

Article

Determinants of Consumer Willingness to Invest in Green Energy Solutions: Perspectives from South Africa

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Abstract

The energy sector holds critical importance for South Africa, particularly as a developing country grappling with persistent economic challenges and energy insecurity. These pressures have stimulated growing scientific and policy interest in renewable energy as a pathway to sustainable development. This study examines public perceptions and awareness of renewable energy technologies and estimates willingness to pay (WTP) for their increased integration into South Africa's energy mix. By linking these objectives, the study provides insights into the social and economic factors that shape a just energy transition and informs targeted policies, investments, and engagement strategies to accelerate the adoption of renewable energy. A descriptive research design was employed, incorporating a systematic random sampling approach to ensure reliability and representativeness. Data were collected through structured questionnaire surveys conducted in both urban and rural households across Limpopo Province, South Africa. Findings reveal a generally positive public attitude toward the expansion of renewable energy, although knowledge levels remain moderate and are most pronounced with respect to solar energy systems. The mean household WTP for increased renewable energy penetration was estimated at ZAR 163.4 per annum. Binary logistic regression analysis identified eight statistically significant predictors of WTP: Education, Occupation, Income, Recognised Advantages (A1), Financial Incentive Schemes for RES (A3), Expansion Strategies for Renewable Energy (A4), Price Parity with Fossil Fuels (A7), and Interest-Free Financing Options (A8). These results highlight the importance of affordability, policy support, and tangible benefits in driving public acceptance. Overall, the findings highlight the potential for targeted policy and educational interventions to foster household participation and advance South Africa's just energy transition.

Keywords: renewable energy sources; willingness to pay; households; binary logistic regression; South Africa



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1. Introduction

One of the most significant challenges of the 21st century is decarbonizing global energy systems. The energy sector plays a central role in addressing climate change, as it is responsible for over two-thirds of global carbon dioxide (CO₂) emissions, mainly from

energy production and use [1]. While global economic growth depends heavily on energy, especially electricity and its primary resources, electricity generation and industry alone account for approximately 65% of energy-related CO₂ emissions, with the remainder stemming from buildings, transport, and district heating [2]. Since the 1970s, global GDP has increased by approximately 4.5 times, while primary energy consumption rose from 37.07 million tonnes of oil equivalent (Mtoe) in 1965 to 132.9 Mtoe in 2020. By the end of 2020, proven reserves of oil, gas, and coal were projected to last 53.5, 48.8, and 139 years, respectively, at current extraction rates [3]. In parallel, global CO₂ emissions surged to 36.3 gigatonnes (GT), a 6% rise, reflecting the environmental toll of continued fossil fuel use [4].

In South Africa, a complete departure from coal dependence remains unlikely, as it is viewed as essential for economic stability and growth [5]. The country's energy system is heavily reliant on deep coal reserves. However, most coal-fired plants are outdated and inefficient, demanding significant investment to sustain the electricity supply and grid stability during the energy transition [5]. Newer coal plants have also encountered quality issues and cost overruns, compounding energy infrastructure challenges. Consequently, South Africa is the largest CO₂ emitter in Africa, accounting for roughly 40% of the continent's emissions [6]. According to the Department of Forestry, Fisheries and the Environment (DFFE), South Africa's total greenhouse gas (GHG) emissions, excluding those from land use, land-use change, and forestry (LULUCF), were approximately 478,888 Gg CO₂-equivalent in 2022 [7]. This high emissions profile reflects the country's historical reliance on coal, which still generates around 82% of its electricity [5]. Despite this, the power sector is plagued by operational inefficiencies, leading to persistent load shedding and controlled blackouts aimed at preventing grid collapse due to high demand [8]. These systemic challenges underscore the urgent need for a strategic and equitable energy transition. Encouragingly, South Africa has made notable strides toward advancing a just energy transition, laying the groundwork for a more sustainable and resilient energy future.

At the same time, energy poverty remains a pressing challenge: nearly 10% of households (about 1.7 million) still lack formal access to electricity, while many connected households face unreliable supply and unaffordable tariffs [5]. Energy poverty exacerbates inequality, limits opportunities for education and livelihoods, and disproportionately affects women and rural populations. Addressing it is central to South Africa's developmental agenda and aligns directly with the goals of the National Development Plan (NDP) Vision 2030.

Despite these challenges, South Africa has vast untapped renewable resources. The country receives over 2500 h of sunshine per year, with direct normal irradiation ranging from 4.19 to 8.50 kWh/m²—among the highest globally, positioning it as a leader in solar energy potential [5]. Wind corridors along the Western and Eastern Cape also present opportunities, with average wind speeds above 7 m/s at 80 m hub height. Hydropower and biomass remain modest but regionally significant, while geothermal potential is largely unexplored. Initiatives such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) have demonstrated early success, attracting over ZAR 200 billion in private investment and installing more than 6 GW of renewable capacity since 2011 [5].

South Africa's commitment to global climate agreements, notably the Kyoto Protocol (1997) and the Paris Agreement (2015), has significantly advanced a shift toward renewable energy. These frameworks have spurred policy reforms and technical interventions in the energy sector, aligning national efforts with international climate objectives. The country's renewable energy strategies are particularly aligned with the United Nations Sustainable Development Goal (SDG) 7, which promotes access to affordable, reliable, and sustainable

energy. Moreover, these efforts contribute to several interconnected SDGs: SDG 1 (No Poverty), by reducing energy costs and generating green jobs; SDG 3 (Good Health and Well-being), by improving air quality and reducing fossil fuel-related pollution; SDG 8 (Decent Work and Economic Growth), through the creation of employment in the renewable energy sector; SDG 9 (Industry, Innovation, and Infrastructure), via investment in modern clean technologies; SDG 11 (Sustainable Cities and Communities), by fostering inclusive urban energy systems; SDG 12 (Responsible Consumption and Production), by promoting energy efficiency; and SDG 13 (Climate Action), by curbing greenhouse gas emissions and enhancing climate resilience, as well as contributing to the broader aspirations of the African Union's Agenda 2063—'The Africa We Want'.

Enhanced public access to environmental information has further strengthened this transition by increasing awareness and demand for clean energy solutions. A wider penetration of information on RES is essential not only for achieving green economic growth [9], but also for meeting climate targets, particularly the goal of limiting global temperature rise to 1.5 °C above pre-industrial levels [10]. In this context, the global investment landscape has witnessed substantial growth in the green energy sector, particularly in the last decade. This is evident in the increased deployment of solar, wind, hydro, and bioenergy systems across various economies as part of broader efforts to align with the principles of sustainable development and low-carbon transitions [11–13]. In response to both international climate commitments and domestic energy challenges, the country has scaled up its adoption of solar photovoltaic, wind, and concentrated solar power projects under initiatives such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) [14,15]. While fossil fuels, especially coal, continue to dominate South Africa's energy mix, the increasing integration of renewables signals a progressive shift toward a more sustainable and resilient energy future [16]. Nevertheless, more concerted efforts are still required to overcome infrastructural, regulatory, and socio-economic barriers that may hinder the broader uptake of green technologies.

Public readiness to invest in renewable energy technologies is shaped by several behavioural theories that explain consumer decision-making regarding environmental products and services. The Theory of Planned Behaviour (TPB) posits that attitudes, perceived behavioural control, and subjective norms influence intentions to adopt green technologies [17]. The Value-Belief-Norm (VBN) Theory emphasizes the role of personal values and moral obligations in driving pro-environmental behaviour [18]. These frameworks are often integrated with models such as the Technology Acceptance Model (TAM) to deepen insights into green energy adoption [19].

More recently, Social Acceptance Theory has emerged as a key analytical framework [20], encompassing socio-political, community, and market acceptance, each reflecting varying levels of public interaction with renewable energy systems [21]. Within this framework, willingness to pay (WTP) is increasingly used as a proxy for market and attitudinal acceptance. Empirical studies indicate a rising public inclination toward renewable energy and environmentally responsible practices [22–24]. These studies underscore that while technical and infrastructural factors are essential to renewable energy deployment, social, economic, and behavioural dynamics, particularly public perception and willingness to act, play a pivotal role in determining the success and sustainability of energy transitions. In many contexts, public acceptance and economic readiness have proven to be as influential as technological feasibility in shaping the trajectory of renewable energy integration. Within this research framework, the scope of this article is to examine the social and economic dimensions influencing the uptake of RES in South Africa. Specifically, the study is structured around two primary research aims. Firstly, to assess public perceptions and awareness regarding renewable energy technologies and their role in ad-

addressing energy and environmental challenges; and secondly, to estimate the public's WTP for an increased integration of renewable energy into South Africa's existing energy mix. By focusing on these two interrelated objectives, the study seeks to provide empirical insights into the societal and economic enablers (or barriers) that could influence the pace and equity of South Africa's transition to a cleaner, more sustainable energy future. These findings aim to inform policy interventions, investment strategies, and public engagement efforts towards increasing renewable energy adoption.

2. Literature Review

In many countries, the level of public acceptance toward renewable energy sources is commonly assessed through the lens of social acceptance [25]. Importantly, social acceptance is not uniform; it varies both between countries and within different regions of the same country. As such, assessing social acceptance at both national and local levels is essential for the successful implementation of green investments and the broader transition to renewable energy systems [26]. While some nations report consistently high levels of public support across a range of energy technologies, the degree of acceptance often depends on a complex interplay of relational factors. In Germany, a nationwide survey found that public acceptance of renewable energy is significantly influenced by grid expansion policies, highlighting the importance of transparent and inclusive infrastructure planning in facilitating energy transitions [27]. Similarly, a human-centered study conducted among homeowners in California and Massachusetts examined the factors influencing the adoption of residential solar photovoltaic (PV) systems. The study identified several key drivers, including age, household income, and the perceived reliability of solar system installers, suggesting that both socioeconomic and trust-based considerations play a critical role in consumer decision-making [28].

In the context of Thailand, Wall et al. [29] demonstrated that heightened green awareness, environmental concerns, and beliefs in the societal benefits of renewable energy significantly drive the uptake of clean energy technologies. The findings underscored that consumers' environmental beliefs and knowledge are central to fostering acceptance and willingness to adopt renewable energy systems. Furthermore, growing concerns over environmental degradation and recognition of the long-term benefits of renewable energy have increased public interest in sustainable energy sources. Similarly, Ulkhaq et al. [30] emphasized that the successful promotion of renewable energy in Indonesia hinges on public awareness and its benefits. The study investigated the determinants of Indonesian consumers' willingness to adopt renewable energy technologies and identified several influencing factors. These included monthly income, level of education, awareness of renewable energy benefits, employment status, average electricity prices, concerns about energy tax incentives, and the rising cost of non-renewable energy sources. Each of these factors was shown to positively impact consumer motivation to transition toward renewable energy, illustrating the complex interplay between economic, educational, and environmental awareness variables in shaping energy consumption behaviour.

Aside from the high infrastructural costs associated with the widespread adoption of RES-based systems, several other critical barriers persist. These include the lack of publicly accessible and shared information, as well as prevailing public behaviours and attitudes toward technological advancements in the renewable energy sector. As reported in a review study by Ahmed et al. [31], insufficient awareness and limited citizen engagement significantly hinder the acceptance and integration of RES technologies, notably when public trust, understanding, and enthusiasm are lacking. This social behaviour is particularly prevalent in economically developing regions, where public engagement with renewable energy technologies remains limited. A study conducted among residents in urban, subur-

ban, and rural areas of China found that inadequate access to reliable and comprehensive information significantly contributed to low awareness and adoption rates of renewable energy solutions [32].

Beyond the framework of social acceptance theory, numerous studies have examined the economic dimension of renewable energy adoption by assessing the amount consumers are WTP for the expansion of renewable energy systems in their residential areas. WTP reflects the economic value individuals hypothetically assign to non-market goods, such as clean energy [33]. To estimate this value, the contingent valuation method (CVM) is widely employed [34]. This approach involves directly eliciting individuals' preferences, typically through structured questionnaire surveys, where respondents are asked to state their maximum WTP for a specified renewable energy improvement or service [34]. In a study conducted in Greece examining consumer attitudes toward RES [35] found that 75% of customers were willing to pay a price premium for hotels that had invested in energy-saving measures and renewable energy technologies. A South African study on WTP revealed that 93% of surveyed households expressed a willingness to purchase indigenous food plants, indicating strong potential demand. Key determinants included age, marital status, household size, farming background, and perceived economic benefits, with household size and financial returns being the most significant [36]. A study from China found that household income, education level, and knowledge of renewable energy positively influence WTP, whereas age and the perception that neighbours are not participating negatively affect WTP [37].

WTP for renewable energy, commonly estimated using the CVM, has been widely applied across both Global North and South contexts. Soon and Ahmad [38] report that the average household WTP for renewable energy across Asia, Europe, and North America is approximately USD 7.76. In Japan, this figure rises to about USD 17 per household per month [39]. In the southwestern United States, households expressed willingness to pay an average increase of 14% (USD/month) on their current electricity bills for a 10% increase in the renewable energy share [40]. Comparable estimates include USD 2.7–3.3/household/month in Beijing, China [41], USD 13–16/household/month in Australia [42]; USD 2.3–4.3/household/month in Italy [43]; and USD 4.1/household/month in Slovenia [44]. In Nigeria, 87.5% of respondents indicated willingness to pay an additional 5–10% on their current electricity bills for renewable electricity, translating to an increase of approximately ₦26.25–₦27.50 [45]. Similarly, in Ghana, a study using CVM with data from 950 households revealed that residents were willing to pay up to 44% more (approximately GH¢6.8), with average monthly electricity bills ranging from GH¢4 to GH¢60. The influencing factors included separate meter ownership, household size, prior notice of power outages, income, business ownership, and education level [46]. In Kenya, a CVM-based study on WTP for renewable energy recommended offering both grid and off-grid options rather than solely focusing on grid-connected models. The study emphasized the establishment of a dedicated rural energy service company as a practical strategy for deploying renewable energy in rural areas [47].

While cross-country evidence demonstrates diverse drivers and barriers, African-specific evidence remains limited compared to studies in the Global North. Few studies directly link renewable energy acceptance to broader just transition policies or contextualize the results within South Africa's unique energy crisis. This creates a gap in understanding how household perceptions in Limpopo Province align with, or diverge from, national and continental trends. By applying TPB, VBN, and Social Acceptance Theory, this study addresses these gaps, situating Limpopo Province households within broader African dynamics while offering insights into the interplay between affordability, cultural values, and institutional trust.

From an economic perspective, the expansion of RES in South Africa presents significant opportunities. Aside from other RES such as geothermal, hydropower, biomass and wind energy, the country possesses one of the highest levels of direct normal irradiation (DNI), ranging from 4.19 to 8.50 kWh/m², which is critical for the efficiency of solar thermal systems [48]. Estimates suggest that South Africa has the potential to generate approximately 42,243 TWh of solar photovoltaic (PV) electricity and 43,275 TWh of solar thermal energy from concentrated solar power (CSP) annually [49]. Across much of the country, average solar radiation reaches approximately 220 W/m², with over 2500 h of sunshine recorded per year, positioning South Africa as an ideal environment [16]. The significance of the energy sector in South Africa, particularly in the context of its status as a developing country experiencing a severe economic crisis has attracted broad scientific interest across several key thematic areas, including Energy Security and Access [50], Renewable Energy Transition [16], Climate Change Mitigation [51], Just Energy Transition (JET) [52], Energy Governance and Policy Reform [53], Energy Poverty and Inequality [54], Social Acceptance and Community Participation [55].

3. Materials and Methods

3.1. Study Motivation

This study is motivated by the need to better understand the factors influencing consumers' willingness to invest in green energy solutions in South Africa, using the Limpopo Province as a case study. It aims to fill a critical knowledge gap by identifying key enablers and barriers to the adoption of green energy at the household level. The research aligns with global sustainability goals (SDGs) and South Africa's National Development Plan (NDP) Vision 2030, which promotes green economy solutions as a strategic pathway toward sustainable development and environmental stewardship. The NDP green economy agenda emerges in parallel with the country's ongoing energy shortages. While there have been efforts to expand coal-fired power plants, there is also a growing imperative to scale up renewable energy generation and promote energy efficiency, aligning with global sustainability goals. The government has set an ambitious target of generating 20,000 MWh of electricity from renewable sources by 2030. However, progress toward this goal has been slow, with current estimates indicating that only about 1% of the country's electricity is derived from renewable energy [56]. A descriptive research design incorporating both qualitative and quantitative methods was adopted, and data was collected using semi-structured questionnaires and self-evaluation, employed as a complementary method across households in Limpopo Province.

Consistent with established approaches in the literature, a descriptive research design was adopted, integrating both qualitative and quantitative methods. The methodology [57] has been particularly influential in shaping the design of this study, as it combines household surveys with econometric analysis to assess willingness to pay (WTP) for renewable energy. While our approach follows the general pattern set out by [57], we extend it by embedding the analysis in the South African context, with a focus on structural inequalities, energy poverty, and localized barriers to adoption in Limpopo Province.

3.2. Study Area

Limpopo Province is South Africa's northernmost province, covering an area of 125,755 km² and comprising five administrative districts: Capricorn, Mopani, Sekhukhune, Vhembe, and Waterberg. Agriculture is the backbone of the local economy, with 8 million hectares of land used predominantly for grazing and crop production [58]. Over 96% of the population lives in rural areas, surpassing the national average of 84% [59]. The province faces limited access to essential services, high unemployment, and economic inequality.

Nevertheless, it is strategically positioned for development due to its rich natural resources and alignment with pro-poor policies and principles.

3.3. Sampling and Data Collection

The study employed a systematic random sampling method to ensure statistical representation. Ethical clearance for the study was obtained from the relevant institutional review board, ensuring compliance with established research ethics protocols. A semi-structured survey was piloted in twenty households from a non-sampled area to refine wording, improve clarity, and provide cultural appropriateness. The primary data collection method employed semi-structured questionnaires complemented by self-evaluation. From an initial pool of 670 households, the Yamane [60] formula was applied to determine a statistically reliable sample size:

$$n = \frac{N}{(1 + Ne^2)} \quad (1)$$

where

n = Sample size

N = population size

e = Margin of error (0.05) Proportion of estimated sample

$$n = \frac{670}{(1 + 670(0.05)^2)} \quad (2)$$

$$= \frac{670}{2.675} \quad (3)$$

Sample size (n) = 250.4 $\approx$ 250.

Fifty households were surveyed in each of the five district municipalities of the province. Systematic sampling involved selecting every fifth household, ensuring geographic and demographic representation, including gender, income, and household size. Households that declined participation were replaced systematically. Data collection took place between February and April 2024. In line with previous studies [61–63], the household head was the primary respondent. In cases where the primary respondent was unavailable, the questionnaire was administered to any adult household member (18 years or older) who had resided in the household for at least one year. Questionnaires were administered in English, with interpreters used where necessary. Trained research assistants conducted the survey, ensuring quality and consistency throughout the data collection process.

3.4. Data Analysis

Data cleaning and statistical analysis were conducted using IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA). Descriptive statistics were used to summarize respondents' socio-demographic characteristics. To examine the relationships between demographic variables (e.g., age, gender, education level, income), awareness, and WTP for green energy, several statistical tests were employed. These included the Principal Component Analysis (PCA) to reduce dimensionality and identify key factors influencing green energy awareness and WTP. Pearson's Chi-square tests were used to assess the associations between categorical variables, and the Binary logistic regression to model the likelihood of WTP based on various predictors. A significance level of $p < 0.05$ was used to determine statistical relevance. To evaluate the internal consistency of Likert-scale items, reliability analysis was performed using Cronbach's alpha. The overall Cronbach's alpha coefficient was 0.83, indicating strong internal reliability. Subscales measuring awareness

also exceeded the acceptable threshold of 0.70. The results are presented in tables and graphical illustrations to aid interpretation. These analytical techniques have been widely used in previous studies to examine relationships among categorical and continuous variables [57,64–66].

4. Results and Discussion

4.1. Demographic and Socio-Economic Characteristics of Respondents

To gain insight into the demographic and socio-economic profile of the participating households, it was necessary to analyse the characteristics of the respondents. Table 1 presents a summary of these attributes. The data indicate that 66.4% of the respondents were male, while 33.6% were female. This gender distribution does not indicate a demographic imbalance in the province but reflects the survey's focus on household heads, who are predominantly male. In instances where the male head was unavailable, female members of the household participated in the survey. Regarding age distribution, most respondents (34.4%) were between 36 and 45 years old, followed by those aged 46–55 (27.2%) and 26–35 (16.8%). Marital status data show that a significant proportion of respondents were married (72.2%), while 12% reported being single. In terms of educational attainment, the most common level of education was secondary school, with 98 out of 250 respondents holding a secondary school qualification. This highlights the prevalence of secondary education among the sampled population.

Table 1. Demographic Characteristics of the Respondents (Source: Field Survey, 2024; see also [67] for similar demographic trend).

Variable	Frequency (N)	Percentage (%)
Gender		
Male	166	66.4
Female	84	33.6
Total	250	
Age		
18–25	18	7.2
26–35	42	16.8
36–45	86	34.4
46–55	68	27.2
56 and above	36	14.4
Total	250	
Marital status		
Single	30	12
Married	182	72.8
Divorced	22	8.8
Widow/Widower	12	4.8
Did not tell	4	1.6
Total	250	
Highest education level		
No formal education	22	8.8

Table 1. *Cont.*

Variable	Frequency (N)	Percentage (%)
Primary	48	19.2
Secondary	98	39.2
Basic degree	64	25.6
Postgraduate	18	7.2
Total	250	

The socio-economic profile of respondents, detailed in Table 2, indicates that trading is the most common occupation (28%), followed by artisans (26.4%), civil servants (21.6%), farmers (8%), and mining sector workers (6.4%). Additionally, 4.8% were involved in other forms of enterprise, and 4% were students. In terms of monthly income, 40.8% earned between R10,001 and R15,000, while 36.8% fell within the R5001–R10,000 range. Lower income groups included those earning below R5000 (10.8%) and those earning above R15,000 (11.6%). Household size data indicates that most respondents lived in families of 2–4 members (44.8%) or 5–6 members (43.2%), with smaller (single-person) households at 7.6% and larger households (7+ members) at 4.4%.

Table 2. Socio-economic Characteristics of the Respondents (Source: Field Survey, 2024; see also [67] for similar socio-economic characteristics trend).

Variable	Group	Frequency (N)	Percentage (%)
Occupation			
	Civil Service	54	21.6
	Farming	20	8
	Trading	72	28.8
	Mining sector	16	6.4
	Artisan	66	26.4
	Student	10	4
	Others	12	4.8
Total	250		
** Income (Monthly)			
	Less R5000	27	10.8
	R5001–10,000	92	36.8
	R10,001–15,000	102	40.8
	R15,000 and above	29	11.6
Total	250		
Household size			
	1	19	7.6
	2–4	112	44.8
	5–6	108	43.2
	7 and above	11	4.4
Total	250		

** As of the time of the survey, 1 USD equals R17.58.

4.2. Background Knowledge of Green Energy

An assessment of respondents' baseline understanding revealed limited familiarity with the concept of green energy. Initially, only 48% of participants reported being aware of the term, while 52% had never encountered it. To bridge this knowledge gap, research assistants offered simplified explanations using familiar terms such as “renewable energy” and “environmentally friendly energy sources.” This intervention substantially improved comprehension, making the concept more relatable. After the clarification, participants reassessed their awareness using a Likert scale. As shown in Figure 1, 46 respondents described themselves as “extremely aware,” 44 as “very aware,” and 70 as “moderately aware.” Meanwhile, 73 indicated they were “slightly aware,” and 17 still had no basic understanding of renewable energy.

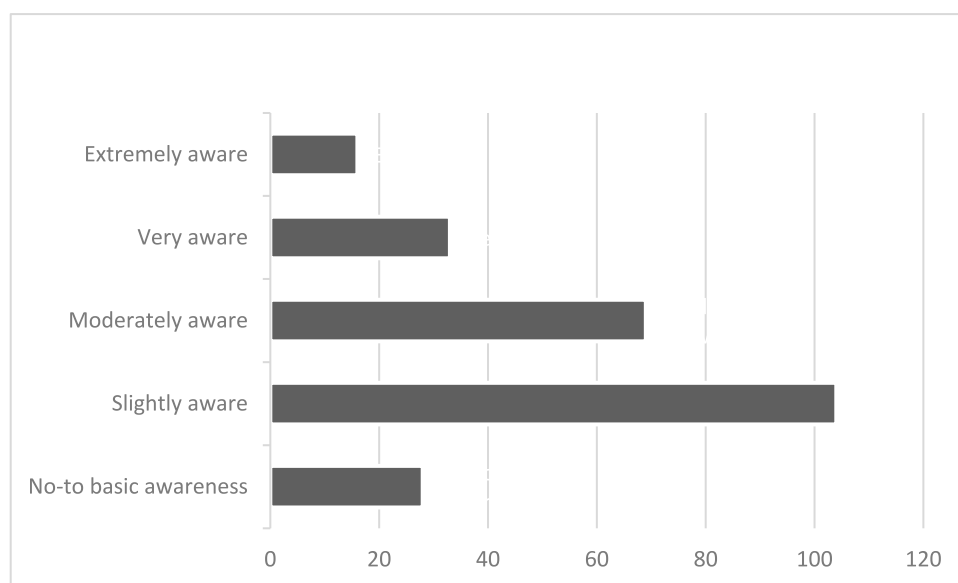


Figure 1. Background Knowledge of Green Energy.

These results suggest that while initial knowledge was limited, targeted and context-sensitive communication can significantly improve public understanding. These findings are significant in filling the research gap identified in this study. Limited household-level awareness has been identified as a barrier to renewable energy adoption in South Africa; however, few empirical studies provide detailed evidence of baseline knowledge among communities. By quantifying levels of awareness and demonstrating how targeted, context-sensitive communication can enhance understanding, this study contributes to the broader discourse on behavioural and informational enablers of renewable energy adoption. This directly supports the study's objective of identifying social and economic factors influencing public perceptions and willingness to pay for renewable energy in South Africa. It also indicates a growing awareness of green energy at the household level, though notable gaps remain. This trend is consistent with Wall et al. [29], who found that increased environmental awareness and belief in the societal benefits of renewable energy positively influence adoption in Thailand.

4.3. Sources of Information on Renewable Energy

To better understand how information on RES is disseminated and received, respondents were asked to identify the channels through which they had encountered such information. This was particularly relevant given ongoing public campaigns promoting renewable energy awareness and adoption. As shown in Table 3, the survey explored various communication mediums, including TV, radio, family or community networks, munic-

pal outreach, social media, workplace communication, educational institutions, internet sources, and public service announcements. Respondents could also indicate if they had not received any information through these channels. The findings highlight the importance of employing diverse and targeted communication strategies to reach different demographic groups. Traditional media such as TV and radio remain crucial in rural or low-digital-access areas, while social media and online platforms are more effective for younger, urban populations. This underscores the importance of a multi-channel communication approach that accounts for socio-demographic differences, digital literacy, and media access. Broadening the reach of RES-related information is essential not only for fostering green economic growth [9], but also for increasing public awareness and encouraging sustainable energy behaviours.

Table 3. Communication Channels for RE Development.

Channel (Multiple Choice)	Number	Percentage (%)
Television (TV)	62	16.5
Radio	60	16
Community or family members	46	12.2
Municipalities	32	8.4
Social media	20	5.4
Workplace or office communication	50	13.2
Schools	36	9.5
Internet sources	18	4.7
Public service announcements	20	5.4
Environmental Organisations/Non-Governmental Organisations	16	4.2
Never heard	17	4.5

4.4. Self-Evaluation Knowledge on RES

To assess respondents perceived knowledge of RES, participants completed a self-evaluation using a five-point Likert scale (Poor to Excellent) across five RES categories: solar, wind, hydropower, geothermal, and biomass/bioenergy. This aimed to gauge both confidence and awareness levels. As shown in Figure 2, most respondents rated their knowledge as Average or Good, while a few rated it as Excellent. A notable portion selected ‘Fair’ or ‘Poor’, indicating significant knowledge gaps and the need for targeted educational outreach. Among the technologies, solar energy was the most familiar, which is likely due to the visible use of rooftop panels and solar water heaters in the community. Biomass/bioenergy followed, reflecting awareness of pilot biogas projects introduced by the government and NGOs. In contrast, geothermal, hydropower, and wind energy received lower ratings, likely due to minimal local presence or exposure. These findings highlight the importance of tailored public education strategies that incorporate local examples, visual aids, and simplified explanations. While solar and biomass are relatively well understood, broader awareness of RES remains limited. Enhancing renewable energy literacy as identified by Ahmed et al. [31] is a key driver of adoption and requires communication approaches that align with local realities and media access to foster informed decision-making at both the household and community levels.

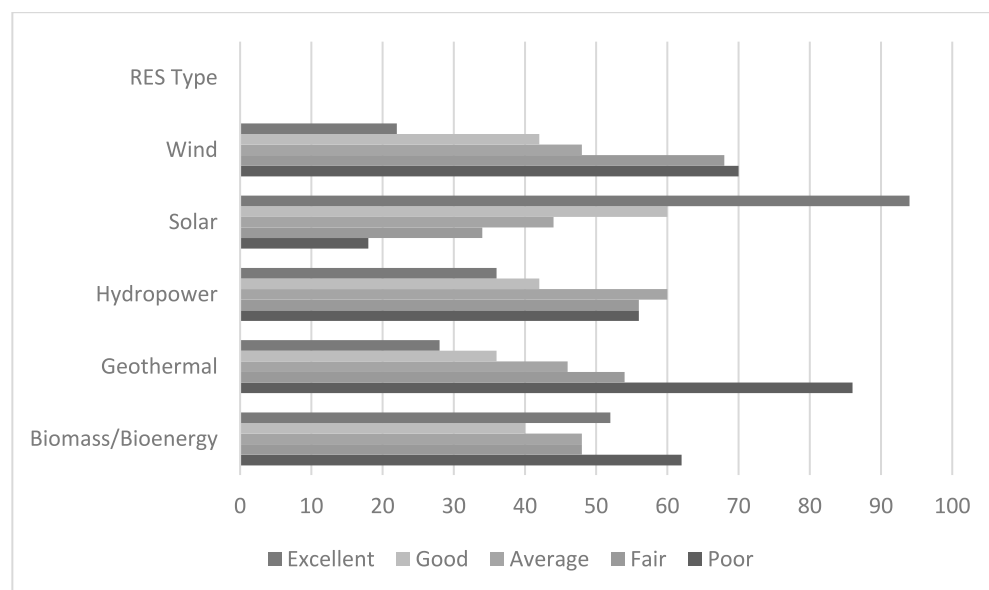


Figure 2. Self-evaluated outcomes of RES knowledge.

4.5. Perceptual Statements Regarding the Benefits of Renewable Energy (RE)

To evaluate public perceptions of RE, respondents rated a series of benefit-related statements using a three-point Likert scale (Agree, Neutral, Disagree). As summarized in Table 4, 70% of participants identified sustainable development as the primary benefit of RES adoption, reflecting strong awareness of its long-term socio-economic and environmental value. Energy self-sufficiency and employment creation followed closely, each cited by 68% of respondents, indicating public recognition of RES to enhance national energy security and generate green jobs. Other notable benefits included improved quality of life (64%) and environmental preservation (62%), while 60% acknowledged economic advancement. Only 58% agreed that RES reduces reliance on conventional energy, suggesting lingering concerns about the feasibility or reliability of renewables. Crucially, 86% of respondents supported the further expansion of renewable energy, highlighting widespread public backing for policies and investments in the sector. These findings suggest that public communication strategies should emphasize the tangible socio-economic and environmental gains and outcomes of RES. Moderate agreement on reducing fossil fuel dependency also highlights the need for continued education to dispel doubts and build confidence in renewable technologies. Consistent with [30], the results reaffirm that increasing awareness of the benefits of RES is key to driving broader adoption.

Table 4. RE perceptual statement.

Perceptual Statement	Responses (%)		
	Agree	Disagree	Neutral
Energy self-sufficiency	68	22	10
Environmental Preservation	62	26	12
Sustainable development	70	22	8
Economic advancement	60	28	12
Emerging employment opportunities	68	20	12
Quality of life	64	26	10
Decreased reliance on conventional energy	58	36	6

4.6. Impeding Barriers to Green Energy Development

The transition to green energy technologies at the household level, particularly in developing regions, is often hindered by a series of interrelated challenges. Despite the growing global emphasis on renewable energy as a cornerstone of sustainable development, several factors continue to constrain its widespread adoption. This study identified key barriers as perceived by household respondents, using a multiple-choice survey format to assess the frequency and perceived significance of each obstacle. These results point to the multifaceted nature of the barriers to green energy development and adoption. While financial concerns remain primary, they are compounded by technical, informational, and regulatory challenges. Consequently, any intervention aimed at promoting green energy at the household or community level must adopt a holistic and context-sensitive approach. Strategies such as government subsidies, capacity building for local installers, user-centered technology design, and consistent policy implementation can help mitigate these barriers and facilitate broader adoption of renewable energy solutions. Despite global momentum toward renewables, this study identified key obstacles perceived by respondents, as summarized in Table 5.

Table 5. Impeding Barriers to Green Energy Development.

Impeding Barrier (Multi Choice)	Number of Respondents	Percentage (%)
High cost of installation	65	18.6
Reliability concerns	60	17.1
Complex installation processes	44	12.6
Risk of fire outbreak	44	12.6
User interface complexity	38	10.9
High maintenance costs	26	7.4
Regulatory and policy difficulties	28	8
Lack of accurate information	22	6.2
Potential hazards (other than fire)	23	6.6

High installation costs emerged as the most cited barrier (18.6%), highlighting a significant financial constraint, especially in low-income communities where upfront costs outweigh perceived long-term savings. Reliability concerns followed (17.1%), with scepticism around system consistency due to variable solar input, technical faults, and limited backup capacity. Installation complexity (12.6%) and fire risks (12.6%) also posed significant concerns, pointing to a lack of skilled technicians and safety concerns, particularly in densely populated areas. Additionally, 10.8% of respondents noted difficulties with operating systems, indicating that user-friendliness is crucial in contexts with low technical literacy. Other reported barriers included high maintenance costs (7.4%), weak policy and regulatory support (8%), limited access to reliable information (6.6%), and non-fire-related safety concerns (6.3%). These findings emphasize that institutional and informational gaps are nearly as impactful as financial and technical challenges. Overall, the results underscore the multifaceted nature of barriers to the adoption of green energy. Effective interventions must therefore be holistic and context-sensitive combining financial support (e.g., subsidies), technical training, user-centered system design, and consistent policy implementation to drive household-level uptake of renewable energy.

4.7. WTP for Increased Renewable Energy Share

As part of the survey, respondents were presented with a dichotomous question to determine their WTP for a further annual increase in the share of RES in the national electricity generation mix. The purpose was to assess the community's financial readiness to support a cleaner and more sustainable energy system. The results revealed that more than one-third of the respondents expressed a positive willingness to pay for a further expansion of renewable energy, indicating a growing awareness and acceptance of the associated environmental and socio-economic benefits. The responses, summarised in Table 6, provide detailed insights into the specific amount households are willing to contribute.

Table 6. Respondents' WTP for Increased RES Penetration.

Amount (ZAR)	Frequency	Percentage (%)
50–100	85	34
101–150	47	18.8
151–200	36	14.4
201–250	34	13.6
251–300	28	11.2
301–350	11	4.4
351 and above	9	3.6
Total	250	100

As shown in Table 6, most respondents (34%) are willing to pay between ZAR 50–100 annually for a further increase in renewable energy share. This was followed by 18.8% of respondents who indicated a willingness to pay between ZAR 101–150, and 14.4% who would pay ZAR 151–200. A smaller proportion (3.6%) expressed readiness to contribute ZAR 351 or more annually. By calculating the weighted mean contribution across the provided payment categories, using the midpoints of each range and applying the frequencies, it is estimated that the mean WTP for an increase in RES penetration in the electricity mix is ZAR 163.4 per household per year. This estimation suggests that, on average, households are prepared to accept a modest increase in their electricity bills to support a greener energy mix. These findings demonstrate a generally favourable disposition towards renewable energy development, with many households expressing a concrete financial commitment. The willingness to pay, however, varies across income levels, which is consistent with socio-economic disparities observed in similar energy valuation studies [38–40,44–46]. Additionally, it was noted respondents with better knowledge of renewable energy benefits and those who perceived higher personal or community-level advantages, such as improved energy security and environmental quality were more likely to adopt a higher WTP. The results are consistent with findings of Bao et al. [28], and Liu et al. [37] in their respective studies which established that household income positively influences consumers' WTP for clean energy solutions.

4.8. Determinants of WTP for Renewable Energy Expansion

To systematically explore the underlying factors influencing respondents' WTP for an increased share of RES in the electricity mix, a factor analysis employing PCA was conducted. This statistical approach enabled the condensation of a large set of interrelated variables into a smaller number of interpretable components, each accounting for distinct portions of the total variance observed in the dataset. Under the PCA framework, each successive component explains a portion of the residual variance not captured by the pre-

ceding components. To ensure the statistical robustness of the factor extraction, Kaiser's eigenvalue criterion (eigenvalues > 1) was employed to determine the number of components to retain. Additionally, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were performed as preliminary diagnostic tests to confirm the suitability of the dataset for factor analysis.

The KMO value of 0.882 and the significant result from Bartlett's Test of Sphericity (Chi-Square = 8951.06, $df = 744$, $p < 0.001$) provided strong statistical evidence that the sample size was adequate and that the correlation matrix was factorable. It is generally recommended that the ratio of observations to variables should exceed 5:1, with an ideal ratio being closer to 10:1 [68], a requirement comfortably met by this study. Based on these diagnostics, the PCA yielded eight distinct components using Kaiser's criterion, collectively explaining 88% of the total variance, a cumulative variance percentage considered highly satisfactory within empirical social science research. To further enhance interpretability, the initial factor matrix was subjected to a Varimax rotation, which maximized the variance of the squared loadings and simplified the factor structure.

The emergent components captured key thematic areas relating to respondents' perceptions, institutional and economic barriers, and regulatory incentives toward renewable energy (Table 7). These components are as follows:

Table 7. Components of households' perception towards RES.

A1: Recognized Advantages of RES
A2: Identified Drawbacks of RES
A3: Financial Incentive Schemes for RES
A4: Expansion Strategies for Renewable Energy
A5: Institutional Barriers to Promotion
A6: Financial and Economic Constraints
A7: Price Parity with Fossil Fuels
A8: Interest-Free Financing Options for RES Procurement

4.9. Determinants of WTP for Renewable Energy

Logistic Regression Analysis To further investigate the key drivers influencing respondents' WTP for additional investment in RES, a binary logistic regression model was employed. In this model, the dependent variable was the dichotomous WTP outcome (Yes = 1, No = 0). In contrast, the independent variables included both socio-demographic factors (Gender, Age, Marital Status, Educational Level, Occupation, Income, and Household Size) and the eight extracted components (A1–A8) from the earlier PCA, which capture various perceptions and attitudes towards RES. The "Yes" category served as the reference group in the regression analysis. The model demonstrated strong reliability, with McFadden's Pseudo R^2 yielding a value of 0.524 (52.4%), indicating a reasonably strong model fit, as values above 0.15 are generally considered acceptable in social science applications [68]. The Hosmer and Lemeshow goodness-of-fit test ($\chi^2 = 8.951$, $df = 8$, $p = 0.000$) further validated the model's adequacy. In contrast, the KMO measure (0.882) and Bartlett's test of sphericity ($p < 0.001$) supported the suitability of the dataset for factor analysis. The regression analysis reveals that education, occupation, income, and household size are among the strongest predictors of WTP. In practical terms, households with higher education levels, stable occupations (such as civil service or trading), and middle-to-high incomes are significantly more likely to contribute financially to renewable energy expansion. Larger households also showed stronger support, perhaps because energy costs

and benefits are more visible when shared across multiple members. For example, the odds ratio for income ($\text{Exp}(B) = 0.542$) indicates that for each incremental increase in income, the odds of a respondent falling into the WTP = Yes category increase by approximately 54%, holding all other variables constant. This highlights the critical role of financial capacity in supporting green energy transitions. Households were also more willing to pay when they recognized clear advantages of renewables (e.g., energy security, environmental benefits) and when supportive policies were in place, such as subsidies or interest-free financing. Respondents exposed to financial incentives or parity with fossil fuel pricing were markedly more positive, underlining the importance of affordability and visible financial benefits in driving acceptance, as illustrated in Table 8.

Table 8. Logistic Regression Result Determinants of WTP for Renewable Energy.

Variable	Coefficient (B)	Std. Error	Wald	Odds Ratio Exp (B)	p-Value
Constant	−2.090	0.642	5.234	0.168	0.025
Gender	0.628	0.285	2.168	−0.682	0.046
Age	0.176	0.612	2.224	−0.702	0.057
Marital Status	1.273	0.851	2.411	−0.864	0.031
Education	1.421	0.212	2.003	0.521	0.001
Occupation	1.034	0.122	1.842	0.489	0.003
Income	1.662	0.842	1.447	0.542	0.001
Household Size	1.427	0.628	1.284	−0.342	0.064
A1: Recognised Advantages	1.248	0.844	1.472	0.562	0.004
A2: Identified Drawbacks	1.206	0.628	1.226	−0.661	0.053
A3: Financial Incentive Schemes	1.189	0.582	1.441	0.283	0.032
A4: Expansion Strategies	1.202	0.841	1.208	0.384	0.002
A5: Institutional Barriers	1.682	0.964	1.446	−0.263	0.021
A6: Financial and Economic Barriers	1.845	0.884	1.626	−0.482	0.048
A7: Price Parity with Fossil Fuels	1.244	0.662	1.648	0.326	0.046
A8: Interest-Free Financing Options for RES Procurement	1.424	0.802	1.664	0.288	0.048

Conversely, concerns about identified drawbacks, financial and economic barriers, and institutional barriers reduced willingness to pay. For instance, the odds ratio for A2 ($\text{Exp}(B) = 0.661$) suggests that a one-unit increase in identified drawbacks of RES decreases the odds of willingness to pay by approximately 34% (calculated as $1 - 0.661 = 0.339$). These findings suggest that positive attitudes, financial capability, supportive policy frameworks, and effective subsidy schemes are pivotal in fostering household willingness to invest in renewable energy solutions. In contrast, identified barriers can substantially diminish public enthusiasm and investment readiness. Overall, the results indicate that education and income open the door, while the recognised advantages, financial and incentive schemes, and interest-free financing options keep households engaged. These insights underscore the need for targeted policy interventions, tailored financing schemes, and streamlined administrative processes to mitigate barriers and bolster public support for renewable energy expansion [53].

Presented in Table 9 are the findings of this study, which closely align with and extend several theoretical frameworks on technology adoption and social acceptance of renewable energy. The Theory of Planned Behaviour (TPB) is particularly relevant, as it highlights how attitudes, subjective norms, and perceived behavioural control shape adoption decisions. In this study, limited baseline awareness was shown to weaken both attitudes and perceived control, whereas socio-economic characteristics (education, income, and occupation) positively reinforced intention to adopt. Similarly, households' willingness to pay (WTP) increased significantly when benefits were made explicit and incentives were provided, underscoring the role of perceived behavioural control in fostering pro-renewable behaviour. The Value–Belief–Norm (VBN) framework also resonates strongly with the results. Solar energy, being both visible and relatable, reinforced value–belief–action linkages, illustrating how experiential familiarity can convert abstract pro-environmental values into concrete adoption behaviour. This confirms that technologies mostly embedded in everyday experiences are more likely to foster positive attitudes and household-level uptake.

Table 9. Key Findings and Their Theoretical, Practical, and Policy Implications.

Key Findings	Theoretical Implications	Practical Implications	Policy Implications
Limited baseline awareness of renewable energy (initially only 48% aware)	Supports Social Acceptance Theory: awareness as a prerequisite for adoption; extends TPB by showing that low knowledge weakens attitudes and perceived behavioural control	Highlights the need for community-based education and culturally relevant messaging	Design and implement provincial renewable energy literacy campaigns in local languages via schools, media, and community forums
Solar energy is the most familiar and trusted RES	Confirms VBN framework: visible, relatable technologies strengthen value-belief-action linkages	Promotes solar as an entry point for household-level adoption	Prioritize solar PV subsidies, rooftop solar initiatives, and community solar farms
Socio-economic factors (education, income, occupation, household size) strongly predict WTP	Aligns with TPB: socio-demographics influence behavioural control and intention to adopt	Households with higher education and income are more likely to invest in RES	Implement targeted subsidies for low-income groups and financing schemes tailored to middle-income households
Mean WTP of ZAR 163.4 per annum for RES integration	Provides empirical evidence of market acceptance and affordability thresholds in Limpopo Province, South Africa	Indicates modest but positive financial commitment among households	Introduce tiered payment models (e.g., pay-as-you-go, microfinance) to match affordability levels
High installation costs and technical complexity are cited as main barriers	Reinforce the framework on barriers to renewable energy adoption	Demonstrates the importance of user-friendly, low-maintenance designs	Expand subsidies, reduce VAT/import tariffs on renewable technologies, and incentivize local manufacturing
Institutional and regulatory weaknesses undermine adoption	Confirms Social Acceptance Theory's socio-political dimension	Institutional inefficiencies erode consumer trust	Streamline licensing/approval processes and harmonize policy across national, provincial, and municipal levels
Households are more willing to pay when clear benefits and incentives are present	Extends TPB: perceived advantages and financial incentives strengthen intention	Design products highlighting visible benefits (energy security, health, job creation)	Offer interest-free loans, tax credits, and direct subsidies tied to household adoption
Negative perceptions (unreliability, safety risks, bureaucracy) reduce WTP	Validates behavioural economics literature: perceived risks deter investment	Necessitates risk communication, safety assurance, and after-sales service	Develop product certification standards, strengthen consumer protection, and invest in grid-stabilizing hybrid systems

Furthermore, the Social Acceptance Theory, particularly its socio-political and community acceptance dimensions, helps to interpret the findings on institutional and regulatory weaknesses. The results reveal that governance inconsistencies and bureaucratic inefficiencies erode consumer trust, thereby constraining adoption. This supports the view

that social acceptance is not only shaped by technological attributes but also by institutional credibility and transparent policy environments. Finally, insights from behavioural economics complement these frameworks by emphasizing how perceived risks (such as unreliability, safety concerns, or fire hazards) can undermine adoption despite potential economic benefits. This indicates that household decision-making is not purely rational but is influenced by risk perceptions, necessitating targeted communication, certification standards, and consumer protection measures to mitigate distrust. Together, these theoretical linkages demonstrate that renewable energy adoption at the household level is a multidimensional process, shaped by the interplay of knowledge, socio-economic capacity, institutional trust, perceived benefits, and risk perceptions.

5. Conclusions and Policy Recommendations

5.1. Conclusions

This study comprehensively investigated household-level perceptions, awareness, and WTP for RES in the Limpopo Province of South Africa. The research provides valuable insights into the socio-economic, informational, and institutional factors that influence household attitudes towards renewable energy adoption as a springboard for sustainability. The findings reveal that while initial awareness of renewable energy technologies was limited, targeted communication and accessible explanations significantly improved respondents' understanding and acceptance. Solar energy emerged as the most familiar and preferred technology, largely due to its visibility and perceived practicality within the community. Socio-economic characteristics, especially income, educational attainment, and occupation, were significant predictors of both awareness and WTP. The mean WTP for expanding renewable energy penetration was estimated at ZAR 163.4 per household per year, signalling a modest yet meaningful financial commitment from the surveyed population. Importantly, most respondents associated renewable energy not only with environmental benefits but also with socio-economic gains such as job creation, energy independence, and community development.

Despite the positive outlook, several barriers continue to constrain household adoption of renewable energy. High initial costs, perceived reliability issues, technical complexity, fire safety concerns, and a lack of user-friendly designs emerged as prominent deterrents. Furthermore, institutional weaknesses, such as inconsistent policy implementation, limited public information dissemination, and bureaucratic hurdles, exacerbate these challenges. The factor analysis and logistic regression further underscored the multifaceted nature of WTP, indicating that financial capacity, knowledge of renewable energy benefits, the availability of subsidies, perceptions of price competitiveness, and the presence of interest-free financing significantly increase the likelihood of household investment in renewable energy. Conversely, perceived disadvantages, institutional barriers, and economic constraints negatively influence WTP. Overall, the study highlights that the transition to renewable energy at the household level is not merely a technological or financial issue but also a socio-cultural and informational challenge. Bridging this gap requires an integrated, multi-pronged approach that addresses structural barriers while enhancing public engagement and financial accessibility.

5.2. Policy Recommendations

To advance household-level adoption of renewable and sustainable energy in South Africa, several coordinated policy actions are essential. Firstly, public awareness and education campaigns must be significantly strengthened. These campaigns should be targeted and culturally sensitive, utilizing community radio, local television, social media platforms, schools, and traditional community gatherings to demystify renewable energy

technologies. Although not treated as separate sources, mass media can collectively provide abundant information about renewable energy in general. Communicating in local languages and using relatable success stories will help improve public understanding and foster wider support for renewable energy initiatives. Secondly, targeted financial support mechanisms need to be introduced. Awareness campaigns should be continuous and gender-sensitive, recognizing women's central role in managing domestic energy. Actions include women-only demonstrations, male-engagement sessions on financing and cost-benefit, and training female community champions/technicians. Success metrics should track female participation, adoption rates in female-led households, and gender-disaggregated satisfaction scores.

Government-backed subsidies, interest-free financing options, and flexible payment plans are crucial to reducing the high upfront costs associated with renewable energy systems. Innovative financial models such as micro-financing, pay-as-you-go schemes, and the establishment of energy cooperatives should be promoted, particularly for low- and middle-income households. Thirdly, renewable energy technologies must be promoted with a focus on user-friendly designs and local adaptability. Renewable energy systems should be easy to install, operate, and maintain, with product designs that directly address safety concerns and reduce technical complexity. In parallel, local capacity-building initiatives should be introduced to train technicians within the communities, ensuring the availability of reliable after-sales service and technical support. Technology design should be user-centred, prioritizing safety, low-maintenance components, and intuitive interfaces to address households' concerns over fire risk and reliability. Hybrid solutions warrant further research for resilience to weather variability and grid instability. Pilot modular hybrid packages with local maintenance contracts could test cost-effectiveness and user acceptance.

Policy consistency and institutional coherence across all levels of government are also essential. Renewable energy policies must be streamlined and harmonized at the national, provincial, and municipal levels to eliminate regulatory bottlenecks. Establishing clear, stable, and transparent policy environments is critical to building public trust and attracting private sector investment in renewable energy projects. Facilitating price parity between renewable and conventional energy sources should also be a priority. Government interventions such as bulk procurement of renewable energy technologies, adjustments to import tariffs, and the provision of tax incentives can help reduce the costs of renewable energy systems, making them more affordable and competitive for households. Additionally, supporting community-centric renewable energy projects will drive greater acceptance and participation. Localized initiatives such as community solar farms, mini-grids, and biomass cooperatives should be prioritized. These projects can enhance local energy security, promote community ownership, and create employment opportunities at the grassroots level. Addressing reliability and safety concerns is equally important. Increased investment in product quality assurance, certification schemes, and public safety education can help alleviate concerns about the reliability and safety of renewable energy systems. Furthermore, integrating hybrid solutions that combine renewable and conventional energy sources can improve overall energy reliability. Policy interventions must also be tailored to the socio-demographic profiles of different communities. Given that willingness to pay for renewable energy varies across income, education, and occupational groups, targeted interventions are necessary to address these differences. For example, lower-income households may require more substantial subsidies, while middle-income groups may benefit from specifically designed low-interest loans and financial incentives.

Lastly, establishing robust, continuous monitoring and evaluation frameworks is critical. These systems should track the performance and impact of renewable energy pro-

grammes, allowing for regular assessment and timely policy adjustments in response to emerging challenges, evolving public perceptions, and advances in renewable energy technologies. The findings from this study underscore that the household-level transition to renewable energy in South Africa is shaped by a complex interplay of economic, technical, institutional, and socio-cultural factors. Addressing the barriers to widespread adoption requires more than financial interventions; it demands inclusive public education, policy stability, user-centered technology design, and active community engagement. By adopting a holistic, context-sensitive approach that integrates financial support, regulatory reforms, accessible technologies, and community-driven solutions, South Africa can accelerate its journey toward a more inclusive, resilient, and sustainable energy future. This progress will not only advance the country's just energy transition goals but also make a significant contribution to achieving SDG 7, alongside other goals that are directly and indirectly related. The findings further support progress on SDG 1 (No Poverty), SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and, in particular, SDG 13 (Climate Action) and the broader aspirations of the African Union's Agenda 2063 [69].

6. Limitations and Future Directions

While this study offers valuable insights into the determinants of WTP for RE in South Africa, based on a case study of Limpopo Province, several limitations warrant consideration and point to avenues for future research. Firstly, the focus on Limpopo Province, though contextually relevant, limits the generalizability of findings to other provinces with differing socio-economic and energy profiles. Comparative studies involving provinces like Gauteng, Western Cape, and KwaZulu-Natal could reveal significant regional disparities in WTP, perceptions, and barriers to RE adoption. Secondly, the study emphasizes positive drivers of WTP such as perceived benefits and policy incentives, while offering limited analysis of deterrents. Factors such as technological scepticism, financial constraints, institutional inefficiencies, and perceived risks require deeper exploration to design balanced policy interventions. Moreover, reliance on self-reported data may introduce social desirability bias. Future research could adopt longitudinal, experimental, or revealed preference methods to validate WTP estimates and better capture actual behaviour over time. The exclusive use of quantitative data also limits the depth of contextual insights. Integrating qualitative methods such as focus groups or in-depth interviews would help uncover the cultural, institutional, and psychological dimensions that shape household energy decisions. Lastly, the study focuses solely on households. Expanding the scope to include small enterprises, cooperatives, and public institutions would provide a more comprehensive understanding of WTP across societal sectors. Addressing these limitations will enhance the robustness of future research and inform more regionally nuanced, inclusive, and evidence-based strategies to support South Africa's just energy transition and broader sustainable development goals.

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