLE) method reveal the mean willingness to pay 308.52 Rs per household/month for consumption of green power in a premium-paying setting. Results indicate that although households hold positive perception of renewable energy, the willingness to pay is not commensurately high, indicating an attitude-action gap. The study recommends green energy defaults in residential energy contracts, direct marketing of non-use value of RE use (altruistic and bequest) by power supplying utilities, and promoting RE use through RE opinion champions/influencers as measures to enhance RE adoption amongst Indian residential energy consumers.

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1. INTRODUCTION

The adoption of Renewable Energy (RE) in Indian residences does not feature prominently in India's clean energy transition journey. For Indian households, RE adoption is most plausible through investments in on-site solar rooftop systems – a sector with many subsidies and monetary incentives [1]. Economic savings on energy costs, pursuit of pro-environmental objectives, energy independence, and the opportunity to generate power closer to the point of consumption are all factors that encourage solar rooftop adoption at homes [2]. Above all, the net metering mechanism (where energy generated from the solar rooftop system is netted against monthly consumption) has been a key motivator [1]. However, available data point to dismal achievement of residential installation of solar rooftops in India, reaching only 1.1 Giga-Watt of capacities as of 2020 [3]. Adoption has been disappointing due to incentive roll-backs as power-supplying utilities face high revenue losses on account of consumer migration to green energy [1]. As a result, solar rooftops and RE-powered mini/microgrids capacity additions have much to achieve [4]. Subsidized cost of electricity consumption in comparison to other consumer categories [5], lack of technical knowledge of owning and maintaining RE systems [4], ownership of premises (rented vs. owned), place of residence (rural/urban), and other financial concerns [6] act as major adoption barriers amongst residences. Third-party project developers who bridge the awareness gap of owning and maintaining onsite rooftop systems for residents have also played an inadequate role [7], thus exacerbating adoption worries. Much remains to be done before residential consumers can transition to "cleaner and renewable" energy consumption.

One strategy to increase RE consumption amongst residences is to use "Green tariffs". Green tariffs are energy supply contracts between electricity consumers and incumbent power supply utilities. Consumers who opt for green tariffs pay a premium to source renewable energy-based electricity supply, facilitated by the local power supplier. With green tariffs, end consumers can consume RE-based power without making capital investments in RE systems, but they merely pay a premium over existing retail tariffs. Green tariffs are either voluntary or default in nature. "Green defaults", as popularly known, have been more successful in nudging green energy consumption [8, 9] as it slows down the switch back to grey power due to consumer inertia [10], thereby helping countries meet RE objectives efficiently [11].

Green Tariffs have been introduced in India recently (in 3 states) [12]. With this introduction, all end consumers of electricity (in applicable states) can opt for a 100 % renewable energy-based electricity supply by paying a premium per unit

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of electricity consumed [13]. India has thus enabled choice-based energy supply contracts for electricity end users, much like many of the European economies [14]. However, existence of green tariffs does not guarantee adoption due to large attitude-action gaps in adoption [15, 16]. The willingness to pay for green tariffs (thereby for renewable energy) and factors driving higher enrollment rates in green tariffs are important considerations in the energy transition success. Focus on the same issue is sufficiently evident in developed economies [17-19]; yet, studies from India are few. This study aims to close this research gap by investigating the Willingness To Pay (WTP) for Green Tariffs (GT) for domestic consumers of electricity and to identify factors affecting the same.

In this study, WTP for GT is estimated using a Double-Bounded Dichotomous Choice Contingent Valuation (DBDC CV) experiment conducted with data collected from 476 residential households in the state of Maharashtra in western India. Responses were collected using a 4-part CV questionnaire from urban residences located in the cities of Pune and Mumbai, which are two major urban concentrations in the state. Maharashtra was chosen as the study area given its highest residential energy costs in the country [20] and in the state, cities of Pune and Mumbai are predicted to exhibit the highest growth rate in domestic energy consumption between 2019-2029 [21]. The DBDC model results are compared with Single-Bounded Dichotomous Choice (SBDC) model results to establish the robustness and efficiency gains in DBDC estimates. DBDC estimates indicate that households are willing to pay a mean monthly premium of 310.84 Rs for green energy contracts. Age exerts a negative influence, whereas higher education and income positively re-enforce the WTP. In addition, attitudinal, perceptional, and behavioral traits of an individual impact the WTP. Based on these findings, this study presents policy recommendations to close the attitude-action gap in RE adoption amongst residences.

This paper is structured in 7 sections. Section 1 introduces the study background and rationale. Section 2 presents a comprehensive literature review of studies investigating WTP for RE. Section 3 details the research methodology. Section 4 then presents data analysis and results, followed by Section 5 that discusses key conclusions. Section 6 contains policy recommendations and finally, Section 7 highlights the study limitations.

2. LITERATURE REVIEW

Studies on willingness to pay for renewable energy, published between 2009 and 2020, were analyzed to better understand the existing literature on the subject. The following keywords were used to retrieve most relevant studies: "Willingness to pay for renewable energy"; "Paying for green energy"; "Willingness to pay for green energy"; "Contingent valuation and renewable energy"; "Discrete choice experiments and renewable energy"; "Choice experiments and renewable energy"; "Willingness to accept for renewable energy", and "Grounded theory and renewable energy". A concept-centric literature analysis approach was used to identify the many concepts/meanings associated with willingness to pay for renewable energy [22].

Literature analysis suggests that Willingness To Pay (WTP) for RE can be interpreted in one of the three ways. First, the end consumer's WTP for renewable energy is a signal of green energy's market acceptance [23], with higher WTP reflecting higher social acceptance of RE. Second, it encapsulates non-use values of RE to consumers such as existence, bequest, and option values [24-27]. Finally, in the context of this study, WTP for RE portrays the preferred attributes of electricity supply, with content of supply (green power /thermal power) being one of them [28-31], especially in competitive retail electricity markets.

Competitive retail electricity markets enable end consumers to choose preferred power supplier and content of power [14]. In such markets, "consumer switching/consumer shopping" is encouraged, where end consumers can switch from one supplier to another based on power supply attributes [32]. High rates of consumer switching reflect the effectiveness and success of competition in retail markets [33]. In consumer switching decisions, many non-price attributes gain significance in the consumer decision-making process such as the type of RE supply [31, 34]. Consumers differ in RE preferences, which translate into differences in consumer's WTP for RE. As can be seen in the literature, solar energy has higher public acceptance than other RE forms, so much so that solar energy-based "defaults" are preferred over voluntary signups for wind and biomass-based energy supply contracts [29, 30]. Preference for hydro is noted over wind energy-based supply [28]; however, wind is the supply of choice over natural gas and nuclear power due to its wider social and health benefits [35, 36].

Other than the type of RE source, nature of power supplying entity and geographical orientation of power supplier also influence WTP for RE significantly. Publicly owned power supplying companies gather a higher WTP for green electricity than energy co-operatives [37]. Transparency in power pricing strategies, a seamless communication strategy, and a more democratic decision-making process followed by power utilities also encourage consumers to pay a premium for RE contracts [38]. Locally procured RE and RE powers supplied by regional power suppliers are preferred over power suppliers with foreign ties [39].

Consumer heterogeneity in green energy preferences can be masked with the introduction of green energy defaults. Evidence suggests that once RE-based energy supply is established as default, consumers seek compensation to move to grey power [15] owing to inertia. Introduction of green energy defaults for residential consumers in India can be a powerful tool to ensure higher RE adoption. However, as a premium paying model, it can put the poor at a disadvantage [40]. Given that India is still a developing country and more than 20 % of the population is below the poverty line (as of last census in 2011) [41], voluntary green energy contracts are more suitable. This study explores the willingness to pay for voluntary green electricity supply contracts. Studies estimating WTP for RE have emanated in plenty from other developing economies. Developing countries report low rates of RE penetration and widespread rural energy poverty. The role of renewable electricity in ending energy poverty and willingness to pay for it has thus been at focus, especially in the South African sub-continent [42-46]. WTP for RE has also been studied to understand social acceptance of RE in Asian countries, where RE adoption is in nascent stages [47]. Indian studies published so far have focused either on WTP for RE among large consumers of electricity where green energy transition has accelerated [48, 49], or for distributed RE in rural areas to increase energy access [50-52] or for better power quality [53, 54]. In contrast to previous Indian studies, this paper estimates WTP for RE in the case of domestic consumers in the context of increased competition in retail electricity supply.

India introduced competition in retail electricity supply via green tariffs [55]. Under Green Tariffs (GTs), consumers can opt to consume RE power by paying a premium over existing retail tariff applicable. Even though GT in India have largely been opted by commercial and industrial consumers [48], domestic consumers can opt for it too and green their own energy consumption. In the Indian market, GTs are available at a premium and the willingness to pay for it remains unknown, especially amongst domestic consumers. This study aims to close this research gap by estimating the Willingness To Pay for renewable energy-based green tariffs amongst domestic consumers and to add to the existing body of literature valuably.

3. METHOD

This section is structured in 3 sub-sections. Section 3.1 contains the survey questionnaire design. Section 3.2 then explains choice of study areas and data collection methods. Finally, Section 3.3 elaborates the statistical model chosen for the study.

3.1. Survey questionnaire design

Since electricity is an "invisible" commodity for households [56], assessment of WTP for RE requires the use of non-market valuation methods. For this study, WTP was estimated using both Single-Bounded Dichotomous Choice Contingent Valuation (SBDC CV) and then, was compared with Double-Bounded Dichotomous Choice Contingent Valuation estimates (DBDC CV) [57-59] to choose the most efficient model [60]. A four-part questionnaire was designed to arrive at an optimal design for the CV survey instrument, suitable for a developing country setup [61].

Part 1 of the instrument included questions testing respondent's perception of renewable energy, generic environmental concerns/environmental responsibility, and presence of altruistic tendencies through 21 questions asked based on a 1-to-5-point Likert scale. Environmental and other socio-economic benefits of RE use shape positive RE perception and motivate consumers to pay [62-65], but social negative externalities and risks associated with RE depressed consumers' WTP for it [66]. Impact of environmental concerns on WTP for RE use remains mixed, while some studies point to its high positive influence on green electricity contract enrollment rates [67, 68]. In other studies, no such impact could be found [69]. Environmental responsibility–the act of feeling responsible to take pro-environmental actions has spurred the willingness to pay a premium for green energy, acting as an internal variable [67]. Finally, individual altruistic tendencies often dominate respondent's willingness to pay for an environment friendly product. Consumers state their willing to pay for a "green" product since it helps them purchase moral satisfaction [70-77]. Questions included in Part-1 were thus chosen basis extensive literature evidence, suggesting possible influence on WTP for RE.

Part 2 then presented information on renewable energy in India, international best practices adopted to promote RE , and introduced the concept of green tariffs. Guidelines were followed to make information presentation as effective as possible [78]. 2 pilot studies were conducted (n=94) to test for response fatigue with the information presented. Based on pilot study feedback, information was converted to graphs and other visual aids from text, to improve cognitive ease and interpretation.

Next in part 3, the WTP question was asked in the DBDC format. 3 bid values (WTP values) were selected (from here on referred to as B^1, B^{higher} and B^{lower}), so as to bind respondent's valuation [60]. A split sample technique with 3 bid combinations/designs was used to avoid starting point bias [79]. As per design, a typical respondent was presented with 1 of 3 bid combinations, where bid values represented premiums to be paid over and above monthly electricity bill amounts. Different bid values were chosen after conducting secondary research on domestic consumer's monthly electricity bill. Bid values chosen constituted a 2-12 % premium over currently monthly electricity bills in the state. A summary of the bid values appear in Table 1.

Table 1. Selection of bid values

	B^1 (Starting Bid) (Rs./month)	B^{higher} (Higher bid) (Rs./month)	B^{lower} (Lower bid) (Rs./month)
Sub-sample 1	100	150	50
Bid as a % of monthly electricity bills	4 %	6 %	2 %
Sub-sample 2	200	300	100
Bid as a % of monthly electricity bills	8 %	12 %	4 %
Sub-sample 3	300	450	150
Bid as a % of monthly electricity bills	12 %	18 %	6 %
Note: the monthly electricity bill is assumed to be the same in all samples, based on average residential consumer's consumption patterns in the state of Maharashtra [80].			

Contingent valuation studies are known to suffer from hypothetical bias, where consumers tend to overstate their WTP due to the hypothetical nature of product/program being valued [81]. Cheap talk scripts are an effective way to reduce this hypothetical bias [82]. It refers to inclusion of body of text within the survey, that reminds the respondent that they may be suffering from hypothetical bias and hence may overstate their actual WTP. Accordingly, a brief cheap talk was also included, to correct for any hypothetical biases.

Finally, part 4 of the instrument contained follow up questions to the WTP valuation questions along with socio-demographic variables. Variables captured respondent's age, gender, income, occupation, education, location of residence, type of utility/power suppliers supply electricity to the household (public Vs private) and number of appliances at home. Data was also collected on monthly hours of electricity consumption, monthly electricity bills and back-up arrangement for power supply (such as generator sets, battery/invertors and use of solar RTPV), with the intention to understand possible influences of prior use of renewable energy on WTP, if any.

3.2. Study area and data collection methods

Responses were collected from 476 residential households from the cities of Pune and Mumbai. Of the total 476 observations, 70 % of the residents belonged to Pune and 30 % resided in Mumbai. The final survey instrument was administered using both offline methods (face to face interviews) as well as online tools, since mixed methods for data collection do not compromise the quality of data in large sample studies [83], but help by reducing time and costs [84].

Data was collected by a team of trained enumerators, trained to conduct CV studies in a developing country setting as per best practices guidelines [85]. The 2 urban centers chosen for the study were divided in zones of electricity supply and samples were collected from each supply zone. A sample inclusion criterion defined a typical respondent to be a resident of either Pune/Mumbai, connected on domestic connection of electricity, and is the head of the household. Stratified purposive sampling was then used to reach more than 1200 respondents, but usable data amounted to only 476 responses. Sample size considered for this study resonates with literature [86, 87], and hence was deemed sufficient.

3.3. Model specification

Latent factors impacting WTP for RE were identified using Exploratory Factor Analysis (EFA). Next, statistical estimation of mean WTP values using the DBDC format was done using parametric methods. Under parametric estimation, the sample data collected is assumed to follow a particular distribution, and the parameter estimates confirm the probability distribution that the observed data belongs to the referenced study [88]. Nonparametric methods, on the other hand, make no apriori assumption about the data distribution. Parametric estimation can be done using either the Least Squares Estimation (LSE) method or the Maximum Likelihood Estimation (MLE); however, MLE has the advantage of estimating the distribution parameters with narrower confidence intervals, thereby rendering this estimation method with higher sufficiency, consistency, and efficiency [88]. For this study, the MLE method of parametric estimation of DBDC CV model was adopted. In the model, a typical respondent can be denoted by "i" and the maximum Willingness To Pay (WTP) for renewable energy-based electricity be denoted by y_i^*. Since a DBDC CV method was used, a typical response could be one of the following four possible responses to the bid values presented (B^1 = Initial Bid, B^{higher} = Higher Bid and B^{lower} = Lower bid):

1) "Yes" to B^1 and a "Yes" to B^{higher}=Yes-Yes (YY)
2) "Yes" to B^1 and a "No" to B^{higher}=Yes-No (YN)
3) "No" to B^1 and a "Yes" to B^{lower}=No-Yes (NY)
4) "No" to B^1 and a "No" to B^{lower}= No-No (NN)

while respondents falling in categories (i), (ii), and (iii) carry a positive WTP, those falling in category (iv) are known as protest respondents. Respondents can reveal zero WTP as either they truly carry zero willingness to pay for the good in question, or the bid values presented are unable to capture the true WTP [89]. Since there is a probability assigned to each answer format, the likelihood functions need to be estimated. The likelihood function helps understand how likely it is for the sample data to come from the assumed probability distribution.

Let "Π" define the likelihood function; then, the 4 answer formats in the DBDC CV experiment can be written as follows [60]:

$$\Pi_i^{YY} (B^1;\ B^{higher}) = \Pr (y_i^* > B^1 \text{ and } y_i^* \geq B^{higher}) = 1 - G (B^{higher}, \theta) \tag{1}$$

where Π_i^{YY} represents a consumer i, with a "Yes-Yes" response in the bid values presented.

Further, G (Bid value, θ) is a statistical distribution function with associated parameter estimates vector "θ", and 1 - G (B^{higher}, θ) represents the cumulative density function (cdf) of the respondent's true maximum WTP. Similarly:

$$\Pi_i^{YN}(B^1;\ B^{higher}) = \Pr (y_i^* \geq B^1 \text{ but } y_i^* < B^{higher}) = G (B^{higher}, \theta) - G (B^1, \theta) \tag{2}$$

$$\Pi_i^{NY}(B^1;\ B^{lower}) = \Pr(y_i^* < B^1 \text{ but } y_i^* \geq B^{lower}) = G (B^1,\theta) - G (B^{lower}, \theta) \tag{3}$$

$$\Pi_i^{NN}(B^1;\ B^{lower}) = \Pr (y_i^* < B^1 \text{ and } y_i^* < B^{lower}) = G (B^{lower}, \theta) \tag{4}$$

Functions (1) to (4) the total likelihood function (L), representing the joint probability distribution of the sample, can be constructed as follows:

$$L(\theta) = \Pi_i^{YY} + \Pi_i^{YN} + \Pi_i^{NY} + \ln\Pi_i^{NN} \tag{5}$$

The best parameter estimates can be achieved when the Log-Likelihood function is maximized [88]. By maximizing the log likelihood function, the probability that the observed data comes from the assumed distribution is maximized. Thus, the log (denoted as "ln") of Equation (5) that must be considered for computational purposes is constructed as follows:

$$\ln L (\theta) = \ln\Pi_i^{YY} + \ln\Pi_i^{YN} + \ln\Pi_i^{NY} + \ln\Pi_i^{NN} \tag{6}$$

For a single respondent i, the response will be any one from YY, YN, NY, or NN formats. Therefore, a dummy binary variable which can take a value of 0 or 1 in the log-likelihood function (based on the respondent's $_i$'s response) is necessary. If "d" indicates the dummy variable, then the final Log-Likelihood function will be constructed as follows:

$$\text{Ln } L (\theta) = \sum_{i=1}^{N} \{d_i^{YY}\ln \Pi_i^{YY} + d_i^{NY} \ln \Pi_i^{YN} + d_i^{YN} \ln \Pi_i^{NY} + d_i^{NN} \ln \Pi_i^{NN}\} \tag{7}$$

where i represents a sample respondents and can range from 1, 2, 3………, N and d_i^{YY}, d_i^{YN}, d_i^{NY} and d_i^{NN} are binary variables with values assigned as either 0 or 1, depending on the i^{th} sample response.

4. RESULTS AND DISCUSSION

This section contains details of the sample statistics in Section 4.1, followed by results from exploratory factor analysis contained in section 4.2. Finally, section 4.3 presents quantitative estimates of WTP for RE.

4.1. Respondent profile

Data for this study was collected in split samples (3 sub-samples) to avoid the starting point bias [79]. Each split sample had a near equal sample size, ensuring that no split sample suffered from over or under representation. Table 2 appends the following summary of the key socio-demographic variables by the split sample.

Table 2. Sample statistics

Socio-demographic variables	Split sample 1 (n = 159)	Split sample 2 (n = 152)	Split sample 3 (n = 165)
Average age (years)	27.9	31.2	29.1
Average annual income (Rs. INR)			
Less than Rs. 10 lacs	111 (69.8)	85 (55.9)	98 (59.4)
Rs. 11 Lacs – Rs. 21 Lacs	20 (12.6)	26 (17.1)	42 (25.5)
More than Rs. 21 Lacs	12 (7.5)	13 (8.6)	19 (11.5)
Did not report	16 (10.1)	28 (18.4)	6 (3.6)
Educational attainment			
Less than school degree			
School degree	4 (2.5)	1 (0.7)	3 (1.8)
Under graduation	65 (40.9)	73 (48.0)	80 (48.5)
Post-graduation	80 (50.3)	71 (46.7)	66 (40.0)
Higher education	10 (6.3)	7 (4.6)	16 (9.7)
Gender			
Male	107 (0.70)	86 (0.60)	109 (0.70)
Female	52 (0.30)	66 (0.40)	56 (0.30)
Average family size (number of members)	2.9	2.8	2.8
Past use of solar (% users)	8.18 %	8.55 %	5.45 %
Alternate sources of electricity (% of yes respondents)	11.32 %	15.13 %	7.88 %

Numbers in parenthesis represent column percentages.
Split sample 1: ($\mathbf{B^1}$, $\mathbf{B^{higher}}$ and $\mathbf{B^{lower}}$) = (100_150_50); Split sample 2: ($\mathbf{B^1}$, $\mathbf{B^{higher}}$ and $\mathbf{B^{lower}}$) = (200_300_100); Split sample 3: ($\mathbf{B^1}$, $\mathbf{B^{higher}}$ and $\mathbf{B^{lower}}$) = (300_450_150)

A typical respondent was 30 years of age on average, completed either an under-graduate or a post-graduate degree, did not exceed annual family income Rs. 10 Lacs, and came from a family of less than 3 members. The majority of the respondents in each split sample were found willing to pay for RE with a share of protest respondents (respondent not willing to pay) limited to 14.7 % (data in Table 3 below).

Table 3. Response to bid values

Response	Split sample 1 (n = 159)	Split sample 2 (n = 152)	Split sample 3 (n = 165)	Total
Yes - Yes	78	71	79	228 (47.8%)
Yes - No	48	39	49	136 (28.5%)
No - Yes	11	17	14	42 (8.8%)
No – No (Protest)	22	25	23	70 (14.7%)
Total	159	152	165	476

Split sample 1: ($\mathbf{B^1}$, $\mathbf{B^{higher}}$ and $\mathbf{B^{lower}}$) = (100_150_50); Split sample 2: ($\mathbf{B^1}$, $\mathbf{B^{higher}}$ and $\mathbf{B^{lower}}$) = (200_300_100), Split sample 3: ($\mathbf{B^1}$, $\mathbf{B^{higher}}$ and $\mathbf{B^{lower}}$) = (300_450_150)

Only 5-8 % of the households (in each split sample) had used solar energy in the past (total 35 out of 476 households: 7, 19, and 9 in split samples 1, 2, and 3, respectively). This finding is in agreement with the literature, pointing to lower RE adoption amongst households [90]. The limited adopters of solar rooftops in the sample (35 of 476) installed battery backups or generator systems as well, indicating the lack of reliability of solar rooftops due to intermittency of the power supply. While the falling costs of solar RTPV have encouraged adoption, conventional backup options are still the mainstay [91]. A near-complete reliance on grid supplied electricity is also evident since only 8-11 % of respondents maintained alternate sources of electricity to fall back upon. Further, more than 60 % of the respondents preferred to switch off appliances while not in use while only 37 % purchased Energy Efficient Appliances (EEAs). This mirrors energy behavior in residential households in other parts of Asia as well [92] and corroborates the results with the literature, suggesting the lagging adoption of EEAs in India due to concerns other than appliance cost [93], and it also confirms the slower pace of energy transition in households [94].

4.2. Exploratory factor analysis and latent factors identification

Reliability and validity of 21 questions captured on Likert scale data were checked based on the Cronbach's alpha statistic. A high alpha value of .740 reflects internal consistency of the instrument [95]. To ensure validity, content validity was used. Content validity refers to expert reviews of questions for establishing validity and verifying the extent to which questions capture the research objectives. Content validity was established by conducting expert interviews with academic and industry experts from the fields of environmental economics and renewable energy. Survey feedback from pilot studies also helped refine the final survey instrument.

Exploratory Factor Analysis (EFA) was conducted on Likert-scale data variables to discover latent variables with possible impact on WTP for renewable energy. EFA was conducted using the Principal Component Analysis (PCA) procedure in SPSS. The Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of Sphericity confirmed the need and applicability of factor analysis [96]. The KMO test returned a high value of 0.772 justifying sample adequacy. Bartlett's test for sphericity was also significant ($\chi^2(210) = 1701.342$, $p = 0.00$), indicating the presence of latent factors. Finally, variable communalities above 0.3 confirmed that latent factors explained a significant amount of variation in the variables [97]. EFA used the varimax rotation and 5 latent factors were discovered, each with an eigenvalue of > 1. The 5 latent factors explained 46.57 % of the total variance. No variables reported cross factor loadings, and all variables with factor loadings less than 0.50 were suppressed. Final factor loading, latent factor identification, and variable communalities are reproduced below in Table 4.

Table 4. Results from exploratory factor analysis

Sample No.	Variable name	Rotated component matrix						Communalities
		1	2	3	4	5	6	
1	Green is as reliable as conventional energy					**0.767**		0.598
2	Everyone should pay extra to contribute to the generation of Green Electricity					**0.649**		0.455
3	I believe the generation of electricity from coal contributes to pollution in the country	0.391						0.453
4	The effects of pollution on public health are worse than we realize	**0.690**						0.518
5	I believe human activities are major contributors to pollution	**0.715**						0.533
6	I believe that electricity generation from renewable energy will clean the environment	**0.557**						0.478
7	I feel partly responsible for the environmental problems on our planet				**0.648**			0.557
8	I recycle what I can (paper, glass, or other recyclables)						-.666	0.608
9	Every citizen must take responsibility for the environment	**0.774**						0.646
10	I feel that pollution from electricity generation should be taxed				**0.692**			0.551
11	I feel a moral obligation to protect the environment				**0.586**			0.507
12	I have given directions to a stranger			**0.514**				0.533
13	I have given money to charity			**0.742**				0.575
14	I have donated goods or clothes to a charity			**0.765**				0.606
15	I have done voluntary work for charity			**0.659**				0.579
16	I have donated blood		0.472					0.353
17	I have helped carry a stranger's belonging		**0.708**					0.577

18	I have delayed an elevator so that someone else can come in		**0.499**					0.456
19	I have allowed someone else to go ahead of me in a line (Xerox line/ supermarket etc)		**0.523**					0.463
20	I have given a stranger lift in my car		**0.728**					0.533
21	I have helped a handicap cross the street		**0.625**					0.519

The 5 latent factors discovered can be interpreted as follows:

- **Perception of RES-E/green energy:** Two variables load on this factor that reflect how respondents perceive RES-E or green energy (Variable 1 and Variable 2). This factor was also identified as a major effect on the consumer's WTP by the researchers in [98] and hence, aligned with the previous literature.
- **Environmental consciousness:** Four variables load on to this factor (Variables 4, 5, 6, and 9), each of which captures the respondent's environmental consciousness and awareness of the impacts from use of green energy. This latent factor was also found to be of significance in influencing pro-environmental behavior in previous studies; hence, it validates the variable grouping [99].
- **Environmental responsibility:** Three variables that captured a sense of environmental responsibility amongst respondents constructed these latent factors (Variables 7, 10, and 11).
- **Tangible altruism:** This factor encapsulated altruistic traits tangible in nature and was constructed out of Variables 12, 13, 14, and 15.
- **Intangible altruism:** Five variables loaded on to this factor that captured altruistic behaviors with intangible nature, namely Variables 17, 18, 19, 20, and 21.

Three variables could not be grouped under any latent factor, each having factor loading of less than 0.50. Hence, they were dropped (Variables 3, 8, and 16).

4.3. Estimates of willingness to pay for renewable energy

The statistical SBDC and DBDC CV model development was done in R software. Table 5 below lists the statistical summary of the considered variables for analysis.

Table 5. List and nature of variables considered for model development

Sample No.	Variable	Mean	Standard deviation
1	Gender (1 if Male, 2 otherwise)	1.37	.482
2	Age of the respondent (years)	29.32	8.72
3	Annual income of the household (1 if < 5 lacs per annum, 5 if > 21 lacs per annum (ordinal variable)	2.29	1.24
4	Level of education of respondent (1 if < school degree, 5 if >= higher education (ordinal variable))	3.58	0.64
5	City of residence (1 if Pune, 0 if Mumbai)	0.69	0.46
6	Household monthly electricity bill (Rs.)	1742.84	1611.15
7	Household size (1 if single, 5 if > 10 members (ordinal variable))	2.83	0.67
8	Past use of solar (1 if yes, 0 otherwise)	0.56	0.50
9	Alternate sources of electricity (1=yes, 0=no)	0.11	.32
10	Factor 1: Perception of RES (PER = V1+V2)	7.34	1.56
11	Factor 2: Environmental Consciousness (EC) = V4+V5+V6+V9	17.56	2.15
12	Factor 3: Environmental Responsibility (ER) = V7+V10+V11	12.00	1.87
13	Factor 4: Tangible Altruism (A1) = V12+V13+V14+V15	13.99	3.64
14	Factor 5: In tangible Altruism (A2) = V17+V18+V19+V20+V21	14.41	4.53
15	Answer to bids presented in YY-YN-NY-YY format (dependent variable)	-	-

For the Single-Bounded Dichotomous Choice (SBDC) model estimation, only the starting bid value for each split sample was considered [100]. Due to the categorical/dichotomous nature of the dependent variable (answer to bid values), Ordinary Least Squares (OLS) method of regression could not be applied since the error distribution violated normality assumption. Hence, Generalized Linear Models (GLM) were chosen [100]. For GLM models where parametric estimations are undertaken, error terms can follow any of the following probability distribution functions: Logistic, Log-normal, Log-logistic, and Weibull distributions [100]. For this study, the Maximum Likelihood Estimator (MLE) method is used to estimate the distribution parameters. The model fit was adjudged by the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) derived from the Kullback–Liebler distance [101]. Parametric models using multiple distributional assumptions namely Logistic, Log-Logistic, and Weibull distributions were analyzed, as reported in Table 6 below.

Table 6. Single-Bounded Dichotomous Choice (SBDC) parametric estimation results

Variable	Logistic	Log-Logistic	Weibull
(Intercept)	-2.67	-0.35	-0.14
Log(bid)	0.00	-0.55*	-0.32
Age	**-0.04*****	**-0.04*****	**-0.04*****
Gender	-0.07	-0.06	-0.06
Income (cat.5)	**1.16*****	**1.17*****	**0.90*****
Income (cat.4)	-0.10	-0.11	-0.01
Income (cat.3)	**0.68****	**0.68***	**0.70****
Income (cat.2)	0.52	0.53	0.50
Education (cat.4)	0.96	0.98	**0.84***
Education (cat.3)	-0.12	-0.14	-0.03
Education (cat.2)	0.10	0.11	0.07
Awareness of consequences	0.03	0.03	0.01
Tangible altruism	-0.01	-0.01	-0.02
Intangible altruism	0.02	0.02	0.02
Perception of RES	**0.34*****	**0.34*****	**0.29*****
Ascription of responsibility	**0.15****	**0.15****	**0.10****
Average monthly electricity bill	0.00	0.00	**0.00032*****
City of residence (Pune)	-0.02	-0.02	0.17
Awareness of RES	0.01	0.01	-0.01
Number of family members	0.03	0.02	-0.06
Past usage of solar	-0.24	-0.24	-0.30
Use of alternate sources of electricity	0.46	0.45	0.40
P-value	0.00	0.00	0.00
AIC	432.5	431.9	438.9
BIC	521.4	520.8	527.7
Mean WTP in Rs. - Truncated at maximum bid value (Figures in brackets represent upper and lower values of the WTP estimate)	**250 (233 – 262)**	**254 (235-265)**	**249 (232-261)**

* Significant at 90 % CI; ** significant at 95 % CI; *** significant at 99 %
Lower and upper bounds of WTP estimated using Krinsky & Robb simulation method
Income and education variables are on the ordinal scale. Results omit the 1st category for estimation.

The SBDC mean WTP value for the given observations ranges from Rs. 249 to Rs. 254/household/month, indicating that the mean values are not sensitive to parametric distributional assumptions. AIC and BIC values for all models were also in similar ranges, indicating that no model was strongly superior to the rest. Four variables emerged to have a common impact on consumers' WTP for RES-E irrespective of the distribution specification. First, age exerts a negative influence on WTP. This indicates that younger consumers are more likely to accept higher bid values. Second, higher income positively influences the willingness to pay, suggesting that RE adoption is more likely amongst high-income households. Third, respondents holding higher RE perception are more welcoming of RE-based electricity contracts and are willing to pay more for it than respondents with lower perception. This suggested a direct correlation between RE perceptions and willingness to pay for it, as has also been documented in the literature [63]. Fourth, respondents who ascribe higher self-responsibilities to undertake pro-environmental actions are more likely to pay more for RE-based electricity supply. Higher education and higher monthly electricity bills also nudge consumers to pay more for renewable electricity; however, these variables were only found significant in the Weibull distribution, but not for the logistic and log-logistic models.

Next, DBDC estimation was conducted next with the same distributional specifications (logistic, log-logistic, and Weibull). However, of the 3 models, Weibull estimation did not converge to a true solution. The variable coefficients, mean WTP values, and model fit values of the Logistic and Log-Logistic distributions are reproduced below in Table 7.

Table 7. Double-Bounded Dichotomous Choice (DBDC) parametric estimation results

Variable	Logistic	Log-Logistic
(Intercept)	-0.53	**9.04*** **
Log(bid)	**-0.01*** **	**-1.92*** **
Age	**-0.05*** **	**-0.05*** **
Gender	0.10	-0.09
Income (cat.5)	**0.89*** **	**0.93*** **
Income (cat.4)	-0.17	-0.44
Income (cat.3)	0.73	0.61
Income (cat.2)	0.29	0.33
Education (cat.4)	**1.11** **	**1.22*** **
Education (cat.3)	0.28	0.14
Education (cat.2)	0.53	0.55
Awareness of consequences	0.04	0.00
Tangible altruism	-0.03	**0.05** **
Intangible altruism	**0.05* **	0.02
Perception of RES	**0.34*** **	**0.33*** **
Ascription of responsibility	0.07	**0.11* **
Average monthly electricity bill	**0.0006*** **	**0.001*** **
City of residence (Pune)	-0.12	-0.01
Awareness of RES	0.02	0.02
Number of family members	**-0.41*** **	**-0.42*** **
Past usage of solar	-0.38	**-0.78** **
Use of alternate sources of electricity	0.34	0.05
P-value	0.00	0.00
AIC	1094.25	1079.7
BIC	1183.14	1168.5
Mean WTP in Rs. - Truncated at maximum bid value (Figures in brackets represent upper and lower values of the WTP estimate)	**316.5 (299 – 332.5)**	**310.8 (283.9 - 317.5)**

* Significant at 90 % CI; ** significant at 95 % CI; *** significant at 99 %
Lower and upper bounds of WTP estimated using Krinsky & Robb simulation method
Income and education variables are on the ordinal scale. Results omit the 1st category for estimation.

The DBDC mean WTP values for the set of observations range between Rs. 310.8 – Rs. 316.5. This again suggests no large impact of the distribution assumption on mean value estimation. While the AIC and BIC values for DBDC models are inflated as compared to the SBDC models, a larger number of significant variables are realized for the DBDC models. Between the 2 models, the log-logistic model had the lowest AIC values and was, hence, considered a better model. First, a positive intercept value (β = 9.04; p-value = 0.00) suggests an inherent willingness to pay for RE, irrespective of other independent variables. This indicates a general positive attitude towards green electricity. Second, a negative Log(Bid) estimate (β= -1.92; p-value = 0.00) indicates that the higher the bid value, the lower the probability of bid acceptance. This result is in alignment with standard economic theory that prescribes the higher the price, the lower the willingness to consume the product. Third, younger respondents exhibit a higher probability accepting the presented bid values (β = -0.05, p-value =0.00). This could be due to a greater awareness of RES-E and rising environmental consciousness amongst the youth. Fourth, higher income households are willing to pay more for RE (β = .93, p-value =0.00) presumably due to higher affordability. Fifth, higher education levels spur willingness to pay (β = 1.22, p-value =0.04). This finding aligns with the literature, as highly educated consumers are found to be more eco-conscious and hence, they support RES. Sixth, consumers engaged in altruistic activities before are found more willing to pay (Altruistic traits (tangible, β =.05, p-value =0.04)). This finding again is in line with the literature, whereby paying for RES is considered to satisfy altruistic considerations [76]. Seventh, respondents holding positive perception of RES are seen as willing to pay more (β= 0.33, p-value =0.00). Eighth, consumers who hold a high ascribed responsibility (ascription of responsibility) for themselves to undertake pro-environmental actions feel more obliged to adopt RES-E and are hence willing to pay more (β = 0.11; p-value = 0.07). Ninth, counter-intuitively consumers with higher monthly bills are willing to pay more. This could be due to the belief that the application of RESs helps save them on monthly electricity bills. However, due to the small value of the estimate, compelling conclusions cannot be drawn (β = 0.001; p-value = 0.000). Next, it is observed that larger families do not support paying more for RES (Number of family members: β = -0.42; p-value = 0.01). This could be attributed to a higher value of electricity consumption that may result in higher monthly bills, thereby discouraging the willingness to pay more. Finally, existing consumers of solar energy (through solar RTPV solutions) appear to be more reluctant to pay for RES than the non-users (β = -0.78; p-value = 0.04). This is counter-intuitive as users of solar should be pro RE, having reaped savings in monthly electricity bill amounts. This result indicates that necessary policy interventions are required to improve user satisfaction.

Efficiency gains from the estimates of SDBC and DBDC models were then checked to choose the best model. Efficiency gains in estimation can be established by considering the variance in confidence interval of mean WTP values as a percentage of the mean values (difference in confidence intervals/mean WTP), with lower variances indicating higher efficiency [102]. Contingent valuation studies in the past also used this ratio to establish the model efficiency of DBDC estimation [103]. Efficiency ratios for this study for both SBDC and DBDC computations are reported and compared below in Table 8.

Table 6. Efficiency ratio estimation of SBDC and DBDC models

Variable	SBDC - Logistic	DBDC - Logistic	SBDC – Log logistic	DBDC – Log logistic
Mean WTP	**250.4**	**316.5**	**253.8**	**310.8**
Lower Bound (LB)	233.2	299.1	235	283.9
Upper Bound (UB)	261.9	332.5	265	317.5
Difference in UB & LB	28.6	33.5	30	33.6
Efficiency Ratio (UB-LB/Mean WTP)	**0.116**	**0.105**	**0.118**	**0.108**

Efficiency ratio estimates report two key observations. First, the DBDC estimates from both the logistic and log-logistic model report lower efficiency ratios than the respective SBDC models, suggesting econometric superiority of DBDC estimation. Hence, it is clear that DBDC models gain inefficiency. Second, between the logistic and log-logistic DBDC estimates, the log-logistic model is weakly inferior (.108) over the logistic model (.105). However, for the purpose of this study and based on the set of observations, the DBDC log-logistic model is considered final due to the lower AIC and BIC values and 11 significant variables influencing WTP for RES-E, thus fitting standard economic theory. Thus, in conclusion, it can be reported that the mean WTP for RES-E rests at Rs. 310.8/household/month when charged as a premium over existing monthly electricity bills for residential households.

Given the WTP achieved as a monthly charge, it was of interest to study the WTP per unit of electricity consumed. To this end, the average residential consumption patterns in the state of Maharashtra were studied. An average residential household in Maharashtra does not consume more than 300 units of electricity (measured in kWh terms) [20]. This number increases exponentially in near future due to higher incomes, affordability, and urbanization in the state, but is currently contained within 300 units per month. Accordingly, the average WTP for GT is calculated at Rs. 1.03/unit/month. Although this number looks sufficiently small, CV studies in developing economies (especially, for pro-environmental products/programs) often report low WTP values. Table 9 appended below compares WTP for RE from other countries with the findings of this study.

Table 7. WTP for RE in other economies

Year of study	Country of study	WTP for RE *	Finding	Authors
2014	China	USD 2.35 – 2.82	Mandatory payment vehicle prompts higher WTP	[104]
2015	Lebanon	USD 20 – 50	For replacement of generator sets with solar PV (lumpsum payment)	[105]
2016	South Korea	USD 3.21	For bequest value of RE	[106]
2017	Hong Kong	USD 16.12	For natural gas based deep decarbonization	[107]
*: WTP per household per month, unless specified otherwise				

In comparison, this study reports a WTP for RE at USD 4.97/household/month (78.05 INR = 1 USD). This finding aligns with the literature pieces as low willingness to pay for pro-environmental products in developing nations is attributed to the higher value assigned to real consumption than to environmental quality [108].

5. KEY FINDINGS AND CONCLUSIONS

This study was undertaken to investigate household willingness to pay for green energy-based electricity contracts. Data was collected from 476 residential households from the twin urban cities of Pune and Mumbai in the western state of Maharashtra. A DBDC CV experiment was conducted with sample respondents to estimate the WTP for RE-based electricity supply and to identify the factors influencing the same. Analysis reveals that residential consumers carry a monthly mean WTP of Rs. 310.83 per household per month when charged as a premium over and above current monthly electricity bills. Higher age influences negatively, whereas higher education and income positively re-enforce this willingness to pay. Perceptions of green energy are positive and widespread. While 71 % of the respondents held positive perceptions of RE and perceived it to be as reliable as conventional energy forms, only 68 % agreed that people should pay a premium for it. Thus, an attitude-action gap appears, which is a phenomena observed in other economies as well [109, 15, 16, 64]. This gap can hinder consumer switching to green energy in deregulated retail energy markets. Other behavioral factors that positively and significantly spur WTP include a high sense of responsibility to undertake pro-environmental actions and past altruistic behavior (tangible altruism).

6. RECOMMENDATIONS

Based on the above findings, this study proposes 4 recommendations for policy consideration.

First, to address the attitude-action gap in RE adoption, it is recommended that "green energy defaults" are introduced for residential consumers, initially. While green defaults are undesirable due to affordability and welfare concerns [19], they are also successful in eliminating lethargy in "consumer switching" from grey contracts to green contracts [110]. Green defaults can be a temporary introduction in the market and slow transition to voluntary contracts can be made following the expedition of RE adoption amongst residences. The feasibility, acceptability, design and welfare impacts of green energy tariffs and contracts need further exploring and are recommended for future research.

Second, marketing of voluntary sign-ups to green tariffs should be based on altruistic and bequest values of RE. Power suppliers would be of benefit by showcasing the non-use values of RE such as altruistic pleasures arising out of green consumption and leaving a greener environment for future generations (bequest values). Targeted consumer awareness campaigns towards this task can be conducted by sharing information passed through monthly electricity bills and other social media campaigns undertaken by power supplying utilities.

Third, since households with higher income, higher education, and lower age profiles exhibit higher acceptability and willingness to pay for RE, it is recommended that a sub-set of households meeting this socio-demographic profile should be identified as "influencers". "Influencers" should be equipped with complete knowledge of benefits of green energy and can be incentivized to conduct awareness campaigns amongst residential societies. Local nodal agencies/state energy development boards can be entrusted to both identify the influencing agents, as well as conduct of awareness campaigns. This will positively fine tune the perception of RE, which also emerged as a key influencing factor of WTP for RE.

Fourth and finally, research design followed in this study can also be replicated to elicit green tariffs amongst Micro Small and Medium Enterprises (MSMEs) in India. Self-financing RE systems have become more challenging for Indian MSMEs in the post COVID-19 times, since MSMEs are unable to justify the cost benefit analysis of high RE system costs vis-à-vis low energy demand. Added business uncertainties on account of COVID-19-related slowdowns are also making financial lenders cautious of lending to SMEs, exacerbating RE financing bottlenecks [111, 112]. Given this, incumbent power suppliers would benefit from marketing green tariffs, especially MSME clusters in the state. By paying the green tariff premium, MSMEs can meet RE procurement targets (voluntary targets or as mandated by business partners, as applicable) without making capital expenditures in RE systems.

7. LIMITATIONS

This study was undertaken in two urban concentrations in the state of Maharashtra. Since the sample was collected from only one Indian state, the willingness to pay estimates are not generalizable to the entire India. However, the research design used in this study could be replicated in other Indian states to elicit WTP for that state, since WTP estimates are sensitive to state-wise social, economic, and individual attributes of respondents.

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