frontiers | Frontiers in Climate

ORIGINAL RESEARCH
published: 30 May 2022
doi: 10.3389/fclim.2022.874753

Public Preferences for Renewable Energy Options: A Choice Experiment in Rwanda

Sydney Oluoch[1], Pankaj Lal[1], Andres Susaeta[2], Rodrigue Mugabo[3], Michel Masozera[4] and Jackline Aridi[5]*

[1] Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ, United States, [2] School of Forest Resources and Conservation, University of Florida, Gainesville, FL, United States, [3] Wildlife Conservation Society-Rwanda Program, Kigali, Rwanda, [4] World Wide Fund for Nature (WWF International), C/O International Gorilla Conservation Program, Scola House, Kigali, Rwanda, [5] Notre Dame International Department, University of Notre Dame, Nairobi, Kenya

Edited by:
Tedd Mose,
University of Oxford, United Kingdom

Reviewed by:
Wasantha Athukorala,
University of Peradeniya, Sri Lanka
Pamela Abbott,
University of Aberdeen,
United Kingdom

***Correspondence:**
Sydney Oluoch
oluochs@montclair.edu

Specialty section:
This article was submitted to
Climate Services,
a section of the journal
Frontiers in Climate

Received: 12 February 2022
Accepted: 10 May 2022
Published: 30 May 2022

Citation:
Oluoch S, Lal P, Susaeta A,
Mugabo R, Masozera M and Aridi J
(2022) Public Preferences for
Renewable Energy Options: A Choice
Experiment in Rwanda.
Front. Clim. 4:874753.
doi: 10.3389/fclim.2022.874753

Rwanda has seen impressive economic growth in the past few years resulting from policy driven initiatives. However, one of the key challenges to economic development in Rwanda has been the provision of reliable and cost-effective energy. As a result, the country has planned to expand its renewable energy portfolio to meet its energy demand and mitigate greenhouse gas (GHG) emissions. Meeting these goals requires a robust policy framework that considers the perspective of the public. Moreso, for women who have been disproportionately affected by climate change especially in developing countries. Gender equality is a key for the Rwanda strategy as gender gaps remain a barrier to equal benefits from energy access to all. Several challenges abound in providing access to electricity and reducing the dependency on wood fuel for cooking, hence deliberate effort needs to be made to ensure gender responsiveness in energy programs and policies. This study applied a choice experiment analysis to determine how renewable energy attributes (type of energy, ownership, impact on environment, distance and visibility, community job creation and renewable energy tax) impacts public willingness to pay for renewable energy development in Rwanda. A nationwide survey was conducted on 1,006 households from which 58.35% were women. We applied both the conditional logit (MNL) and random parameter logit (RPL) framework. We found that the Rwandan public has a high utility for the following issues: environmental impact, distance and visibility, and type of renewable energy, respectively. Further analysis focused on the gendered impacts of renewable energy revealed that women had the strongest preference for interventions with low impact on the environment. From a policy standpoint women's input should be incorporated in future decision-making processes through public participation to guide policymakers in developing beneficial renewable energy programs.

Keywords: renewable energy, choice experiment, Rwanda, women, conditional logit, random parameter logit, willingness to pay

INTRODUCTION

One of the key challenges to economic development in Rwanda is the provision of reliable and cost-effective energy (Bimenyimana et al., 2018). Rwanda plans to increase the total household electricity access to 100% from the current 52% by 2024 through both grid (52%) and off-grid (48%) alternatives (Bimenyimana et al., 2018; Rodriguez-Manotas et al., 2018). Energy transformation of this magnitude requires the provision of affordable and reliable power supply (IOB Evaluation, 2014; REP, 2015; Niyonteze et al., 2019). To achieve these goals, the energy sector requires significant changes in terms of policy and infrastructure development (Power Africa, 2018). Nonetheless, Rwanda has made progress by increasing generation capacity from 97 MW in 2011 to 226 MW in 2019 (IOB Evaluation, 2014; Niyotenze et al., 2020). In total, the targeted energy demand by 2024 is projected to stand at 563 MW (Uwisengeyimana et al., 2016; Bimenyimana et al., 2018; Rodriguez-Manotas et al., 2018). The current electricity generation technology in Rwanda consists of hydropower (39.0%), 25.0% methane gas, 19.0% thermal sources, 4.0% peat, 2.0% solar and 11.0% imports from neighboring countries (Niyotenze et al., 2020).

In terms of renewable energy resources, Rwanda has significant hydropower generation potential due to its ideal topography for medium to high run of river projects (Niyotenze et al., 2020). Small hydro is key to rural energy strategy, with up to 1.6 MW being developed (Safari and Gasore, 2010). Rwanda has a strong daily solar radiation of about 5.2 kWh/m^2, ideal for small/minigrid electricity for health centers in remote areas (Safari and Gasore, 2010). Rwanda lies in a region of intensive volcanic activities with existing geothermal field potential between 170 and 300 MW (Safari and Gasore, 2010; Rutagarama, 2013). Rwanda's current strategy is to assess the geothermal potential available to meet energy demand (Rutagarama, 2013). Biomass resources in Rwanda include biogas, peat, wood, methane gas, and other organic wastes constituting 85% of the national energy consumption (Bimenyimana et al., 2018). Rwanda's land area covered by forest is 20% of the total; dependence on wood fuel as a key source of energy (90%), especially in rural areas, has resulted in pressure on forest resources and increasing environmental degradation (Safari and Gasore, 2010; Bimenyimana et al., 2018). Hence, Rwanda has enough renewable energy potential to sustain its energy needs and support economic development; the next step is exploring innovative, sustainable, and viable options (Safari and Gasore, 2010; IOB Evaluation, 2014; Niyotenze et al., 2020).

Decisionmakers in Rwanda agree that deploying renewables (solar, geothermal, biomass, and small-hydros) will not only bridge the energy access gap, but will also generate cleaner, cheaper energy and reduce health and environmental impacts associated with greenhouse gas emissions (REP, 2015; Niyotenze et al., 2020). Despite these concerns, there are still challenges arising from the lack of a modern long-term policy framework, proper implementation and regulation, appropriate curricula in energy studies, gender disparities in awareness and knowledge of energy information and adequate infrastructure (REP, 2015). Furthermore, provision of energy sources alone is not enough to achieve the desired empowerment levels and economic freedom for women (Klege et al., 2021). These factors put together have resulted in coordination failures and institutional underperformance in development of renewable energy (REP, 2015). Moreover, vulnerability to climate change, misalignment of power supply and demand, limited financing for off-grid companies, and high costs have made electricity unattainable for most rural households with female led households bearing the brunt of lack access to electricity (Rutagarama, 2013; REP, 2015; Hakiziamana et al., 2016; Uwisengeyimana et al., 2016; REU, 2018; Rodriguez-Manotas et al., 2018). Other challenges are low public awareness on the benefits of renewable energy technologies particularly for female led households, underdeveloped markets for renewables, inadequate mechanisms to monitor renewable energy standards and lack of adequate data on the potential renewable energy sources (REP, 2015). In Rwanda women face social challenges that impede their ability to engage in economic activities. In most cases, their voices in participation of public policies are further restricted (Barron et al., 2020). Fast tracking women representation at all levels of the energy supply chain, especially the decision-making processes will result in better welfare opportunities and livelihoods (Klege et al., 2021).

Rwanda in recognition of these challenges has implemented several reforms that target operational efficiency, affordability, and accountability of electricity services with the goal of attracting private sector investments (REU, 2018). These are measures such as implementing least-cost sector planning and streamlining operations (REU, 2018). Other strategies include the adjustment of tariffs to reduce the cost of electricity to end-users while keeping energy investments viable (REU, 2018). The Rwandan government also supports research and development in renewable energy through academic and research institutions (REP, 2015). The core pillars of the Rwandan energy policy strategy is thus based on decarbonizing the power sector by placing a priority on cleaner new energy investments, climate resilient energy infrastructure to adapt to climate change, developing robust national energy standards, clear environmental guidelines and creating awareness on renewable energy (REP, 2015; REU, 2018). Rwanda is also well known for its commitment toward women's participation and gender equality policies despite being a traditionally patriarchal society (Klege et al., 2021).

Despite, these notable policy initiatives and vast potential, the challenge remains in bridging the energy access gaps among female led households, increasing the renewable energy share and increasing public participation at all levels of policy development. This paper contributes to the policy debate, by adopting the discrete choice experiment method, that leverages on survey data from 1,006 respondents in Rwanda. To the best of our knowledge, literature on renewable energy development in Rwanda involving choice experiments with a focus on gender disparities are scarce. Hence, there is a lack of public perspective that is highly relevant in designing amenable policy to guide renewable energy development in Rwanda.

For this study, we examined the marginal valuation of economic, social, and environmental impacts of renewable energy sources [small-hydro, solar, biomass (biofuel and biogas) and geothermal] using the choice experiment method in Rwanda. Specifically, we determine how renewable energy attributes such as type of energy, ownership, distance and visibility, impact on the environment and cost impact the public willingness to pay for renewable energy development in Rwanda. By using interaction factors such as gender we further explore how the preference heterogeneity accounts for diverging concerns using the random parameter logit model. Currently, in Rwanda there is no information available on the public preferences for renewable energy attributes. Our study is timely and fills this gap by focusing on key attributes of renewable energy development that enable effective trade-offs, further assisting policy designs in settings where gender disparities in awareness, attitudes, preferences, and energy access are apparent. The rest of the paper is outlined as follows: the next section discusses the methodology. The results and discussion are presented in the third section and conclusion in the fourth section.

METHODOLOGY

Choice Experiments

The choice experiment is based on Lancaster's random utility theory. The underlying assumption of choice experiments is that the utility an individual derives from a good depends on its individual characteristics, and the unobserved (stochastic) components (Lancaster, 1966; McFadden, 1973). The derivation of the theoretical framework for our study was based on Bergmann et al. (2006), Ku and Yoo (2010), and Brennan and Rensburg (2016) protocols and summarized as follows. Within the random utility theory framework, a respondent is faced with a set of three alternatives (Renewable energy project option A and B defined with different attribute levels, and option C representing the status quo) that are defined by different attribute levels in each choice set (**Table 1**). In general, a respondents q's utility from choosing alternative j in choice situation t in a utility function with random parameters can be defined as

$$U_{jtq} = V_{jtq} + \varepsilon_{jtq} = \beta\prime_{qk} X_{jtqk} + \varepsilon_{jtq} \quad (1)$$

Where respondent q ($q = 1,\ldots Q$) obtains utility U from choosing alternative j (Option A, B or C) in each of the choice sets t ($t = 1,\ldots X$). The utility has a non-random component (V) that is a function of renewable energy development attributes represented by $\beta\prime_{qk} X_{jtqk}$ a deterministic observable component, and a stochastic term (ε) that captures any influences on individual choices that are (omitted or) unobservable to the researcher (Matero, 2013). The non-random component (V) is assumed to be a function of the vector k of choice specific attributes X_{jtqk}, with corresponding parameters $ß_{qk}$ which may vary randomly across respondents due to preference heterogeneity with a mean $ß_k$ and standard deviation δ_k. The utility function of the model with the error term ε_{jtq} that includes the alternative specific constant (ASC) representing a dummy for respondent choosing the status quo, can be expressed as a linear function of an attribute vector (X_1, X_2, X_3, X_4, X_5, X_6) = (type of renewable energy, ownership, impact on the environment, distance and visibility, job creation, and proposed yearly tax).

The utility function of the model without covariates, except for the error term $\varepsilon_{jtq,}$ can be expressed as a linear function of an attribute vector

$$V_{jq} = ASC_q + \beta_1 X_{1qj} + \beta_2 X_{2,qj} + \beta_3 X_{3},_{qj} + \beta_4 X_{4,qj} + \beta_5 X_{5,qj} + \beta_6 X_{6,qj} \quad (2)$$

The probability that a tourist q will choose alternative i over any other alternative j belonging to some choice set t of:

$$Prob_{iq} = Prob(V_{iq} + \varepsilon_{iq} > V_{jq} + \varepsilon_{jq}) \qquad \forall_j \in t \quad (3)$$

To empirically estimate the observable parameters of the utility function (3) that allows for the conversion of the random utility model into a choice model (3), we assume that the joint distribution of the vector of random error terms (stochastic components) are independently and identically distributed (IID). This leads to the use of multinomial/conditional logit (MNL) which assumes that unobserved factors affecting the choice of alternatives are strictly independent of each other (Independence of Irrelevant Alternatives, IIA) (Bergmann et al., 2006; Matero, 2013). Hence determines the probabilities of choosing i over j options

$$Prob_{iq} = exp(\mu V_{iq}) / \sum jexp(\mu V_{jq}) \, \forall_j \in t \quad (4)$$

The marginal rate of substitution between any pair of attributes is obtainable from equation 4, as the scale parameter cancels out. For our study in which the cost attribute (proposed yearly tax) is included. The WTP can be calculated by dividing the attribute coefficient of the β *attribute a* with the coefficient associated with cost to produce an estimate of the "implicit price" P^*a (Bergmann et al., 2006).

$$P^*a = -(\beta a / \beta cost) \quad (5)$$

The implicit prices express the marginal WTP for a discrete change in an attribute level. The RPL framework allows for variation across individuals. By introducing individual characteristics, Z_q, sources of preference heterogeneity can be identified. These variables are interacted with the choice-varying attributes $Z_{jtqk.}$ This will identify variation in preference associated with individual specific characteristics (Ku and Yoo, 2010; Brennan and Rensburg, 2016).

Attributes and Optimal Choice Profiles

We considered the Rwanda energy policy framework, outcomes from focus group discussions, and existing literature from studies such as Bergmann et al. (2006), Ku and Yoo (2010), O'Keeffe (2014), Vecchiato and Tempesta (2015), and Oluoch et al. (2021) to determine the attributes and corresponding levels. In this choice experiment, respondents traded-off six attributes described in **Table 1**. Type of renewable energy project (TOR) attribute explored the different options of renewable energy

TABLE 1 | Attributes and levels in the choice tasks.

	Description	Levels
Types of Renewable energy source (TOR)	The type of energy source responsible for energy generation.	• Solar (Sol) • Small hydro (Hydro) • Geothermal (Geo) • Biomass (Bio)
Ownership (OWN)	Defined as public (government and community owned) and Private (individually, institution or company owned).	• Public (Pub) • Private (Pri)
Impact on the environment (IOE)	In-terms of air pollution, effect on wildlife, destruction of ecosystems and deforestation.	• Low (Low) • Medium (Med) • High (Hig)
Distance and Visibility (DandV)	The distance and visibility of the project to your home.	• <10 Km and visible (<10 Km and V) • <10 Km and Not Visible (<10 Km and NV) • More than 20 Km and Not Visible (>20 Km and NV)
Community job creation (CJC)	Creation of new employment opportunities.	• <10 Jobs (<10 Jobs) • Between 10 and 20 Jobs (10–20 Jobs) • More than 20 Jobs (>20 Jobs)
Yearly tax on Renewable energy project (COST).	Proposed yearly tax on renewable energy projects.	• Rwf 3000 • Rwf 6000 • Rwf 9000

1 US $ = Rwf 1000 (2019). These are approximate values rounded off.

TABLE 2 | Sample choice card including 2 options for renewable energy projects and an opt out.

Attribute	Option A	Option B	Option C
Type of renewable energy	Small hydro	Solar	No renewable energy project
Ownership	Public owned	Private owned	
Impact on the environment	Low	High	
Distance and visibility	10–20 Km and Not Visible	<10 Km and not visible.	
Community job creation	<10 Jobs	10–20 Jobs	
Proposed yearly tax on renewable energy development.	Rwf 9,000	Rwf 3,000	
Your choice (tick only one)	☐	☐	☐

in Rwanda, which are Solar, Small-hydro, Biomass (biofuel and biogas) and Geothermal (REP, 2015). The social attributes selected were Type of ownership (OWN) and Distance and Visibility (D&V). The D&V attribute was a proxy for the Not in My Backyard (NIMBY) effect drawn from studies by Bergmann et al. (2006) and Vecchiato and Tempesta (2015) where it has been demonstrated that the public have views on visual impact of large projects. In the case of OWN attribute, the levels were classified as public (government owned and community owned projects) and private (company, corporation, or individual owned). For impact of environmental attributes (IOE), we considered generalizable levels such as low, medium, and high. This was because different renewable energy sources have diverging environmental concerns such as disruption of local biodiversity, carbon emissions, and local climatic changes (Oluoch et al., 2021). The economic attributes considered were community job creation (CJC) local jobs and yearly household energy taxes (COST) that is the cost attribute covering the capital cost of the hypothetical renewable energy projects.

The associated levels resulted in 648 possible profiles (4*2*3*3*3*3) which was not practical to employ in the survey. A D-efficient design was applied to give an efficient combination accounting for orthogonality, level balance, and minimum overlap using the software R. We used a fractional factorial design to reduce the full factorial to 72 choice set profiles that were randomly paired to form 36 choice cards representing two renewable project alternatives and an additional fixed alternative described as "no new renewable projects", equivalent to the status quo alternative (**Table 2**). Based on this design, 36 different choice sets were divided into six blocks of choice tasks.

Questionnaire and Sampling Framework

The questionnaire consisted of three sections. The first section contained a brief introduction of the survey and background information on renewable energy, the environment, and government policy toward increasing renewable energy. The second part of the survey was the choice experiment in which respondents were asked to choose between different renewable energy development scenarios. The last part contained socioeconomic information regarding respondent's characteristics such as gender, age, education, residence, occupation, household income, and access to electricity.

In this study, we used the random stratified sampling technique that organizes the sample in hierarchical geographic units of Rwanda for national representativeness. To ensure that the sample selection is randomly distributed across important population sub-groups, it was necessary to treat the administrative regions such as Provinces/Districts/Sectors/Wards as domains of interest. The domains are based on recent census data from National Institute of Statistics Rwanda (NISR) that divides the population in terms of basic units (enumeration areas) from which a sample of the total population can be surveyed (National Institute of Statistics of Rwanda (NISR), 2018). Consequently, all the 5 provinces were selected. The next successive hierarchical levels came from a total of 22 districts, 47 sectors, 74 cells, and 130 villages, respectively (**Figure 1**; **Table 3**). The secondary level of stratification involved considering both the urban and rural components of the villages. The village/ward was the smallest unit from which the enumerators began at a centralized location and sampled every third household, with ∼15 households in each village. At each household, the

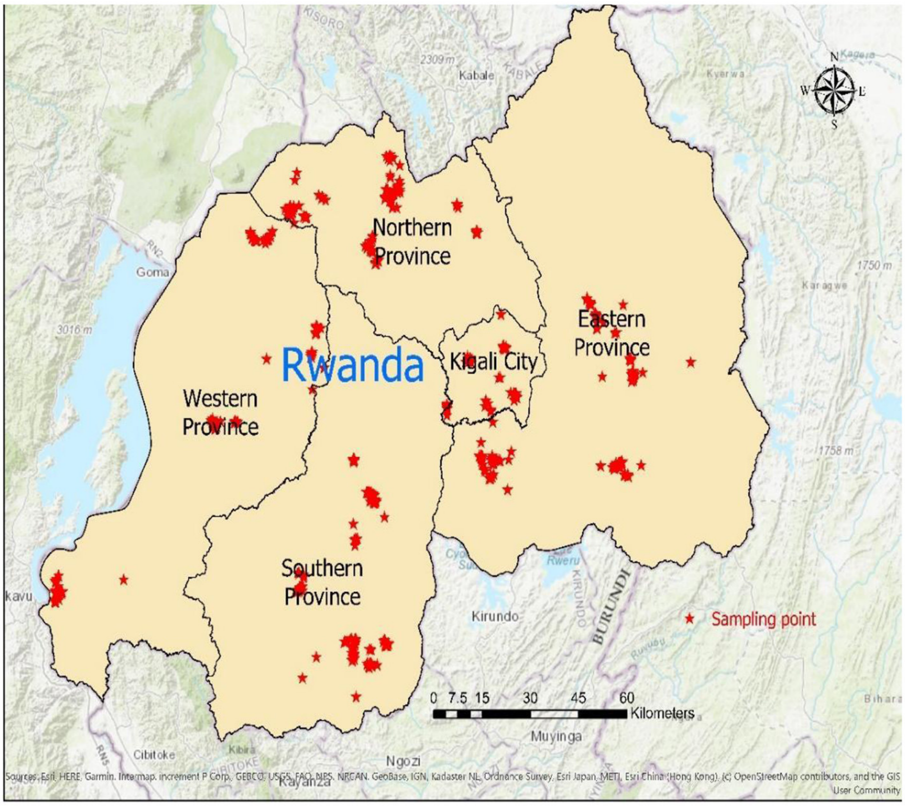

FIGURE 1 | Survey Area and sample points for Rwanda.

TABLE 3 | Sampling framework.

Households	Rwanda	
Administrative units	**Sampled**	**Total**
Province	5	5
District	22	30
Sector	47	416
Cell	130	2,184
Respondents per ward/cell	15	
Total sampled	1,006	

head of household/or defacto head representing a population sample of 18 years or older was selected as a respondent to ensure the sampling was random. The survey information was collected by face-to-face interviews *via* the Kobo Collect mobile application.

Model Estimation

To evaluate the results, we applied the MNL and RPL model as described in the Ek and Persson (2014) study. We were interested in applying interactive factors such as gender to control for the possibility of selecting specific attributes for renewable energy projects. The econometric analysis for the parameter and willingness to pay estimates for both models was conducted with the software STATA 15 S.E. In the RPL model, we applied 400 Halton draws to give the mean and standard deviation for preference heterogeneity. In-order to avoid a saturated model, the attribute level with the lowest utility was chosen as the baseline or reference case.

RESULTS AND DISCUSSION

Socio-Demographic Characteristics

A total of 1,019 in-person interviews were conducted for a month beginning in October 2019. After missing and inconsistent answers were removed, 1,006 responses (98.72%) were found to be valid for further examination. The representativeness of the sample for the population was tested with the Pearson chi-square χ^2 independence test for the socio-demographic variables for both countries. **Table 4** presents the average sample values of several socio-demographic characteristics and their corresponding average values from statistical data (National Institute of Statistics of Rwanda (NISR), 2018; WDI, 2018; WPRR, 2019). The chi-square tests show that the sample and population have a goodness of fit for most of the socio-demographic factors. The null hypothesis for equality of means at 1% significance level was rejected for the annual household income. For the other 5 socio-demographic characteristics, there were no statistically significant differences reported, indicating

TABLE 4 | The comparison of the socio-demographic factors in the sample data and the corresponding population data.

	Rwanda		
	Sample	**Population**	**χ^2-test**
Sample size	1,006	12,785,472	
Gender (% of females)	58.35%	51.8%	***
Age (median)	35.5	31.43	***
Household size (mean)	4.54	4.3	***
Annual household income	*$358.72*	*$441.45*	
Marital status (% married)	63.32%	47.4%	*
Education.	10.43%	7%	***

- *Annual household income (mean in Rwf converted into 2019 USD).*
- *Education % college degree.*
- *Population Age Median and mean adjusted to fit sample demographics.*
- ****, **, and * indicate statistical significance at the 1%, 5%, and 10% levels.*

the representativeness of our sample population to the NISR census data.

The population data is from National Institute of Statistics of Rwanda (NISR) (2018), WDI (2018), and WPRR (2019). In italics the sample mean, and the population mean are not equal at the 1, 5, and 10% level according to the Pearson χ^2-test.

Survey Responses Related to Awareness, Acceptance, and Attitudes Toward Renewable Energy

Some general findings about Rwandan respondents on awareness, acceptance, and attitudes can be summarized as follows. Our survey results show the comparable electricity access of female and male respondents in both rural and urban areas in Rwanda (**Figure 2**). Rural residents (67.95%) show a higher percentage without access to electricity than their urban counterparts (11.72%). One unexpected outcome is that female electricity access in both rural and urban areas is greater than electricity access for male respondents. On average female led households in both rural and urban settings show electricity access above 52%, whereas the male led households the electricity access is below 50% in both rural and urban settings. One surprising outcome is that rural males (46%) have higher electricity access percentages than urban males (38%). Perhaps, this could be attributed to the effects of the 1994 Rwandan genocide that resulted in the death of at least 500,000 people most of whom were male (Klege et al., 2021). Consequently, many women became widows taking over traditional male-dominated social and economic activities (Klege et al., 2021). Even so, implementation of several gender policies, such as creation of a Ministry of Gender Equality that has enforced a gender quota system for local and national government, has further leveled the playing field resulting to improvement in female participation on development issues (Klege et al., 2021). Despite, the progress in women representation in terms of 30% in the public sector, house of representative (60%) and cabinet (50%), there is still lack of substantive lobbying for women interest by women in these leadership positions (Klege et al., 2021). As a result, issues that affect women, and families that have children under 15 years are often not included in development programs.

Secondly, the respondents were asked about their approval of development of renewable energy in their area of residence. The most salient finding was that 96.5% of the respondents strongly endorse development of renewable energy. A further comparison of approval levels between urban and rural residents shows that urban residents strongly approve renewable energy development in the area at 95% as compared to rural residents at 97%. A follow up question assessed respondents' view of whether renewable energy has the capacity to reduce the cost of electricity (**Figure 3**). To this end nearly 78.5% of the respondents believe that renewable energy has the capacity to reduce the cost of electricity. A closer analysis on the gender differences shows that female respondents in both rural and urban settings have a higher belief (81%) as compared to the male respondents (72%) that renewable energy will reduce the cost of electricity. Perhaps, these differences can be in part attributed to female lower levels of awareness to energy issues as compared to males that results in some degree of less skeptism about the ability of deployment of renewables to reduce the cost of electricity.

In the third question we were interested in investigating respondent attitudes toward renewable energy. Results shown in **Figure 4** show that renewables received the highest percentages of respondents with positive attitudes in Rwanda with solar (98%), hydro (94%), biomass (85%), geothermal (53%), and wind (49%). This outcome contrasted with other non-renewable sources of energy having lower percentages [methane (63%), coal (40%), diesel (47%) and nuclear (20%)]. It is notable that the highest-ranking positive attitude for non-renewable energy (methane) was still lower than the lowest ranking positive attitude for renewable energy (wind and geothermal). Also, wind and geothermal had the greatest number of respondents that indicated a neutral attitude with scores of 46 and 32%, respectively. This was comparable to the neutral attitudes toward nuclear energy (54%), methane (23%), diesel (32%), and coal (44%). The neutral attitudes were mainly evident among respondents when a source of energy such as wind was not present in the country. For negative attitudes, other sources of energy perceived as not clean dominated with diesel at 31% followed by nuclear (27%), and coal (15%). Based on percentage scores, most of the respondents have a positive attitude toward renewable energy. This outcome is similar to studies by Oluoch et al. (2020) on public awareness, attitudes toward renewable energy in Kenya. Overall, these findings indicate an overwhelming public support for renewable energy in Rwanda. There were no apparent differences in gender trends for the respondents except that urban female had the highest neutral attitudes (28%) toward renewables. The indifference to renewables by urban females could be due to their greater

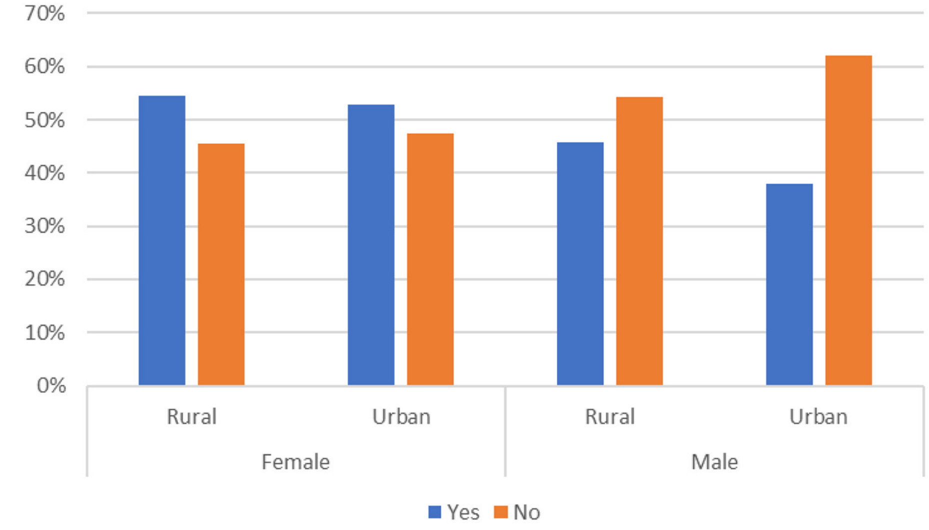

FIGURE 2 | Percentage respondent access to Electricity in Rwanda.

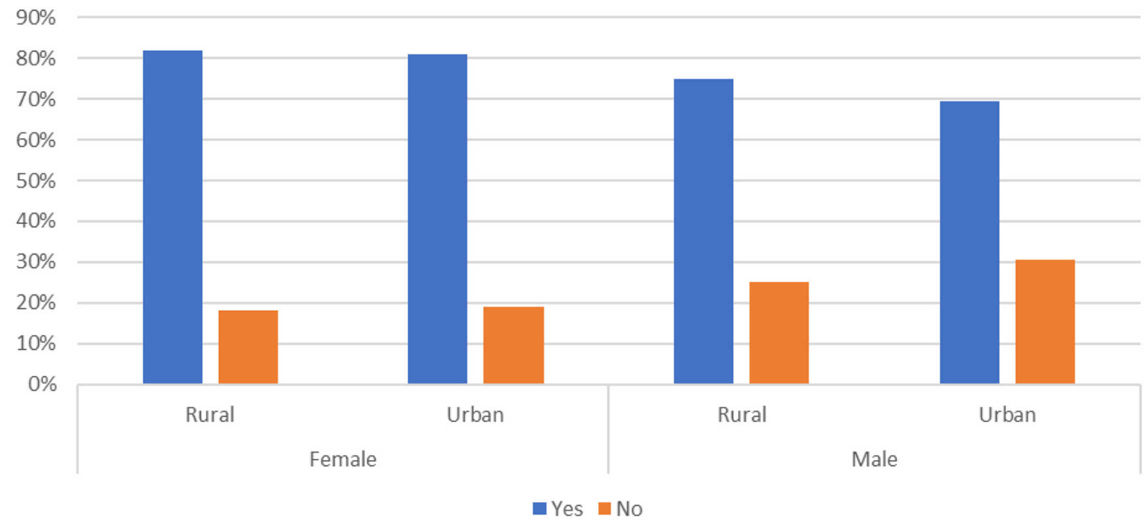

FIGURE 3 | Do you feel renewable energy sources will reduce the cost of electricity?

exposure to information through television and internet as compared to their male counterparts (**Figure 5**). This was an unexpected outcome as there is a general consensus in most societies that women are usually more sustainability conscious, and are concerned about energy needs while they are also more prone to be affected by issues of energy and climate change (Rao and Tilt, 2016; Opoku et al., 2021).

In the fourth part of the questionnaire, participants were asked questions about their awareness of renewable energy. Specifically, the question pertained to the level of awareness of respondents to six common terms related to renewable energy debate, these were terms such as renewable energy, global warming, climate change, sustainable development, the greenhouse effect and carbon emissions. Overall, Rwandan respondents were most aware of the terms "renewable energy" (98.5%), "climate change (92.5%)," and "sustainable development (87%)", respectively. For all the terms, urban residents in Rwanda have a higher level of awareness than their rural counterparts. The terms were further converted into scores of 1 for each term, and the average score for each respondent was measured. For this analysis we found that the male respondents had higher awareness scores in comparison to their female counterparts with urban males showing scores of 5.315 followed by rural male (5.146), whereas the urban female had scores of 5.087 and rural females 5.074 as expected. Nonetheless, Rwanda's rural respondent's awareness levels are almost the same as urban residents. Also, there was minimum

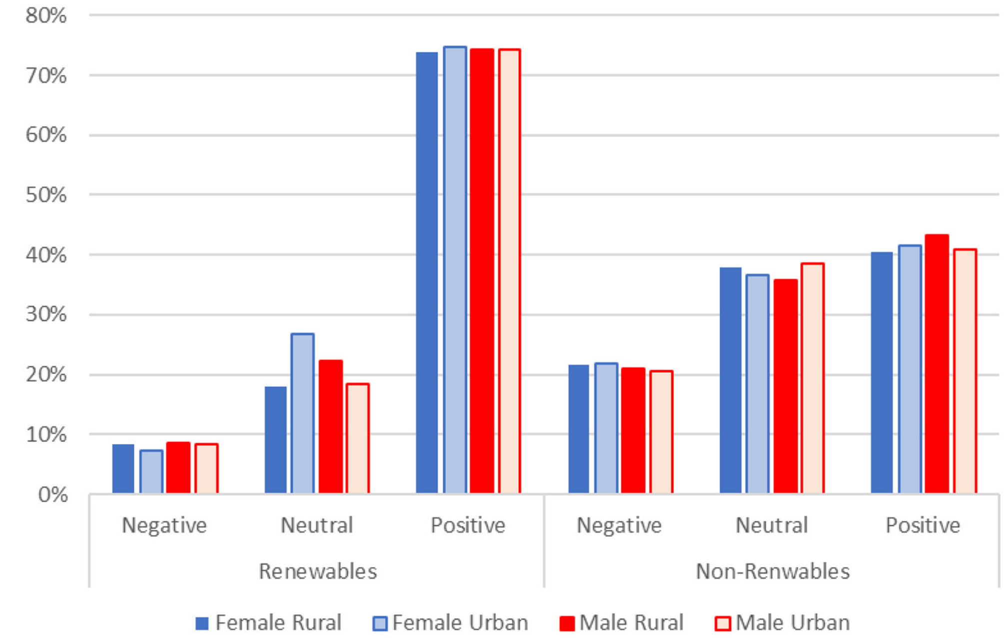

FIGURE 4 | Gender comparisons to attitudes toward different type of energy sources.

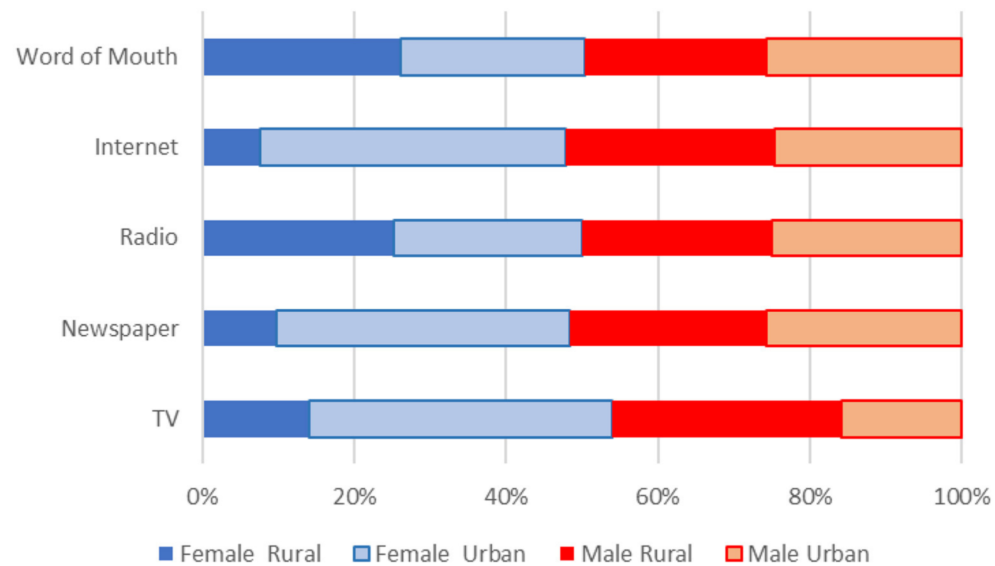

FIGURE 5 | Generally, where did you hear of the renewable energy terms.

disparities in awareness between male and female respondents. This in part could be attributed to the size of the country, Rwanda being small (26,338 km^2) and densely populated (525 people per km^2) (National Institute of Statistics of Rwanda (NISR), 2018), translates to minimal population dispersal. As a result, any awareness campaigns or knowledge dissemination processes in Rwanda are bound to be more effective in terms of reaching both rural and urban residents. This finding is further supported with the results in a follow up question, where respondents were further asked in what form of media, they first heard the renewable energy terms. The results show that radio (86.68%) is the main source of information on renewable energy related terms, followed by word of mouth (82.41%), whereas television (29.97%), newspapers (12.70%), and internet (11.73%) were the least popular forms of media. Interestingly, urban female respondents are more inclined to internet and television as compared to male respondents. There are no differences between rural and urban residents in Rwanda. However, urban residents tend to show an increased use of television and internet as sources of renewable energy terms. Radio was the most common source of information among rural residents is due to lack of access to electricity (67.5%) and electrical appliances such as televisions and computers (National Institute of Statistics of Rwanda (NISR), 2018). As a result, respondents from rural areas rely mostly on radio and word of mouth as a source of information for renewable energy. Moreover, radios are relatively cheaper and can be powered by batteries or solar as opposed to television and computers. Radio networks also cover remote areas of the country whereas television networks are mostly confined to urban areas so having television may not be effective as a source of media in rural areas. Further efforts by the Rwandan government to augment these sources of media have been through support of research and development of renewables through academic and research institutions (REP, 2015).

Estimation Results

The estimated coefficients derived from the MNL and RPL model and their corresponding interaction effects are shown in **Table 5**. The coefficients of the utility function for the attribute levels had some expected and unexpected signs in both models, indicating a very good fit when comparing the log likelihood values. However, the log likelihood value of function of the RPL model was much higher than the MNL model, indicating that the RPL is random and provides better estimates than MNL. The goodness-of-fit of the RPL model (pseudo-$R^2 = 0.0316$) was not as high as the equivalent MNL model with a pseudo-$R^2 = 0.5632$. Overall, both models reveal higher preference for small hydro followed by solar and biomass, respectively.

In the MNL model, all the coefficients for the attribute levels are significant (p-value < 0.01) except the ASC (alternative specific constant) which was not significant (p-value > 0.10). This outcome implies that the Rwandan respondents derived no utility from opting out of renewable energy programs presented. Correspondingly, in the RPL model the mean coefficients for all the attribute levels are significant except for biomass, yearly household tax and ASC. The standard deviation in the RPL model was significant all the attribute levels except 10–20 jobs level and the ASC. This outcome indicates considerable preference heterogeneity among the Rwandan respondents for the different attributes.

Intriguingly for solar, small hydro, low impact on the environment, medium impact on the environment, <10 km and visible, <10 km and not visible, between 10 and 20 jobs and more than 20 jobs attribute levels the standard deviation coefficient had a lower magnitude than its respective mean. On the other hand, biomass, and private ownership levels the standard deviation coefficients are greater than the mean indicating a segment of the respondents having preference heterogeneity. Although, for biomass, the preference heterogeneity can be because of the negative view of biomass, due to excessive traditional biomass exploitation (Safari and Gasore, 2010; Rukundo et al., 2018), there is a segment of the population that indicated a greater preference for this source, that can be attributed to the dependency of households on this source of energy (**Table 5**).

The standard deviation for the RPL model shows a part of the population with preference heterogeneity for private owned renewable energy projects. This was an expected outcome given the negative perception and lack of support toward privately owned renewable ventures by the public. This view may arise from the public perception that everything owned and sold by private companies is expensive (Lorenzo, 2008). The Rwandan government needs to further promote private-public partnerships by promoting market-based practices to increase competition, reduce costs, and improve the choice of technologies (Niyonteze et al., 2019).

A positive and significant ASC coefficient is an indicator that respondents derive a higher utility for opting out of the renewable energy program presented. In both our models the ASC constant was positive but not significant, indicating that the public support renewable energy programs. The yearly household tax was significant in the MNL model and standard deviation of the RPL model, indicating preference heterogeneity. The negative sign of the cost coefficient in both models is an indicator that as utility decreases as the price for renewable energy projects increases, which is consistent with economic theory. Kosenius and Ollikainen (2013) noted that reluctance to pay more for renewable energy may not necessarily be because of opposition to renewable energy production, but due to other unknown factors. To further investigate the preference for the attribute levels among gender differences, we considered the socio-economic variable gender as an interaction effect for impact on environment and ownership attributes. We found that these gender interactions were significant for both the attribute levels as expected. These results show that female respondents have a high preference for renewable energy projects that are publicly owned and have a low impact on the environment.

Marginal Willingness to Pay

Table 6 presents the marginal willingness to pay estimates for the renewable energy attributes that was estimated using the model coefficient in **Table 5**. Both models indicated similar trends, hence, we considered the MNL model as they gave more realistic measures that are within the range of household utility taxes paid by the Rwandan public. The impact on environment attributes seems to have a relatively large impact on the utility, followed by distance and visibility, type of renewable energy, community job creation, and ownership, respectively, for Rwandan respondents. From these results, it is apparent that the Rwandan public value other attributes other than the type of renewable energy. For the type of energy (TOR) attribute, the highest willingness to pay was for small hydro followed by solar and biomass. It is evident that respondents' willingness to pay is determined by their familiarity of these technologies, as small hydro energy is the most well-known and preferred energy source for Rwandan residents. Respondents are willing to pay Rwf 7,563.31 more for small hydro as compared to solar, and Rwf 8,143.95 more for solar as compared to biomass. Despite solar technologies being available as stand-alone units, and lower initial costs as compared to small hydro, there is greater public support for small hydro as compared to solar. This can be attributed to the lack of public awareness of the advantages of solar energy. The

TABLE 5 | Parameter estimates standard errors within parenthesis.

Attribute levels and interactions	Conditional logit		Random parameter logit
	Estimate	Mean	Std dev
Type of energy			
Solar	0.525 (0.065)***	0.971 (0.137)***	−1.031 (0.256)***
Small hydro	0.722 (0.064)***	1.349 (0.155)***	−1.532 (0.216)***
Biomass	0.312 (0.059)***	0.186 (0.119)	1.521 (0.247)***
Ownership			
Private	0.153 (0.056)**	0.177 (0.139)	1.537 (0.164)***
Impact on the environment			
Low	2.854 (0.103)***	6.123 (0.475)***	3.435 (0.391)***
Medium	1.750 (0.101)***	3.033 (0.267)***	−0.725 (0.331)**
Distance and visibility			
<10 Km and Visible	0.728 (0.067)***	1.208 (0.159)***	1.130 (0.207)***
<10 Km and Not visible	0.832 (0.067)***	1.586 (0.173)***	−1.152 (0.251)***
Job creation			
10–20 Jobs	0.466 (0.056)***	1.1139 (0.148)***	−0.152 (0.303)
>20 Jobs	0.304 (0.062)***	0.993 (0.151)***	−1.403 (0.206)***
Yearly household tax	−0.001 (0.001)**	−0.001 (0.001)	−0.001 (0.001)***
ASC	52.275 (1.54)	58.376 (1.476)	−4.864 (1.354)
Interactions			
Gender*medium	0.176 (0.101) *	0.552 (0.224) **	−0.722 (0.398)*
Gender*low	0.438 (0.110)***	1.599 (0.377)***	−2.998 (0.418)***
Gender*public	0.499 (0.071)***	1.086 (0.183)***	0.351 (0.251)
Pseudo R^2	0.5632	0.0316	
Wald chi^2 (15)	7,468.74	561.22	
Prob > Chi^2	0.000	0.000	
Loglikelihood	−2,895.75	−2,615.14	
No of respondents		1,006	

****, **, and * indicate statistical significance at the 1, 5, and 10% levels. Values in parentheses show standard errors.*
Gender: Coded as 0 for male and 1 Female.

outcome translates to lack of an effective solar market in Rwanda (Niyonteze et al., 2019).

On the contrary, Rwandan respondents are willing to pay Rwf 5,859.06 more for privately owned as compared to the publicly owned baseline attribute level. The general appeal for privately owned renewable ventures can be due to the public view that such ventures are more reliable in terms of power supply and bridging the gap of energy access (Niyonteze et al., 2019). Closer inference on the distance and visibility attribute further reveals that Rwandan residents are willing to pay Rwf 3,995.09 more for renewable energy projects that are <10 Km and not visible as compared to projects that are <10 km and visible. This outcome can be interpreted as the Rwandan public are willing to pay more to have renewable energy projects closer to their homes. From the perspective of the Not in my backyard (NIMBY) debate, this was an unexpected outcome and for Rwandan policy makers, it is an indicator that there is minimal objection to bringing renewable energy projects close to the public residences provided they are not visible. For the impact on environment attribute, Rwandan residents are willing to pay Rwf 42,334.55 more for renewable energy projects with a low impact on the environment as compared to medium impact. In the case of the job creation attribute, Rwandan residents show a higher willingness to pay of Rwf 6,213.95 for between 10 and 20 jobs as compared to more than 20 jobs. From economic theory we expected that more than 20 jobs will elicit a greatest preference among respondents. However, it appears that the Rwandan public considered the various environmental and social tradeoffs and settled for between 10 and 20 jobs.

CONCLUSION

The study uses choice experiments as an economic assessment method to assess respondent preferences through trade-offs among non-market commodities. This was geared toward providing important information for Rwandan energy policy. We determined that respondents have a higher preference for small hydro, followed by solar, and biomass, respectively. The results suggest that the Rwandan public are not only willing to support renewable energy development but are more conscious of other benefits that these programs will bring to their communities. Interestingly, female respondents in both rural and urban settings have a higher perception

TABLE 6 | Marginal willingness to pay estimate (95% confidence intervals).

Attribute	MNL		
	WTP	Lower limit	Upper limit
Type of energy			
Solar	20,115.21	1,749.19	38,481.22
Small hydro	27,678.52	2,644.88	52,712.15
Biomass	11,971.26	57.18	23,885.35
Ownership			
Private	5,859.06	−580.32	12,298.45
Impact on environment			
Low	109,416.42	11,037.56	207,795.28
Medium	67,081.87	8,334.16	125,829.57
Distance and visibility			
10 km and not visible	31,892.43	2,118.81	61,666.05
10 km and visible	27,897.34	3,019.52	52,775.16
Job creation			
10–20 Jobs	17,867.82	618.98	35,116.67
More than 20 Jobs	11,653.87	2,364.06	20,943.69

Currency in Rwf, where Rwf 1000 = 1 US $ (2019).

as compared to the male respondents that renewable energy will reduce the cost of electricity. Perhaps, these differences can be due to male higher levels of awareness to energy issues as compared to females that makes them more skeptical about the ability of deployment of renewables to reduce the cost of electricity. Given that Rwandan women show neutral attitudes toward unfamiliar sources of energy underscores the valuable input in the form of a cautionary approach that can be harnessed by incorporating their views in decision making processes. We also note that women awareness, attitude and preferences can play a great role in developing amenable policies. From a policy standpoint the valuable public input should be incorporated in future decision-making processes through public participation to guide policymakers in developing beneficial renewable energy programs. Support for privately owned renewable ventures by Rwandan residents, implies that the Rwandan government needs to further develop public-private partnerships with the aim of increasing participation and inclusion of the public in the renewable energy market (REP, 2015). Such efforts will serve to increase competition, resulting in cost reduction and improved choice of technologies in the market. This can be achieved by facilitating, loans and incentives through formation of cooperatives for community owned small/minigrid renewables.

Overall, this study showcases how socio-economic tradeoffs should be considered for effective outcomes. For example, we have seen that small hydros have a greater utility to the public as compared to solar, due to their greater presence in the market. This is a major caveat in the application of public preferences to guide policy interventions. As the choice of technology is guided by the publics' familiarity to these technologies, which may result in the public approving forms of technologies that may be outdated or one that is having significant environmental concerns. Lessons drawn from this these tradeoffs, is that a more a balanced focus that accounts for both public perspectives and emerging market trends should be incorporated in policy designs. The focus should emphasize on effective solar products that benefit public and small-scale businesses. For example, by introducing community solar products that are privately owned, can assist in speeding the gap between energy access as well as provide income sources to the public and bridge the poverty gaps. Even so, further caution in interpretations of these outcomes should be factored into policy interventions with the goal of understanding why the public have preferences toward certain types of energy as opposed to others. A wholistic approach will enable suitable programs that will enable Rwanda to a more sustainable renewable energy program.

Nonetheless, for Rwandan decision makers, the public momentum to participate in development of renewables should be harnessed for meaningful strides in securing energy access and enhancing the economy. This can be incorporated by first, creating awareness and increasing knowledge on renewable energy issues at all curriculum levels in academic institutions. Civic education through all forms of media and social work is also necessary to sensitize local populations on their benefits, roles, and input for renewable energy development. Finally, decision-making processes involving renewable energy development, should include stakeholders from diverse interest groups especially women to be involved in an active debate to streamline renewable energy policy. The role of the Rwandan government is to show political will by ensuring focus is on strong long-term policies to enable renewable energy development. Finally, negotiations with local community and clear processes outlining the benefits of renewable energy projects should be facilitated by the Rwandan government to increase public approval of renewable energy.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Montclair State University, Institutional Review Board. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SO and PL: conceived present idea. SO, AS, and JA: developed theory and performed computations. SO, MM, RM, and JA: data collection and analysis. SO and JA: developed manuscript. All authors contributed to the article and approved the submitted version.

REFERENCES

Barron, M., Clarke, R. P., Elam, A. B., and Klege, R. A. (2020). Gender and entrepreneurship in the renewable energy sector of Rwanda. *IDS BULL* 51, 153–70.

Bergmann, A., Hanley, and, N., and Wright, R. (2006). Valuing the attributes of renewable energy investments. *Energy Policy* 34, 1004–1014. doi: 10.1016/j.enpol.2004.08.035

Bimenyimana, S., Godwin, N., Asemota, O., and Lingling, L. (2018). The state of the power sector in rwanda: a progressive sector with ambitious targets. *Policy Pract. Rev*. 6, 68. doi: 10.3389/fenrg.2018.00068

Brennan, N., and Rensburg, T. M. (2016). Wind farm externalities and public preferences for community consultation in Ireland: a discrete choice experiments approach. *Energy Policy* 94, 355–365. doi: 10.1016/j.enpol.2016.04.031

Ek, K., and Persson, L. (2014). Windfarms-Where and how to place them? A choice experiment approach to measure consumer preferences for characteristics of wind farm establishments in Sweden. *Ecol. Econ*. 105, 193–203. doi: 10.1016/j.ecolecon.2014.06.001

Hakiziamana, J. D., Yoon, S. P., Kang, T. J., Kim, H. T., Jeon, Y. S., and Choi, Y. C. (2016). Potential for peat-to-power usage in Rwanda and associated implications. *Energy Strat. Rev*. 13–14, 222–235. doi: 10.1016/j.esr,.2016.04.001

IOB Evaluation (2014). *Access to Energy in Rwanda: Impact Evaluation of Activities supported by the Dutch Promoting Renewable Energy Program*. Available online at: https://www.oecd.org/derec/netherlands/Access-to-Energy-in-Rwanda.pdf (accessed October 19, 2019).

Klege, R. A., Visser, M., Manuel, F. B., and Rowan, P. C. (2021). Competition and gender in the lab vs field: Experiment from off-grid renewable energy entrepreneurs in Rural Rwanda. *J. Behav. Exper. Econom*. 91, 101662. doi: 10.1016/j.socec.2021.101662

Kosenius, A., and Ollikainen, M. (2013). Valuation of environmental and societal trade-offs of renewable energy sources. *Energy Policy* 62, 1148–1156. doi: 10.1016/j.enpol.2013.07.020

Ku, S., and Yoo, S. (2010). Willingness to pay for renewable energy investment in Korea: a choice experiment study. *Renew. Sustain. Energy Rev*. 14, 2196–2201. doi: 10.1016/j.rser.2010.03.013

Lancaster, K. (1966). A new approach to consumer theory. *J. Polit. Econ*. 74, 132–157. doi: 10.1086/259131

Lorenzo, M. D. (2008). *The Rwandan Paradox. Is Rwanda a model for an Africa beyond Aid?* Available online at: https://www.aei.org/articles/the-rwandan-paradox/ (accessed May 1, 2020).

Matero, S. R. (2013). Stated preferences of Finnish private homeowners for residential heating systems: a discrete choice experiment. *Biomass Bioenergy*. 57, 22–32. doi: 10.1016/j.biombioe.2012.10.010

McFadden, D. (1973). Conditional logit analysis of qualitative choice behavior. in *Frontiers in Econometrics*, ed P. Zarembka (New York, NY: Academic Press).

National Institute of Statistics of Rwanda (NISR) (2018). *Population Report, 2018*. Available online at: https://www.statistics.gov.rw/ (accessed September 26, 2019).

Niyonteze, J. D., Zou, F., Norense, G., Asemota, O., and Bimenyimana, S. (2019). Solar-powered mini-grids and smart metering systems, the solution to Rwanda energy crisis. *IOP Conf. Series J. Phys. Conf. Series* 1311, 012002. doi: 10.1088/1742-6596/1311/1/012002

Niyotenze, J. D., Zou, F., Norense, G., Asemota, O., Bimenyimana, S., and Shyirambere, G. (2020). Key technology development needs and applicability analysis of renewable energy hybrid technologies in off-grid areas for the Rwanda power sector. *Heliyon* 6, e03300. doi: 10.1016/j.heliyon.2020.e03300

O'Keeffe, L. A. (2014). Choice experiment survey analysis of public preferences for renewable energy in the United States. *J. Environ. Resour. Econ*. 1, 1–21. Available online at: https://digitalcommons.colby.edu/cgi/viewcontent.cgi?article=1007&context=jerec

Oluoch, S., Lal, P., Susaeta, A., and Wolde, B. (2021). Public preferences for renewable energy options: A choice experiment in Kenya. *Energy Econom*. 98, 105256. doi: 10.1016/j.eneco.2021.105256

Oluoch, S. O., Lal, P., Susaeta, A., and Vedwan, N. (2020). Assessment of public awareness, acceptance, and attitudes towards renewable energy in Kenya. *Sci. Afri*. 9, e00512. doi: 10.1016/j.sciaf.2020.e00512

Opoku, O. E., Kufour, N. K., and Manu, A. S. (2021). Gender, electricity access, renewable energy consumption and energy efficiency. *Technol. Forecast. Soc. Change*. 173, 121121. doi: 10.1016/j.techfore.2021.121121

Power Africa (2018). *Power Africa USAID Report*. Available online at: https://www.usaid.gov/powerafrica/Rwanda (accessed September 23, 2019).

Rao, K., and Tilt, C. (2016). Board composition and corporate social responsibility: the role of diversity, gender, strategy and decision making. *J. Bus. Ethics* 138, 327–347. doi: 10.1007/s10551-015-2613-5

REP (2015). *Rwanda Energy Policy (REP)*. Available online at: https://www.mininfra.gov.rw/fileadmin/user_upload/new_tender/Energy_Policy.pdf (accessed September 26, 2019).

REU (2018). *Rwanda Economic Update, Strategic Plan 2019–2024*. Available online at: https://www.reg.rw/public-information/policies-regulations/?itemPerPage=30andcHash=bbcd8c8df2734436c5e43ceae9c27b6e (accessed October 15, 2019).

Rodriguez-Manotas, J., Bhamidipati, P. L., and Haselip, J. (2018). Getting on the ground: exploring the determinants of utility-scale in Rwanda. *Energy Res. Soc. Sci*. 42, 70–79. doi: 10.1016/j.erss.2018.03.007

Rukundo, E., Liu, S., Dong, Y., Rutebuka, E., Asamoah, E. F., Xu, J., et al. (2018). Spatio-temporal dynamics of critical ecosystem services in response to agricultural expansion in Rwanda, East Africa. *Ecol. Indicat*. 89, 696–705. doi: 10.1016/j.ecolind.2018.02.032

Rutagarama, U. (2013). *Geothermal Exploration and Development in Rwanda. Short Course VIII on Exploration for Geothermal Resources*. Available online at: https://rafhladan.is/bitstream/handle/10802/6069/UNU-GTP-SC-17-1006.pdf?sequence=1 (accessed October 11, 2019).

Safari, B., and Gasore, J. (2010). A statistical investigation of wind characteristics and wind energy on the Weibull and Rayleigh models in Rwanda. *Renewable Energy* 35, 2874–2880. doi: 10.1016/j.renene.2010.04.032

Uwisengeyimana, J. D., Teke, A., and Ibrikci, T. (2016). Current overview of renewable energy resources in Rwanda. *J. Energy Natl. Resour*. 5, 92–97. doi: 10.11648/j.jenr.20160506.13

Vecchiato, D., and Tempesta, T. (2015). Public preferences for electricity contracts including renewable energy: a marketing analysis with choice Experiments. *Energy* 88, 168–179. doi: 10.1016/j.energy.2015.04.036

WDI (2018). *World Bank Indicators (WDI)*. Available online at: http://datatopics.worldbank.org/world-development-indicators/ (accessed October 20, 2019).

WPRR (2019). *World Population Review Report (WPRR)*. Rwanda Population. Available online at: https://worldpopulationreview.com/countries/rwanda-population (accessed September 24, 2019).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.