RESEARCH ARTICLE

Modeling factors of biogas technology adoption: a roadmap towards environmental sustainability and green revolution

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Abstract

In a developing country such as Pakistan, adopting biogas technology is a complicated process. The government has taken several steps to address energy issues by increasing biogas facilities. This research seeks to identify the major barriers to the deployment of biogas plants. Respondents were selected using the snowball sampling method. As a result, 79 adopters of biogas plants participated. Utilizing a structured questionnaire, primary data were collected. Hypotheses were evaluated using partial least squares structural equation modeling (PLS-SEM). Study results demonstrate that all influencing factors are favorably associated with implementing biogas technology, minimizing energy crises, and achieving cost-cutting objectives. In addition, the findings show that properly reducing economic and governmental barriers, encourage farmers to use biogas plants productively and substantially. To build biogas facilities, the government should adopt an economic strategy, owner training, day-to-day operations, and professional technical assistance.

Keywords Biogas plants · Renewable energy · Biogas expertise · Barriers · Environmental sustainability · Green energy · Pakistan

Introduction

Climate change, depletion of natural resources, increasing air and water pollution, and a reduction in biodiversity are effects of rising material consumption on environmental quality. Like the rest of the developing world, Pakistan needs extensive energy to sustain its people and businesses (Irfan et al. 2021). Decades of uncontrolled electricity demand and supply gaps have plagued the country. During the summer, this vacuum is obvious. 16 to 18 h per day in rural regions and 10 to 12 h per day in metropolitan cities are without electricity in Pakistan. About 51 million people in Pakistan lack access to electricity, and 50% of the population lacks access to clean cooking facilities (IRENA 2020). Pakistan's installed power generating capacity reached 34,501 megawatts in May 2021 (MW). It is anticipated to grow by 53,315 MW by 2030. The renewable energy contribution to energy needs is about 0.5%, which is insignificant (NEPRA 2021). Pakistan's national energy mix for the fiscal year 2019–2020 is 121,691 Gigawatt hours (GWh) by the end of May 2021, with thermal plants accounting for 57% of power output, hydroelectric plants for 32%, renewable energy for 3%, and nuclear plants for 8% (NEPRA 2021).

Pakistan's geographical location offers significant potential (about 81 million tonnes per year) for all types of renewable energy, including solar energy, wind energy, and bio-energy. Utilizing combustion, trans-esterification, gasification, and pyrolysis, the USA has enormous potential for producing biomass bio-energy. The impact of modern technology on the nation's sustainable economic growth is

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enormous. Solar isolation (5.5Wh $^{m-2d-1}$) and annual mean sunlight duration of 8–10^{hd-1} are a boon in Pakistan. In the coastal areas of Sindh and Baluchistan, wind speeds range from 5 to 7 m per second, and the wind energy potential reaches 20,000 MW. Eighty percent area of Sindh, South Punjab and 65% area of Baluchistan's daily average solar radioactivity force array from 1600 to 2750 W$^{/m2}$ during 10 h. Monthly energy output per 100 m^2 in Pakistan must range between 45 and 83 MW (Ali et al. 2021).

This research model investigates the moderating influence of technical knowledge via social media on Pakistanis' propensity to embrace biogas technology. We have addressed with farmers the major obstacles to implementing biogas plants in this nation. In this research, respondents were selected using a systematic sampling technique. Using quantitative data collection techniques, questionnaires were utilized to obtain the information required to achieve the study goals. PLS-SEM was utilized to evaluate the collected data. The findings show that Pakistan's thorough elimination of economic and governmental barriers stimulates farmers to build biogas systems greatly and favorably. The report suggests that the government draught an economic strategy, raise awareness via social media, teach owners, and eliminate maintenance hurdles with skilled technicians to promote biogas facilities. The regulatory authorities must prioritize the usage of biogas plants and attract investment. This research investigated the technical obstacles and important sociocultural factors preventing Pakistan from adopting biogas-powered plants. Existing social practices are related to individual behavior, which is the source of social niche. The reasons of plant users acquire biogas plants are outlined in Table 1.

Table 1 demonstrates why biogas plant building is of relevance to farmers. Consequently, several obstacles and important issues hinder the nation's adoption of biogas technology. This research aims to identify the key barriers and causes why farmers abandon biogas technology. Despite its economic benefits, scientific viability, and environmental advantages, biogas technology is still not widely accepted in Pakistan. Existing research has shown a considerable knowledge gap about the most important contributory factors of dependence, including the selection of market, institutional, and home fuel sources. Adopting biogas has negative implications on collection time and fuel wood prices but large favorable benefits on agricultural income and revenue (GoP 2020).

All previous research on the energy sector in Pakistan (Ali et al. 2022b) focused on energy gap based on demand and supply, (ii) source of energy production, (iii) upcoming of energy division, (iv) the valuation of the whole energy area in Pakistan, and (v) the renewable energy combination. Investors and all kinds of investments are discouraged by the absence of an examination of technical obstacles and critical social considerations related to adopting biogas-installed plants; and (iii) planned expenditures to realize the economic advantages of biogas-installed facilities. We analyses the key obstacles and crucial variables of biogas-installed plants in the country that impede the sustainable development of biogas technology; (ii) we emphasize installation and maintenance hurdles for the elimination of these obstacles to attracting biogas plant investors for the growth of biogas energy on a sustainable basis; and (iii) we practically evaluate the moderation of biogas plant size. The conclusions of this research study will aid government institutions, competent authorities, and non-governmental groups in simplifying the wasteful procedure. Biogas plants are meant to deliver renewable energy at an affordable price to reduce rural farmers' greenhouse smoke discharges via biogas and effective leftover controlling. In addition, the present study seeks to educate farmers on the benefits of adopting biogas plants, enhance their abilities, and urge them to extend their installations owing to the low initial share and long-standing profits. This research work aims to decrease economic threats, eliminate barriers to farmer biogas plant investment, provide free energy for farmer self-consumption through small-scale biogas plants, and improve biogas plant competence. In addition, the objective of this study is to enhance collaboration between knowledge institutions, government organizations, and municipalities in the biogas business.

Consequently, the key aim of this research was to identify and explain the most significant obstacles that deter agrarians to adopt modern biogas machinery. This study demonstrates Pakistan's biogas potential to persuade financiers to spend in biogas technology sector for the justifiable for biogas energy expansion. This article explores the important characteristics of biogas-installed plants in Pakistan to promote the long-term expansion of modern biogas machinery. The subsequent sector examines the literature assessment,

Table 1 Motivation to attract farmers on different factors

Explanations	Circumstances (%)	Response (%)	Frequency
Social reputation	33	13	21
Energy-saving	39	16	18
Time-saving benefits	31	13	19
Health advantages	18	7	12
Environmental advantages	20	8	11
Unavailability of alternative fuels	25	11	17
Subsidy	46	16	24
Motivation by existing plants	44	17	25
Motivation by construction body	36	14	19

research methodology, study design, and formulation of hypotheses. The discussion focuses on the findings, implications, conclusion, and important research limitations.

Literature review

The production of energy from fossil fuels is a global concern (Curtin et al. 2019; Gani 2021). Without a sustained global energy supply, the current standard of living and economic growth are unattainable (Azam et al. 2019; Gielen et al. 2019; Hoang et al. 2021; Lowe and Drummond 2022). Consistent energy supply is essential for contemporary life (Gabr et al. 2018; Grunewald and Diakonova 2018; Popp et al. 2021). The nation's economic growth and prosperity rely heavily on efficient energy resources (Bhattacharya et al. 2020; Usman et al. 2020). Improving a country's or nation's level of living and economic growth requires energy (Roy and Dalei 2020; Sueyoshi and Yuan 2018). Energy was vital to emerging countries' economic and social growth (Saito et al. 2019; Wang et al. 2021). It keeps around USD 214,406 (PRs 46,290) million on runny fuel gas, firewood, paraffin oil, and bio fertilizer every month (Arshad et al. 2018). Biogas is a crucial inexpensive drive basis for the maintainable growth of any country. Utilizing modern technologies, energy production is now a challenging endeavor. The country's high energy consumption is due to its growing population and economy. The disparity between energy demand and supply causes issues in almost every aspect of national life, plus supportable growth, affluence, the expansion of supplementary productions houses, and commercial progress. These type of barriers harm anthropological fitness, liquid supplies, agrarian output, and environmental actions (Amir et al. 2019; Murad et al. 2019).

Multiple investigation studies demonstrate that biogas offers energy to pastoral regions and fulfills several economic demands, such as reducing poverty, providing local jobs, and improving local health (Bates et al. 2019; Mikhail et al. 2020; Ozturk 2016). Biogas production provides several environmental benefits, including producing electricity and renewable energy, treating waste, and using bio-slurry as biological nourishment to recover crop resilience. In rural regions of low- and middle-income countries, other reasons for deforestation are investigated, including energy shortages, slow economic development, and a lack of biogas production. In rural places, women are thus responsible for cooking and heating using fire and wood (Jayarathne et al. 2018; Liu et al. 2021). Biogas enabled the generation of biogas and the collection of bio-slurry for soil enrichment (Ashraf et al. 2019). Importing petroleum and natural gas throws rising countries under severe economic strain. Adoption of biogas is economically and environmentally feasible (Sun et al. 2021). Pakistan derives the bulk of its energy

from fossil fuels. These energy sources are pricey and have variable environmental consequences. To overcome the grave energy problem, the government of Pakistan has decided to use an alternative, cost-effective, and ecologically friendly energy sources. Modern RE plans to account for environmental limits and provide practical answers to all energy concerns (Morgunova et al. 2020; Nasirov et al. 2018; Wu et al. 2020a). Despite this, the government of Pakistan has pledged to boost the RE share by 5% by 2030, and biomass energy will be essential to achieving this goal (Yasmin and Grundmann 2019). Pakistan spends a large percentage of its national budget on gas and oil imports to compensate for a temporary energy deficit. Pakistan saved $8–$9 billion on energy imports in 2019–2020 (Aziz et al. 2018; Roussel et al. 2021).

Biogas may be a viable and efficient alternative energy source for addressing the nation's energy deficit. As the sixth-largest livestock-based economy in the world, Pakistan has considerable potential for biogas energy production (Khan et al. 2021b; Yasmin and Grundmann 2019). Of Pakistan's energy demands, 28.12% are met by imported oil and gas (Rafique and Rehman 2017; Yaqoo et al. 2021). Over the last two decades, commercial contractors, (global private organizations), (local governmental organizations), and the government sector have erected biogas facilities. Pakistan has a large animal population and can produce biogas from animal waste (Awan et al. 2022). The biogas plant is cost-effective and excellent for lowering ophthalmic and lung pollutants due to its cheap installation cost. Animal dung may create an average of 12–804 m^3 biogases per day in rural Pakistan (Sun et al. 2021). The Pakistani government began biogas project 4109 in 1974 using biogas technology for societal gain. In rural areas, 4137 biogas plants were constructed by 1987. The daily biogas plant capacity for cooking and lighting varied from 3000 to 5000 Free Triiodothyronine Feet (biogas measurement unit) (Kamran 2018). Agriculture is Pakistan's major sector, providing 18.5% of its gross domestic product (GDP) and employing 38.5% of the population (Afridi and Qammar 2020).

Daily animal dung production in the nation is 650 million kilograms. In addition, it can provide clients with 16.25 million m^3/day if 50% of animal waste is collected and handled domestically. More than 8 million families produce animal products directly, accounting for 35–40% of their entire output (Jabeen et al. 2020; Ullah et al. 2021). The government devoted fewer resources to the agricultural subsector of forestry, which was judged inferior to others (Mir et al. 2021). Pakistani literature suggests that many research types focus on biogas technology (Iqbal et al. 2018). However, this study's major objective was to adopt biogas technology. No one has investigated why farmers abandoned biogas technology and the fundamental barriers they encountered. Adopting biogas technology will provide Pakistani farmers

with a prosperous future and alleviate the country's energy issue (Wang et al. 2020c). In 2008–2009, Pakistan began its home biogas project program to offer biogas plants and replace conventional fuels such as residual crops, liquefied petroleum gas, wood, and animal dung cake with biogas (Jan 2021). EKN-RSPN (embassy of the Netherlands-rural support programs network) reported that Pakistan had built the maximum number of biogas plants authorized for phase one of the domestic biogas program (PDBP) in Punjab: ten biogas plants. This program's primary objective was to establish 12,000 biogas plants. Unfortunately, only around 3000 biogas plants were networked, and the intended results were not achieved. The project offered subsidies as incentives to encourage and support rural residents' social and technical adaptation. However, biogas technology acceptability has not yet reached an adequate level (Gelani et al. 2022; Lei et al. 2021).

As the world's fourth most significant energy source, biogas provides more than 14% of primary energy (Khan et al. 2021a; Yaqoo et al. 2021; Yasar et al. 2017a). Numerous countries, especially those with low-to-middle incomes, have exploited energy sources like hydro, biomass, and solar thermal, to provide dependable, local, and inexpensive power (Mohsin et al. 2022; Saghir et al. 2019; Tareen et al. 2018). Reputation and time savings are two more driving factors that account for 33.5% each. Technical advancement and social acceptability are strongly correlated in low- and middle-income nations. In Pakistan, the installation and construction of biogas plants are largely driven by energy, time savings, and subsidies. Of the most significant motivating and subsidizing aspects, 42.5% were support, taxation, and finance for using cleaner fuels (Puzzolo et al. 2016). However, this depends on adoption awareness (Mohsin et al. 2022; Pilloni et al. 2020). Biogas production from biological leftover has recognized as a renewable energy cause (Afridi et al. 2019). There are several productive biogas plants in South Asian nations, including India, Bangladesh, China, and Nepal (Wang et al. 2020b).

Formulation of hypotheses with the theoretical background

Maintenance barriers of biogas plants

The development of biogas technology in rural areas of Pakistan establishes its dominance over energy decisions to alleviate the economic problems caused by energy inefficiency. Analyzing the durables dominating energy efficiency and the consequences of biogas technologies requires dominance. Biogas energy has huge potential and is a promising form of renewable energy for satisfying the nation's energy and financial requirements. There are 15 million potential biogas

power plants in Pakistan, which might greatly influence the country's economic growth (Kamran 2018). Biogas facilities require qualified technicians nationwide. The government has abundant biogas supplies, such as agricultural wastes, fuel wood, municipal solid waste, and animal manure. Forty-eight percent of the country's energy needs are met by burning wood, while animal byproducts and crops meet 32%. Pakistan's potential energy output of 4800 to 5600 MW from animal waste. The biochemical and thermochemical potential for generating power from municipal solid waste is 220 kWh/t and 560 kWh/t, respectively (Afridi and Qammar 2020). Due to its agricultural character, Pakistan possesses many animal-based biogas resources. In rural locations, the successful deployment of these biogas resources might offer positive outcomes. Using manure and straw biogas properly can reduce emissions and increase economic benefits (Nevzorova and Kutcherov 2019). The biogas plants provide electricity, reduce greenhouse gas emissions, stimulate economic expansion by improving earnings, and their upgrading can enhance environmental performance (Iqbal et al. 2018; Iram et al. 2020). Adopting biogas technology in rural regions can substantially help the nation's economic growth. Its parallel situation correctly depicts sites' biogas uptake and economic growth projections. Based on these findings, we offered the following initial hypothesis:

> **Hypothesis 1 (H1):** There is a correlation between the maintenance difficulties of biogas plants and the desire to embrace biogas technology in Pakistan.

Economic and policy barriers

Approximately 63% of the population of Pakistan lives in rural regions and requires business and household energy sources. Existing portable biogas plants are desirable owing to their high methane gas output, low price, open policy, and portability. This biogas factory may aid rural communities in increasing and meeting their domestic requirements (Wang et al. 2020b). There is a correlation between the deployment of biogas plants and the prosperity of rural areas. Components of biogas development include household biogas digesters, biomethane plants, biogas grid plants for electricity generation, large-scale biogas plants, and micro biogas digesters in rocky locations (Baloch et al. 2020; Iqbal et al. 2018). These findings fit with Pakistan's goal to construct biogas facilities. This sign highlights the relevance of biogas for private share and this one connection to economic development. Utilizing biogas plants efficiently in rural areas may provide financial development that exceeds the limitations of biogas adoption. Biogas is, from the perspective of a professional management unit, the finest renewable energy choice for the development and prosperity of the area. In addition to its social, economic, and environmental advantages,

commercial biogas is seen as the future of rural communities (Haile et al. 2019). This study's conceptual approach overcomes the issues of Pakistan's solar biogas plant and rural prosperity in general. These factors lead to the formation of the following next supposition:

Hypothesis 2 (H2): There is a correlation between economic and policy barriers and adoption intentions for biogas technology.

Owner satisfaction with biogas plant

Biogas has recently been used to generate power. The feedstock substantial is a supportable renewable energy (RE) basis (Luyer et al. 2021). Using biogas to generate energy might minimize power outages, enhance feedstock material management, and alleviate Pakistan's environmental problems. Agricultural, plant, and nutrition excess are the most efficient drive causes and crucial elements of a supportable evolution. Enhanced use of these resources for energy production may reduce the nation's CO_2 emissions. The overall biogas production potential in Pakistan is 226.8 Mm^3 d1, whereas the predicted power generation for 2018 is 59,536 GWh^{y1} (Sun et al. 2020; Wu et al. 2020b; Yaqoo et al. 2021). The use of biogas may create 280 MWh of electricity per day from chicken dung (Gebreegziabher et al. 2018). It enhances people's living level and may also affect their lives favorably. The utilization of Pakistan's biogas potential is essential for its economic growth. In all rural regions of the country, the biogas support program (BSP) must be implemented (Jan and Akram 2018). Due to the fixed installation cost of the biogas plant, the advantages achieved in later years exceed those of the first year. Affording to a cost-energy benefit study, by rice peapod and chicken manure to produce a biogas modern technology in Pakistan, is possible. The third hypothesis was formulated based on the following findings:

Hypothesis 3 (H3): There is a correlation between owner satisfaction with biogas plants and the intention to adopt biogas technology in Pakistan.

Financial support for biogas plants

The biogas business in Pakistan has enormous unrealized potential, which must be achieved by disseminating relevant information to local farmers. If the Pakistani government offers operational and maintenance assistance to biogas plant customers, foreign investors may aid in addressing the sector's issues. Operating and maintenance expenditures vary based on the magnitude of the installation. For similar projects, the technical and operational design of the chosen biogas plant should be evaluated. The government

may significantly promote the biogas industry in the USA by providing grants, enticements, and existing plans that entice investors and financiers (Jarrar et al. 2020). Permanent cupola biogas unit offer excellent economic enactment due to cheap investment expenditures (fixing and response), reduced operating and maintenance budgets, and a short reimbursement period (Wu et al. 2020c; Yasar et al. 2017b). The thermal energy supplied by biogas has a favorable effect on evaluation outcomes. If the policy is updated to permit independent renewable plug-in projects, the RE policy incentives may attract biogas investors and improve the economic sustainability of biogas facilities (Govender et al. 2019). Pakistan's economic position may help the biogas power plant. These variables are potential outcomes of certain parts of operation and maintenance, and they have an immediate impact on the growth of biogas power plants. In light of these reasons, the following idea was proposed:

Hypothesis 4 (H4): Financial assistance for biogas plants correlates positively with the desire to embrace biogas technology in Pakistan.

The moderating role of awareness through social media between maintenance barriers of biogas plants and the intention to adopt biogas technology in Pakistan

Positive and considerable economic feedback is related to rural farmers' exposure to biogas technology through social media. Adaptation to climate change is contingent upon the contribution, availability of local specialists, and attractiveness of the expanding biogas technology RE market (Hasan et al. 2020). Biogas technology may improve biogas output in developing nations such as Pakistan, as has been convincingly proved. Fifty percent of productive biogas systems fail after 2 years of contracting owing to technological and logical obstacles. Due to poor digester feed eminence and a nonexistence of facility expertise, biogas production could not be maintained. Local technical expertise in replacing replacements is inadequate to maintain biogas production in the case of a lack of primary feedstock (Tumusiime et al. 2019). The evaluation is based on biogas plant knowledge and comprehension, encompassing a broader geographical perspective. These parameters have a close relationship with the installation and production of biogas. Certain circumstances contributed to the postponement of certain biogas plants, although developing nations view biogas plants and their services favorably. Recognizing responsibility, customer effectiveness, environmental concern, and repercussions knowledge have a substantial and lasting influence on the farmer's standards. Therefore, human variables impact Pakistani farmers' propensity to employ biogas technology

(Hao et al. 2020; Wang et al. 2020). Considering these factors, the following hypothesis was formulated:

Hypothesis 5 (H5): The project's awareness through social media positively moderates the association between biogas plant maintenance barriers and the intention to adopt biogas technology in Pakistan.

Hypothesis 6 (H6): The project's awareness through social media positively moderates the association between financial support for biogas plants and the intention to adopt biogas technology in Pakistan.

Hypothesis 7 (H7): The project's awareness through social media positively moderates the association between economic and policy barriers and the intention to adopt biogas technology in Pakistan.

Hypothesis 8 (H8): The project's awareness through social media positively moderates the association between Owner satisfaction with biogas plants and the intention to adopt biogas technology in Pakistan.

Hypothesis 9 (H9): There is a relationship between the awareness through social media and the intention to adopt biogas technology in Pakistan.

The theory backs the energy selection hypothesis in this paper. This research applies the concept of energy choice to a particular issue. Depending on the availability of gas connections in areas where it is viable to connect to a Sui fume nationwide, biogas from agricultural leftover, or additional substitute energy, the study will be done. Each household can choose a certain fuel according to the energy ladder paradigm. This linear process allows for the transformation of several fuel kinds. Depending on the median household income in Pakistan, old-fashioned energies corresponding slurry cube, plants, and fuel are utilized less often than contemporary gases alike electrical cooktops and methane gas. This strategy emphasizes the specific cost of each energy option (Gautam et al. 2020). For many countries studying new RE sources, meeting the clean energy demands of their people with conventional energy sources is a problem. This notion consists of two essential elements: economics and wealth (Ozoh et al. 2018; Wu et al. 2021). This study was conducted in Pakistan using a theoretical framework to investigate the variables influencing the adoption of biogas energy plants. It cannot be ruled out that environmental, social, and technological aspects are responsible for the failure or success of biogas energy plants with customers or society. The mental paradigm shown in Fig. 1 may influence a customer's selection of a living energy source. The conceptual model depicts the predictable association between the self-determining variable (IV) and reliant variable (DV) (DV). In addition, the suggested model illustrates the estimated moderation between the independent and dependent variable.
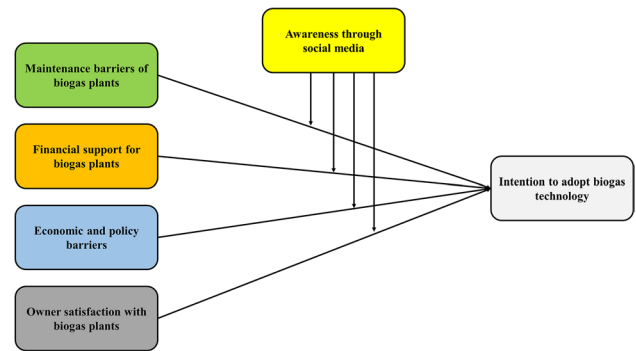

Fig. 1 Conceptual model

Research methodology

This study assessed the potential of biogas using non-random sampling (snowball) sample surveys and transportable presentations to enhance the present biogas technology in Pakistan. The non-random sampling technique is used for exploratory research, pilot studies, and qualitative research. Existing biogas plants were selected for research to enhance their service and quality. Using the snowball sampling approach, a representative sample of biogas plants from around the country was gathered, beginning with particular biogas plants. To do this, researchers conducted a poll between March and September 2021; when the fourth wave of the delta mutant coronavirus (COVID-19) peaked in Pakistan, there was a considerable risk of addressing applicable defendants (biogas plant financers). Moreover, each delegate has a unique grasp of biogas technology and demographic measurements (see Tables 9 and 10 in Appendix). In addition, this study used snowball sampling to choose Pakistani respondents (owners of biogas facilities) exhibiting varied performances. Snowball selection is insufficient for hypothetical oversimplification, especially in the absence of randomization and when participants are linked to one another (Ozoh et al. 2018). This research aims to examine the benefits and drawbacks of biogas technology and assess the financial performance of biogas plants whose owners are satisfied. Awareness and comprehension are moderating influences on biogas plant adoption is one of the satisfaction nexus' moderating elements and removes barriers. Following a quantitative research approach, questionnaires were utilized to obtain quantitative data from respondents in this study (biogas plant financer).

Our study used structural equation modeling (SEM) to examine facts (Ali et al. 2022a). Because it is a component-centered technique, it was utilized to investigate the relationship dimensions (Urbach and Ahlemann 2010). Widespread adoption of PLS-SEM in succeeding research is proof of

its validity; the author of this work also used it (Ying et al. 2020). Conventional statistical analysis methods lag behind structural equation modeling (SEM). It is useful for statistically assessing a product's effectiveness, convenience, and precision (Franziska et al. 2016). SEM addresses the issues inherent to first-generation analysis while being a technology of the second generation. SEM is a multivariate analysis method that may be used to examine numerous variables concurrently. SEM is prevalent in business research due to its potential to concurrently handle complicated and many interactions (Chin and Newsted 1999). Variance-based SEM (VB-SEM), partial least square (PLS)-SEM, and covariance-based SEM (CB) are well-known SEM techniques (Henseler et al. 2009). Utilizing improper analytical procedures may result in erroneous findings.

For commercial and social science research, however, a reliable statistical approach is of utmost importance (Ramayah et al. 2010). PLS-measurement structural equation models and structural models are dual phase analytical procedures consisting of measurement outcomes (Osborne et al. 2010). Measurement investigation revealed convergent validity based on the average variance extracted (AVE), interior constancy dependability based on composite reliability (C.R.), and item reliability based on external loading. The measurement assessment model includes the evaluation of reliability and validity as well as the inner model. The structural assessment model includes evaluation of external models and testing of hypotheses/relationships. This study examined the associations between the relevant variables by analyzing primary data using PLS 3.0 software. Moreover, smart-PLS for VB-SEM use PLS-SEM route modeling to assess the association between variables (Solangi et al. 2019). Smart-PLS is designed to test hypotheses, and complex model research has changed accordingly. Smart-PLS utilizes two methodologies: measurement evaluation and structural model-based analysis. The evaluation measurement model includes convergent and discriminant validity tests for the dependability and validity of the constructs.

Sample and procedure

We were able to reach 91 pertinent responders (biogas plant owners). Eighty-six (86) of these individuals consented to participate in the poll. After receiving permission from respondents (owners of biogas plants), the researchers distributed open- and closed-ended questionnaires to every responder (biogas plant financer) through what's App and *LinkedIn*. The total number of completed questionnaires received for the questionnaire survey was 79. The response rate was 86.81%; however, the researchers eliminated 5 surveys because of unmatched and inadequate responses. The sample yielded 79 valid respondents (owners of biogas plants) for study analysis. The respondents collected their personal information based on the visit of researchers and friends in the study area. The conclusion is based on an accurate depiction of the sample. The demographic characteristics of the respondents, which include age, experience, education, and gender, also demonstrate the various backgrounds of the respondents who supplied the correct response in this study (see Appendix Table 9). The first half of the questionnaire pertains to the respondents' personal information, while the second piece is concerned with the characteristics of biogas plants. Using non-probability (snowball) sample surveys and mobile applications, this study assessed the potential of biogas in Pakistan and enhanced existing biogas plants. This sampling technique is utilized for specialized demographic features, pilot studies, qualitative research, and exploratory research; it does not give every population member an equal chance to participate. Existing biogas facilities were chosen for study to improve their service and quality. Due to the unique nature of biogas plants, the snowball sampling method was used to create a nationally representative sample of biogas plants. To do this, researchers conducted a poll between March and September 2021; when the fourth wave of the delta mutant coronavirus (COVID-19) peaked in Pakistan, there was a considerable risk of addressing appropriate defendants (biogas plant financer). Moreover, each delegate has a wealth of knowledge about biogas plants and demographic measurements (see Tables 9 and 10 in Appendix). In addition, this study used snowball sampling to choose Pakistani respondents (owners of biogas plants) with different habits. Snowball sampling is inadequate for theoretical generalization, especially in the absence of randomization and when participants are linked to one another (Ozoh et al. 2018). This research aims to investigate the pros and cons of installing biogas technology and assess the financial performance of biogas plants whose owners are satisfied. The moderating influence of awareness and understanding on adopting biogas plants is part of the satisfaction nexus and decreases hurdles. This study used questionnaires to obtain respondents' information per a quantitative data collection strategy (biogas plant financer).

Our study combined structural equation modeling with data analysis (SEM). Because it is a component-centered method, this approach was used to explore the relationship factors (Urbach and Ahlemann 2010). The widespread use of PLS-SEM in subsequent research is proof of its validity; the author of this work also employed it (Ying et al. 2020). SEM is better than standard statistical approaches for modeling. It is beneficial for the statistical analysis of efficiency, comfort, and accuracy (Schlegel et al. 2016). As a second-generation technique, SEM overcomes the problems inherent to first-generation analysis. SEM is a multivariate analytic technique that may be used to investigate many variables simultaneously. SEM is common in business research owing to its ability to

manage complex simultaneously and many interactions (Chin and Newsted 1999). Variance-based SEM (VB-SEM), partial least square (PLS)-SEM, and covariance-based SEM (CB) are established SEM methods (Henseler et al. 2009). If analytical processes are used poorly, erroneous conclusions are generated for commercial and social scientific research.

However, a trustworthy statistical methodology is highly significant (Ramayah et al. 2010). PLS-measurement structural equation models and structural models are two-stage analytical procedures comprised of measurement outcomes (Osborne 2010). Measurement analysis was used to assess the convergent validity of the extracted average variance (AVE), inner stability dependability regarding composite reliability (C.R.), and element consistency regarding outer loading. The measurement assessment model includes the evaluation of reliability and validity as well as the inner model, and the structural assessment model tests hypotheses/ relationships and evaluates the outer model. This study evaluated the associations between the researched variables using PLS 3.0 software to analyze primary data. In addition, smart-PLS for VB-SEM use PLS-SEM route modeling to examine the relationship between variables (Solangi et al. 2019). Cronbach's alpha, composite reliability, and item loading were used to assess the link between the items'' convergent validity. Despite this, discriminant validity depends on the correlation between variables as assessed by Fornell Larker, cross-loading, and the ratio of heterotraits to monotraits. In addition, the evaluation of the measurement model includes testing hypotheses using route analysis, as mentioned in the section describing the study's findings. Path analysis has shown interdependencies between variables.

Instrument and variables measurement

In this study, the researchers have included all elements from earlier works. The investigation led to the construction of items depending on maintenance barriers of biogas plants (Jan 2017). The financial support for biogas plants aspects of government assistance was taken from the research (Shah and Sahito 2017). Assumed were items associated with the economic and policy barriers (Ozoh et al. 2018). The construction of objects is connected to owner satisfaction with biogas plants (Chin and Newsted 1999). Adopted were components of awareness through social media (Wang et al. 2020c). Finally, this research embraced elements linked to adopting biogas technology (Hair et al. 2014).

Data analysis and results

The following tables detail the confirmed validity and reliability of this measuring approach. Figure 2 of the measurement assessment model shows the variable influence

loadings. All factor loading levels are more than 0.5, and all items' convergent validity in the measurement assessment model is valid. According to the findings of the route analysis performed to test the hypotheses, MBBP, ATSM, and FSFBP are all true. In contrast, MBBP is detrimental to ITABT but acceptable to MBBP, ATSM, EPB, and OSWBP. ATSM moderates the associations between MBBP, FSFBP, EPB, OSWBP, and ITABT and accepts MBBP, FSFBP, OSWBP, and EPB. This section investigates convergent validity, which demonstrates the connection between things. Table 2 shows the loadings and AVE values above 0.50, while the alpha and composite reliability (C.R) values exceed 0.70. These results indicate that convergent validity is a substantial and valid relationship between the components. AVE levels exceed 0.50, but composite reliability (C.R) standards surpass 0.70. These numbers imply a significant level of item correlation and convergent validity.

Measurement assessment model

The measurement model evaluates the constructs' dependability and cogency and the item influence loadings (Hair et al. 2019). Consistent is the paradigm for testing validity and reliability (convergent and discriminant validity, respectively) (Hair et al. 2011). All item loadings exceed the 0.5 thresholds (Hair et al. 2014) (Table 2). Each average factor loading was above 0.50, and every reflection subsidized to the generated adjustable, as determined by the study's analysis (Arbuckle 2011). AVE larger than the recommended criterion of 0.5. Each standard's composite dependability rating is more than 0.70, indicating the accuracy of the measurements (Anderson and Gerbing 1988). From 0.913 (implementation of biogas technology) to 0.979 (economic and transparent policies), C.R. scores range (low-cost and clear policy). All additional loadings have values between 0.5 and 0.946%.

The study results also analyze the discriminant validity of the relationship between variables. To examine the discriminant validity, cross-loading was performed. These results support discriminant validity and show a low correlation between variables. In addition, Table 3 of the findings section illustrates the discriminant validity using Fornell-Larcker for the variable relationships. Table 4's italicized numbers show that the components have a high correlation, while the remaining elements have a poor correlation. The discriminant validity is examined by comparing the bold values of the cross-loadings with other components in each column. The variable's values show that those indicating a link through the inconstant are larger than folks indicating a connection through extra inconstant. These findings indicated that discriminant validity is a genuine, tenuous relationship between variables. All factor loading levels above 0.5 and the convergent cogency of all items are valid.
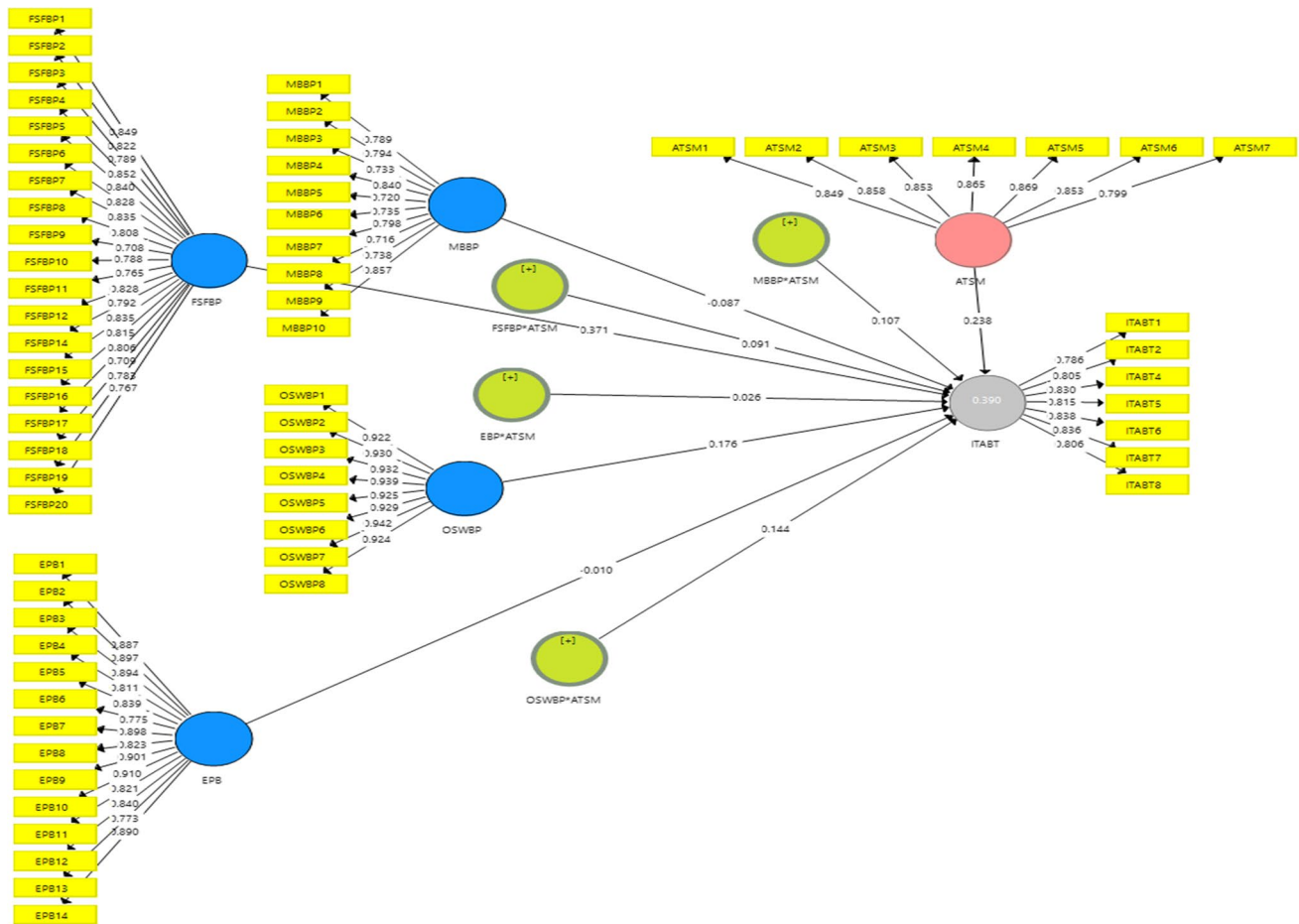
Fig. 2 Measurement model assessment

Numerous studies have critiqued the Fornell-Larcker criterion; hence, the heterotrait–monotrait ratio of correlations (HTMT) is regarded as a suitable discriminant validity measure (Akbar et al. 2019). It is confirmed if the discriminant validity value is less than 0.85 or 0.90 (Ali et al. 2022b). Each number in Table 5 is below 0.90. The results section also presents the discriminant validity of the variable' nexus. The values of the variable indicate that values suggesting a relationship with the variable are greater than those indicating a connection with other variables. This study also assessed the interaction between factors using the HTMT ratio. According to HTMT statistics, the values are less than 0.85.

Structural assessment model

The measuring model was evaluated first, followed by the structural assessment model, which examined the link among exogenous and endogenous components. The structural model is evaluated using many statistical measures, including effect size (f^2), t values, predictive relevance (Q^2),

coefficient of determination (R^2), and path coefficient (values). Using PLS-SEM literature criteria, this research analyses hypotheses and estimates the significance of path coefficients. To determine the significance of the hypotheses, the bootstrapping method was utilized using 5000 subsamples and a significance level of 5% (one-tailed). The results reveal that all hypotheses except H2 and H3 are accepted. MBBP ($\beta = 0.238$, $t = 4.251 > 1.64$, p 0.05), maintenance barriers of biogas plants relationship (moderator), ($\beta = 0.026$, $t = 0.045 < 1.64$, p 0.281), FSFBP ($\beta = 0.107$, $t = 2.148 >$), 1.64, p 0.05), financial support for biogas plants relationship (moderator), ($\beta = 0.176$, $t = 2.342 > 1.64$, p 0.05), EPB ($\beta = 0.010$, $t = 0.212 < 1.64$, p 0.05), economic and policy barriers relationship (moderator) ($\beta = 0.371$, $t = 4.861 > 1.64$, p 0.05), OSWBP ($\beta = 0.091$, $t = 1.650 > 1.64$, p 0.05), owner satisfaction with biogas plant relationship (moderator), ($\beta = 0.087$, $t = 1.729 > 1.64$, p 0.05), ATSM ($\beta = 0.144$, $t = 2.016 > 1.64$, p 0.05), and intention to adopt biogas technology affect significantly and positively. All biogas plants have positive significance results for the intention to adopt biogas technology.

Table 2 Convergent validity analysis

Constructs	Items	Loadings	C.B Alpha	C.R	AVE
Maintenance barriers of biogas plants	MBBP1	0.789	0.929	0.937	0.598
	MBBP2	0.857			
	MBBP3	0.794			
	MBBP4	0.733			
	MBBP5	0.84			
	MBBP6	0.72			
	MBBP7	0.735			
	MBBP8	0.798			
	MBBP9	0.716			
	MBBP10	0.738			
Financial support for biogas plants	FSFBP1	0.849	0.969	0.972	0.643
	FSFBP2	0.788			
	FSFBP3	0.765			
	FSFBP4	0.828			
	FSFBP5	0.792			
	FSFBP6	0.835			
	FSFBP7	0.815			
	FSFBP8	0.806			
	FSFBP9	0.709			
	FSFBP10	0.783			
	FSFBP11	0.822			
	FSFBP12	0.767			
	FSFBP13	0.789			
	FSFBP14	0.852			
	FSFBP15	0.84			
	FSFBP16	0.828			
	FSFBP17	0.835			
	FSFBP18	0.808			
	FSFBP19	0.708			
Economic and policy barriers	EBP1	0.887	0.978	0.981	0.865
	EBP2	0.910			
	EBP3	0.821			
	EBP4	0.840			
	EBP5	0.773			
	EBP6	0.890			
	EBP7	0.897			
	EBP8	0.894			
	EBP9	0.811			
	EBP10	0.839			
	EBP11	0.775			
	EBP12	0.898			
	EBP13	0.823			
	EBP14	0.901			
Owner satisfaction with biogas plant	OSWBP1	0.922	0.978	0.981	0.865
	OSWBP2	0.930			
	OSWBP3	0.932			
	OSWBP4	0.939			
	OSWBP5	0.925			
	OSWBP6	0.929			
	OSWBP7	0.942			
	OSWBP8	0.924			

Table 2 (continued)

Constructs	Items	Loadings	C.B Alpha	C.R	AVE
Awareness through social media	ATSM1	0.849	0.936	0.948	0.722
	ATSM2	0.858			
	ATSM3	0.853			
	ATSM4	0.865			
	ATSM5	0.869			
	ATSM6	0.853			
	ATSM7	0.799			
Intention to adopt biogas technology	ITABT1	0.786	0.917	0.933	0.667
	ITABT2	0.805			
	ITABT3	0.830			
	ITABT4	0.815			
	ITABT5	0.838			
	ITABT6	0.836			
	ITABT7	0.806			

$N = 79$; *SFL*, standard factor loading; *AVE*, average variance extracted; *CR*, composite reliability

Table 3 Fornell-Larcker

Variables	ATSM	EBP	FSFBP	ITABT	MBBP	OSWBP
ATSM	0.850					
EBP	0.168	0.855				
FSFBP	0.447	0.165	0.802			
ITABT	0.427	0.163	0.518	0.817		
MBBP	0.106	0.017	0.054	0.149	0.774	
OSWBP	0.428	0.338	0.492	0.432	0.136	0.830

$N = 79$; *MBBP*, maintenance barriers of biogas plants; *FSFBP*, financial support for biogas plants; *EPB*, economic and policy barriers; *OSWBP*, owner satisfaction with biogas plant; *ATSM*, awareness through social media; *ITABT*, intention to adopt biogas technology

The R^2 value for maintenance hurdles of biogas plants is 0.462, showing that the model has substantial explanatory power for adopting biogas technology in Pakistan. However, aiding a model based on its R^2 score is not a practical and successful technique. The model's Q^2 projected relevance measurement is hence the most accurate. Showing that the value of Q^2 exceeds zero, the latent exogenous norms have excessive predictive importance, indicating that Q^2 is greater than zero. The findings suggest that the value of Q^2 is 0.231, indicating that social media may increase the desire to embrace biogas technology, confirming the model's excellent predictive validity. These are the typical values of f^2, containing 0.02, 0.15, and 0.35, representing modest, moderate, and major effects, respectively, across three categories. Consequently, f^2 assumed the impact magnitude fluctuated between mild and big (see Table 6). Table 6 contains a variety of statistical methods. Figure 3's structural evaluation model suggests a substantial connection between the variables since the *T*-values are greater than zero (1.64). All hypotheses except H2 and H3 are approved. All moderated

variable values in the structural assessment model for biogas technology adoption in Pakistan are positive and exhibit a substantial association.

t-values are more significant than *p*-values; the structural assessment model depicts the relationship between the variables (1.64). Adopting biogas technology benefits and considering the maintenance barriers of biogas plants in Pakistan. All moderated variable values are indicative of favorable outcomes. The structural evaluation approach for deploying biogas technology in Pakistan to attract green FDI demonstrates a substantial correlation. We conducted semi-structured interviews with illiterate biogas plant owners (those unable to fill out the questionnaires) to acquire insight into the genuine problems of biogas plant owners and practical information about the maintenance difficulties. Aspects include the economic and policy barriers, maintenance barriers of biogas plants, the original installation and investment cost, and knowledge of new technology. We have interviewed 37 rural Pakistani biogas plant proprietors. Tables 7 and 8 provide the examined criteria intended for

Table 4 Cross-loading

Items	ATSM	EBP	FSFBP	ITABT	MBBP	OSWBP
ATSM1	0.849	0.127	0.324	0.344	− 0.104	0.351
ATSM2	0.858	0.134	0.398	0.348	− 0.091	0.354
ATSM3	0.853	0.140	0.370	0.329	− 0.119	0.345
ATSM4	0.865	0.185	0.394	0.322	− 0.100	0.368
ATSM5	0.869	0.129	0.415	0.390	− 0.088	0.376
ATSM6	0.853	0.132	0.406	0.422	− 0.075	0.392
ATSM7	0.799	0.157	0.346	0.359	− 0.061	0.351
EBP1	0.161	0.887	0.141	0.179	0.007	0.31
EBP2	0.153	0.910	0.153	0.127	− 0.029	0.290
EBP3	0.120	0.821	0.064	0.094	− 0.035	0.297
EBP4	0.114	0.840	0.110	0.076	− 0.021	0.271
EBP5	0.121	0.773	0.139	0.079	0.038	0.208
EBP6	0.156	0.890	0.134	0.184	0.008	0.307
EBP7	0.159	0.897	0.182	0.20	− 0.011	0.314
EBP8	0.141	0.894	0.146	0.122	− 0.042	0.287
EBP9	0.130	0.811	0.068	0.083	− 0.029	0.290
EBP10	0.109	0.839	0.121	0.094	− 0.042	0.283
EBP11	0.117	0.775	0.135	0.089	0.033	0.212
EBP12	0.151	0.898	0.152	0.126	− 0.04	0.292
EBP14	0.118	0.823	0.123	0.097	− 0.052	0.286
EBP15	0.186	0.901	0.204	0.200	− 0.013	0.332
EBP16	0.161	0.887	0.141	0.179	0.007	0.310
FSFBP1	0.371	0.118	0.849	0.470	− 0.079	0.405
FSFBP2	0.347	0.126	0.788	0.389	0.002	0.393
FSFBP3	0.34	0.181	0.765	0.400	− 0.105	0.386
FSFBP4	0.384	0.096	0.828	0.401	− 0.014	0.353
FSFBP5	0.350	0.068	0.792	0.315	− 0.045	0.324
FSFBP6	0.350	0.187	0.835	0.469	− 0.052	0.452
FSFBP7	0.370	0.137	0.815	0.471	− 0.001	0.435
FSFBP8	0.366	0.125	0.806	0.449	− 0.012	0.451
FSFBP9	0.345	0.102	0.709	0.338	− 0.091	0.315
FSFBP10	0.355	0.121	0.783	0.393	− 0.009	0.398
FSFBP11	0.387	0.096	0.822	0.399	− 0.016	0.351
FSFBP12	0.341	0.177	0.767	0.397	− 0.107	0.379
FSFBP13	0.358	0.061	0.789	0.308	− 0.053	0.326
FSFBP14	0.370	0.126	0.852	0.456	− 0.068	0.395
FSFBP15	0.371	0.148	0.840	0.449	− 0.029	0.425
FSFBP16	0.358	0.147	0.828	0.449	− 0.023	0.415
FSFBP17	0.348	0.204	0.835	0.471	− 0.048	0.442
FSFBP18	0.377	0.126	0.808	0.443	− 0.013	0.456
FSFBP19	0.342	0.108	0.708	0.325	− 0.086	0.313
FSFBP20	0.371	0.118	0.849	0.470	− 0.079	0.405
ITABT1	0.368	0.108	0.478	0.786	− 0.167	0.430
ITABT2	0.365	0.169	0.431	0.805	− 0.107	0.345
ITABT4	0.306	0.129	0.381	0.83	− 0.067	0.306
ITABT5	0.366	0.099	0.386	0.815	− 0.14	0.322
ITABT6	0.356	0.14	0.418	0.838	− 0.152	0.332
ITABT7	0.324	0.145	0.377	0.836	− 0.127	0.307
ITABT8	0.340	0.139	0.467	0.806	− 0.085	0.398
ITABT9	0.368	0.108	0.478	0.786	− 0.167	0.430
MBBP1	− 0.118	0.012	− 0.073	− 0.168	0.789	− 0.107

Table 4 (continued)

Items	ATSM	EBP	FSFBP	ITABT	MBBP	OSWBP
MBBP2	− 0.038	− 0.024	− 0.064	− 0.137	0.857	− 0.124
MBBP3	− 0.065	− 0.041	0.023	− 0.077	0.794	− 0.067
MBBP4	− 0.067	− 0.033	0.042	− 0.035	0.733	− 0.087
MBBP5	− 0.037	− 0.005	− 0.079	− 0.141	0.84	− 0.121
MBBP6	− 0.129	− 0.053	− 0.051	− 0.105	0.72	− 0.084
MBBP7	− 0.077	0.012	− 0.024	− 0.083	0.735	− 0.097
MBBP8	− 0.075	− 0.028	0.020	− 0.083	0.798	− 0.075
MBBP9	− 0.130	0.001	− 0.062	− 0.118	0.716	− 0.158
MBBP10	− 0.055	− 0.003	0.061	− 0.02	0.738	− 0.069
OSWBP1	0.402	0.332	0.458	0.392	− 0.165	0.922
OSWBP2	0.426	0.307	0.464	0.379	− 0.119	0.930
OSWBP3	0.397	0.331	0.466	0.397	− 0.16	0.932
OSWBP4	0.412	0.321	0.458	0.408	− 0.114	0.939
OSWBP5	0.371	0.292	0.448	0.419	− 0.088	0.925
OSWBP6	0.396	0.316	0.461	0.396	− 0.159	0.929
OSWBP7	0.416	0.318	0.461	0.402	− 0.122	0.942
OSWBP8	0.369	0.299	0.446	0.417	− 0.091	0.924
OSWBP9	0.402	0.332	0.458	0.392	− 0.165	0.922
OSWBP10	0.426	0.307	0.464	0.379	− 0.119	0.930

$N = 79$; *MBBP*, maintenance barriers of biogas plants; *FSFBP*, financial support for biogas plants; *EPB*, economic and policy barriers; *OSWBP*, owner satisfaction with biogas plant; *ATSM*, awareness through social media; *ITABT*, intention to adopt biogas technology

Table 5 Heterotrait–monotrait ratio (HTMT) for discriminant validity

Variables	ATSM	EBP	FSFBP	ITABT	MBBP	OSWBP
ATSM						
EBP	0.17					
FSFBP	0.469	0.158				
ITABT	0.454	0.154	0.537			
MBBP	0.11	0.048	0.081	0.138		
OSWBP	0.446	0.339	0.5	0.45	0.133	-

$N = 79$; *MBBP*, maintenance barriers of biogas plants; *FSFBP*, financial support for biogas plants; *EPB*, economic and policy barriers; *OSWBP*, owner satisfaction with biogas plant; *ATSM*, awareness through social media; *ITABT*, intention to adopt biogas technology

Table 6 Structural model results (hypotheses testing)

	Hypothesis	B-values	S.D	T-values	P-values	Supported	R^2	Q^2	f^2
H1	MBBP − > ITABT	0.238	0.056	4.251	0.000	Yes	0.462	0.231	0.081
H2	MBBP*ATSM − > ITABT	0.026	0.045	0.583	0.281	No		0.158	0.026
H3	EPB − > ITABT	− 0.010	0.046	0.212	0.416	No			0.101
H4	EPB*ATSM − > ITABT	0.371	0.076	4.861	0.000	Yes			0.013
H5	OSWBP − > ITABT	0.091	0.055	1.650	0.0510	Yes			0.014
H6	OSWBP*ATSM − > ITABT	− 0.087	0.051	1.729	0.043	Yes			0.011
H7	FSFBP − > ITABT	0.107	0.050	2.148	0.017	Yes			0.012
H8	FSFBP*ATSM − > ITABT	0.176	0.075	2.342	0.011	Yes			0.014
H9	ATSM − > ITABT	0.144	0.071	2.016	0.023	Yes	0.477		0.009

$N = 79$; *MBBP*, maintenance barriers of biogas plants; *FSFBP*, financial support for biogas plants; *EPB*, economic and policy barriers; *OSWBP*, owner satisfaction with biogas plant; *ATSM*, awareness through social media; *ITABT*, intention to adopt biogas technology

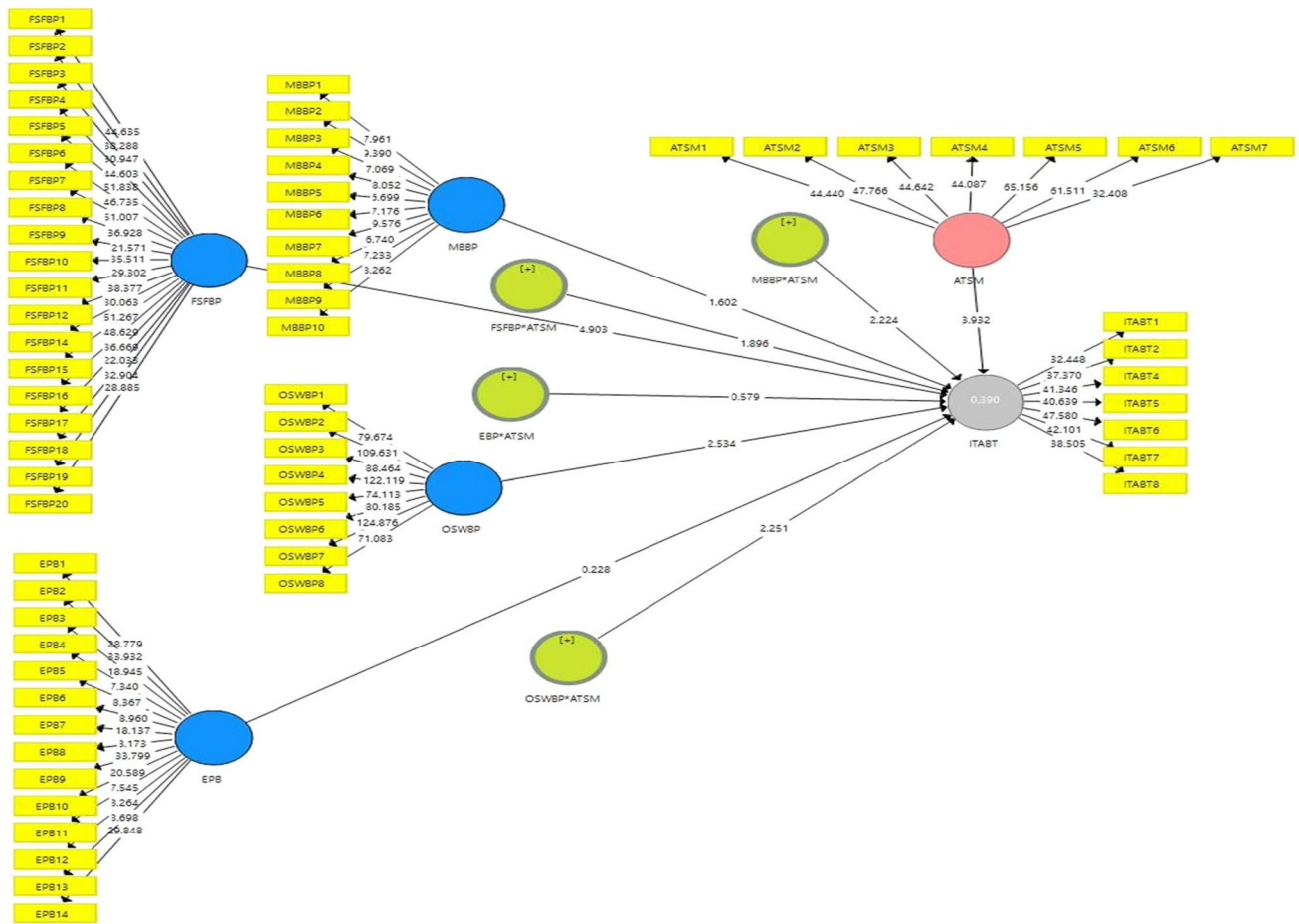(*), the moderating relationship indicated by the asterisk among the variables

Fig. 3 Structural model assessment

biogas technology and the responses (%) from biogas plant financer. All percentages reflect responses from (illiterate) proprietors of biogas plants. The viewpoints and degrees of satisfaction of Pakistani respondents (biogas plant financer) to their biogas technology are shown in Table 7. The key factors are the ease of biogas plant operation, the availability of engineers and experts, the economic policy benefits, the suitable collection of gas for kitchen use, the use of gas for illumination, and the positive social reputation. Countries in South Asia, including India, Nepal, and Bangladesh, have a sufficient supply of technical services to stimulate the expansion of social projects in general (Breitenmoser et al. 2019). Fifty-nine percent of respondents (biogas-plant financiers) indicated that customer satisfaction with a Pakistani biogas plant is necessary for adopting biogas technology. About 23% of respondents (biogas plant professionals) said biogas technology needs a cheaper price and simpler policy. In addition, 16% of respondents recognized that customer happiness and plant quality are vital. Additionally, 50% of biogas plant customers (financiers of biogas plants) said that their facilities are operational and functional.

Table 7 Views and satisfaction of biogas plant owners

Explanation	Circum-stances (%)	Response (%)	Frequency
Environmental advantages	11.9	5.2	4.9
Health advantages	7.7	5.1	4.2
Availability of technicians	22.6	11.8	9.10
Lighting and food preparation (sufficient gas)	14.7	8.5	8
Easy operation of biogas plant	13.4	8.2	7.1
Made easy cooking	7.2	5.1	4.9
Reduction of workload	8.9	5.3	5
Advantages of economics	13.8	8.2	6.9
Preparation of appliances	3.8	4.3	1.2
Reputation in society	12.7	7.2	5.8
Improve food taste using biogas	11.9	7.3	5.9
Others	11.9	6.4	8

Inspiring factors and important barriers

A variety of problems hinder the partial adaptation of biogas plants. Unavailability of experts and fully trained technicians was the greatest response at 17.5%, followed by frequent operational problems at 14% and insufficient biogas pressure at 5.5%. The biogas facilities confront various operating issues, including rusting of the steel components, roof and wall cracking, and gas pressure leaks (Haile et al. 2019; Scheutz and Fredenslund 2019). The lowest pressure reported for biogas was 5.8%, which poses a serious problem for cooking meals adequately. The key cause aimed at squat heaviness or biogas secret the device is inadequate mixing of the feed. Twenty-one biogas facilities must have the right

stirring mechanism to increase gas burden aimed at ulti-mate − user convenience (Nsair et al. 2019). Regular techni-cal troubles have delayed the biogas plant's functioning, as 23% of the owners have complained. The controlled biogas plan used 16% of the globe, 13.5% of gas was lost, and cus-tomers of biogas got no technical help. Due to these factors, biogas plant customers endure failure and disillusionment, and the regulatory framework of the project is blamed for the technicians' poor acceptability. Without a background framework and technical assistance, the profitability of a biogas plant project is severely compromised (Pandyaswargo et al. 2019). The barriers and problems faced by Pakistan's biogas consumers are outlined in Table 8.

Table 8 Barriers and challenging factors

Variables	Description	Circum-stances (%)	Response (%)	Frequency
Specific reasons through which investors are part-ily satisfied with biogas plant	Prepared food (not pleasant)	8	9	12.8
	Biogas plant operational difficulty	4	4.7	5.9
	Technical problems encounter frequently	8	10	9
	Through extra workload	5	6.3	8.8
	Unavailability of technicians	10	12.8	15.6
	Insufficient gas for lighting and to prepare food	8	10	11
	Others	5	6.3	8.9
Biogas plant accepting barriers	Malfunctioning of stove	6	6.2	7.8
	Difficulty in gas leakage	8	9	10.8
	Food has less taste with biogas	7	7.4	11.4
	Extra workload	9	7.5	12.3
	Delay to solve technical problems	10.5	12.4	18.9
	Issues in availability of technicians	10	8.4	15.6
	Insufficient gas for lighting and food	9	9.5	13.6
	Occasionally completely no working	8	7.54	11.7
	Others	10	8.6	15.5
Core issues of a biogas plants, failure in operation	Pipeline blockage through compressed water	11	9.5	17.4
	Pipeline bio-slurry obstruction	13	7.2	21.6
	Natural misadventure	11	8.5	17.6
	Poor and unbalanced operations for water and dung	21	14.4	41.4
	Biogas plant skilled operator issues	14	11	22.5
	Empowerment issues due to local gas distribution authority	9	7.2	13.6
	Malfunctioning of stove	5	5.3	8.7
	Spare parts availability issues	11	8.4	20.7
	dissatisfactory maintenance	13	11.4	25.4
	Day-by-day increasing workload increasing	9	4.3	13.6
	Bio-slurry improper management	5	4.3	5.8
	Attachment toilet un − sacred	5	4.5	6.7
	Ancient procedure and outdated design	9	6.4	15.4
	Poor service quality during installation	6	4.3	7.5
	Poor construction material used	10.2	5.8	16.4
	Others	17	18.8	31.4

Discussions and implications

This study has together hypothetical and practical consequences. The present important fictional effort underwrites to the literature on bio-technology and socioeconomics. The current research examines the impact of four influences, including the MBBP, FSFBP, EPB, OSWBP, ATSM, and ITABT, on the adoption of biogas plants by Pakistani farmers and the growth of biogas technology over the long term. This research study suggested government sector executives, private, non-governmental organizations (NGOs), policymakers, and advice for encouraging farmers to adopt biogas plants and develop biogas technology. This study emphasizes the critical need for politicians, economists, and energy sector authorities to eliminate key hurdles and provide financial aid to farmers who embrace biogas technology plants. Superior planning may limit the impact of a biogas plant's essential components and hurdles, advancing biogas-related knowledge. Biogas technology may reduce the energy problem and improve farmers' financial conditions.

Nonetheless, government assistance may enhance biogas plant adoption in rural regions and investor excitement among new investors. The findings imply that biogas plant maintenance and economic and legislative constraints must be addressed to attract investment. Social media and open policies significantly influence the adoption of biogas plants and attract fresh financiers outstanding to cost savings and fulfillment with the machine. Removing economic and governmental hurdles with care encourages farmers to use biogas plants and improves rural living conditions. Similar results are supported by prior research (Garfí et al. 2019). This research also demonstrates that social media knowledge is not an ideal moderator of the link between the maintenance barriers of biogas plants and the desire to embrace biogas technology. According to the research, the adoption potential of biogas technology in rural Pakistan is affected by the awareness of biogas plants via social media. The given results correlate to the findings of this research (Luo et al. 2021). A prior study reveals that social media knowledge of biogas plants affects installation parameters and the uptake of biogas technology. This research also shows that social media knowledge of biogas plants is a key mediator of the relationship between financial support for biogas plants and the desire to use biogas technology. Consistent with a previous study's results (Havrysh et al. 2020), the findings show that social media knowledge of biogas technology influences government economic policies and encourages rural farmers to use biogas plants and save money (Wang et al. 2020c).

According to this study, eliminating maintenance obstacles and the availability of professionals validates the choice to adopt biogas plants and provides social and economic benefits for rural farmers. Farmers and new investors are drawn to biogas facilities by the advantageous economic policies, low price, and maintenance assistance. The research also reveals a strong correlation between government funding, the appeal of biogas plants to consumers, and their socioeconomic worth. Investor's fulfillment and plant eminence are inventive ways to persuade agrarians and original financiers to use biogas technology, minimizing the global energy disaster and stimulating the home economy. Purchaser fulfillment and plant eminence may show a crucial part in enticing home–grown agrarians, commercial and non-governmental organizations, and fresh financiers to Pakistan's biogas technology and reaping commercial and societal advantages. These findings provide policymakers, experts, institutional bodies, regulators, the ministry of water power, and the upper management of the alternative energy development board (AEDB) with guidelines for adopting these factors in order to achieve a high level of former satisfaction, thereby attracting rural farmers of certain regions to the sustainable development of biogas technology. The relevant institutional authorities must investigate the MBBP, FSFBP, EPB, and OSWBP in order to save farmers time, decrease costs and energy crises, and improve the living conditions of rural farmers who provide inexpensive biogas energy systems.

Based on respondents' comments, this study also evaluates the financial benefits of biogas technology. Fifty-six percent of respondents (financiers of biogas plants) feel that biogas plants have decreased fuel prices, while 41% disagree. A recent study indicates a drop in gas prices (Negri et al. 2020). In addition, 36% of respondents (financiers of biogas plants) said their family's financial status improved after constructing a biogas plant. Fifty-four percent of respondents (financiers of biogas plants) said their financial status had not changed. This difference is due to the number of family members and related expenses. In rural Pakistan, joint families save less, but nuclear households benefit more from equivalent contributions. Fifty-one percent of families could not retain their money owing to the causes above. The results of the present investigation are comparable to those of prior studies (Akter et al. 2021). In addition, the results of this research suggest that the availability of specialists and the elimination of maintenance barriers for biogas plants evaluating the adoption of biogas plants have a significant and favorable relationship with the development of supportable biogas technology. Current research verifies the results of a prior study stressing the importance of biogas plant technicians on farmers' intent to employ biogas technology (Getachew et al. 2016). The current study reveals that technology for biogas plant components promotes biogas plant adoption and enhances biogas plant management by reducing installation barriers. In addition, the research results indicate that maintenance and financial government

assistance substantially impact the adoption and motivation of biogas plants among farmers. This research reveals that government support for biogas plant maintenance has large societal and financial paybacks. These consequences confirm the conclusions of earlier investigation (Wang et al. 2020a). This research demonstrates that management assistance for the operation and maintenance of biogas technology increases the likelihood that new farmers will embrace this technology and the demand for biogas plants.

After establishing a biogas plant, the customers' expenditures have fallen considerably. Cost reduction is the most important adaptive element for partly pleased consumers at a given period. This variable implies that biogas plants may enhance the financial status of a family. After the construction of biogas plants, the environment is enhanced in several ways, including cleanliness and safety, a large reduction in fire incidents, and reduced smoke generation due to better health and cleaner kitchens. Thirty-five percent of respondents (financiers of biogas plants) reported a significant decrease in fire incidences. Seventeen percent of respondents claimed to be free of disease, which was connected with the absence of black filth in the kitchen and house, and 11% of respondents opted to reduce their regular expenditures on fitness. However, the key benefits of biogas plants are cleanliness and wellness. Forty-three percent of the interviewees did not reply to the questions.

Our research findings give vital information to rural Pakistanis and government/NGO staff. The study demonstrates that biogas facilities are well suited for rural areas of Punjab, Pakistan, reducing expenses and boosting economic growth and prosperity. Government and non-governmental organizations (NGOs) should commence the simultaneous deployment of biogas plants with comprehensive material on the fixing procedure to aid pastoral individuals and economic development. Adopting biogas plants positively and strongly correlates with technician availability and plant owner satisfaction in Pakistan. The owners of biogas plants must comply with biogas plant maintenance regulations to reduce production costs. In addition, the study reveals that knowledgeable and educated owners enjoy more financial and upkeep benefits than incompetent and uneducated owners. In addition, the research indicated that biogas facilities are more advantageous when both specialized knowledge and necessary equipment are readily available. Moreover, we recommend that the government of Pakistan INGOs and NGOs provide supports for biogas technology and financial expansion for native agrarians. Assume that one member of the biogas plant's family is trained and capable of managing maintenance difficulties. In such a case, most problems may be resolved, and the family's day-to-day expenses may drop. Instead of Faisalabad, the report recommended expanding biogas facilities to other regions of Punjab with government and NGO participation.

Conclusions and policy implications

Biogas is generally recognized as an effective energy source. The greatest barrier to installing modern biogas technology in Pakistan and additional small revenue nations is the growth rate of biogas plants. Although Pakistan's government and many prominent INGOs and NGOs are attempting to make this technology acceptable by sponsoring biogas systems for home farmers, the acceptance rate among rural and village residents remains abysmally low. The main determination of this investigation is to assess the significant problems and maintenance obstacles Pakistani farmers encounter while establishing biogas systems. This study seeks to analyze the key features of biogas − installed plants in Pakistan to encourage biogas technology's long-term growth. This report highlights Pakistan's potential to attract investment in biogas technology for the supportable expansion of biogas drive. The energy choice theory indicates that the locals of this research region were more interested in using biogas in traditional farming practices than modern methods. Contrarily, the most challenging feature of biogas plants was their maintenance obstacles. Installation and building of biogas plants are generally driven by structure-based incentives, social subsidy benefits, present biogas plant owners as examples, and energy conservation. Although an increase in workload, gas leaks from connections, inadequate gas for cooking and lighting, complicated biogas plant operations, technical problems, and a shortage of easily accessible specialists are the most common reasons, they are not the only ones.

In conclusion, the current research reveals that all independent variables are important and favorably associated with rural Pakistan's adoption of biogas technology, alleviating the energy crisis, and achieving cost-saving goals. Before installing biogas plants in rural areas of Pakistan, it is preferable and more pertinent to eliminate specific obstacles, according to the findings of this study. These obstacles include financial management, cost-effectiveness, capital investment return, and fixed component evaluation. The research findings will also demonstrate to the government the urgency with which it must share information about adopting biogas technology and initiate its future development initiatives. Table 6's R^2 value for MBBP is 0.462, indicating that the current conceptual model has a high explanatory capacity for encouraging farmers in rural Pakistan to employ biogas plants. Q^2 yields a score of 0.231, indicating that the theoretical outline consumes strong and optimistic extrapolative value and proposing that the highlighted restrictions be resolved to enhance the possibility that biogas facilities would be constructed in rural Pakistan. Figure 1 of the model depicts the significant relationship between the selected variables and an EPB; the standards of the t measurement are outcome-oriented and greater than (1.64), indicating that the EPB has a positive and statistically significant

impact on encouraging farmers in rural Pakistan to install biogas plants. The relevance of the moderated variable gives positive signals in the structural evaluation model, suggesting the existence of a substantial relationship.

Moreover, the current research demonstrated that the chosen criteria and their moderation in this conceptual model had a substantial and positive effect on the structural assessment model for developing biogas plants in rural Pakistan. In conclusion, customers did not assist the after-sales services offered by construction and installation businesses and bodies. The following suggestions are offered to the government of Pakistan about developing and promoting biogas technology in rural Pakistan. To encourage biogas plants, the government should develop an economic strategy for the maintenance barriers of renewable energy projects, capacity-building sessions, financial and technical assistance, and media complaints about maintenance. Biogas technology has the potential to reduce household energy shortages in rural Pakistan. Therefore, the appropriate NGO/INGO and

the Pakistani government should conduct certain training measures to guarantee the sustainable development, maintenance, and social media awareness of rural biogas plants. Therefore, Pakistani government institutions and relevant INGO/NGOs should develop technical centers operated by trained professionals and provide after-sales services for the construction of biogas plants. Other elements that impact the adoption of biogas plants, like deficiency, biogas technology investors learning, the number of animals, the needed acreage, and other social and economic factors, have been largely ignored. Consequently, interested academics must determine the remaining components of biogas plant acceptance while reviewing the outcomes of this research. The researchers decided to establish a biogas technology in the pastoral zones of Pakistan, a growing nation. Therefore, the conclusions of the present research do not apply equally to industrialized and underdeveloped countries. Therefore, the authors must investigate the incentives for farmers in developed countries to use biogas plants in the future.

Appendix

Table 9 The level of questions and how respondents (owners of biogas plants) contradicted the semi-structured interview. Part A: Demographic features of respondents (biogas plant owners)

Part A: Demographic characteristic of respondents (biogas plant owners)			
Variables	Features	Frequency	%
Gender	Male	68	79.06
	Female	11	12.79
Age	Less than 26	7	8.86
	25–31	17	21.51
	31–45	21	26.58
	45–53	11	13.92
	57–65	15	18.98
	65 and above	8	10.12
Education of biogas plant users	Under metric	18	22.78
	Metric	19	24.05
	Faculty of Arts	17	21.51
	Bachelor	14	17.72
	Master	11	13.92
Experience of biogas plant users	1–4 years	18	22.78
	4–6 years	11	13.92
	6–8 years	16	20.25
	8–10 years	15	18.98
	10–12 years	12	15.18
	12- and above	7	8.86
Brand names of biogas plants	**Fixed drum**		
	Chinese fixed − dome plant	18	22.78
	Janata model	17	21.51
	Deenbandhu	14	17.72
	Camartec model	11	13.92
	Floating drum		
	A mild-steel gas storage drum	13	16.45
	Inverted over the slurry	6	7.59

Table 10 Adoption of sustainable upgrading measures for biogas plants

Variables	Items	Interrogations	%
Maintenance barriers of biogas plants	MBBP1	The availability of technicians is a factor in favor of biogas plant adoption	11.5
	MBBP2	The technician's availability can increase biogas plant owners' sense of confidence	18.3
	MBBP3	Due to the ready availability of trained technicians, biogas plant operators can save time by hiring one	15.2
	MBBP4	The skilled technicians of a biogas plant can contribute more to economic growth	14.5
	MBBP5	The availability of technicians might mitigate the concern of adopting a biogas plant	18.3
	MBBP6	The maintenance capacity of a biogas plant can increase its sales potential	7.5
	MBBP7	Biogas plant maintenance security can cause the buyer to disregard cost	13.7
	MBBP8	The regular visits of technicians to the biogas plant are an attractive feature for the plant owners	6.4
Financial support for biogas plants	FSFBP1	Operational and maintenance government support can enhance biogas plant adaptability	21.4
	FSFBP2	villagers can adopt biogas plants with confidence through operational and maintenance government support	18.9
	FSFBP3	The sale turnover of a biogas plant can be increased through operational and maintenance government support	16.6
	FSFBP4	Operational and maintenance expenditure paid by the government for biogas plants can attract farmers to adopt	22.8
	FSFBP5	There is a need to encourage rural areas to adopt biogas plants by giving them an incentive and operational support	22.8
Economic and policy barriers	EPB1	The government must create a low-cost and transparent strategy to attract biogas plant users	27.4
	EPB2	A clear and low-cost policy for biogas plants can lower the grid-connected energy load caused by adopting biogas plants	13.5
	EPB3	Over sixty percent of the population resides in rural areas, and we must encourage them to embrace biogas plants	14.3
	EPB4	A clear and low-cost strategy for biogas plants is enticing for off-grid communities and farmers	11.2
	EPB5	Renewable energy can significantly eradicate energy problems if a clear policy and low-cost biogas plant are implemented	16.4
	EPB6	A cost-effective strategy for renewable energy can motivate biogas plant users	9.6
	EPB7	The government must adjust its renewable energy policy to encourage off−grid farmers to employ biogas plants	8.3
Owner satisfaction with biogas plant	OSWBP1	User satisfaction and quality are key in luring new biogas plant consumers	24.5
	OSWBP2	Plant quality improves the satisfaction of biogas plants now in use	22.7
	OSWBP3	Studying the performance of existing biogas plants makes it possible to entice new consumers with the quality of biogas plants	19.8
	OSWBP4	The happiness of current biogas plant customers is crucial for attracting new users and investors	15.6
	OSWBP5	Biogas plant quality and existing user satisfaction can play a significant part in alleviating Pakistan's energy issue	16.5
Awareness through social media	ATSM1	Biogas technology awareness through social media is a key issue	30.5
	ATSM2	Rural farmers must be made aware of the benefits of biogas plants	18.5
	ATSM3	Villagers should be provided with information and education on renewable energy by government agencies	15.7
	ATSM4	The biogas plant's awareness enables the production of cost−effective energy	14.7
	ATSM5	A better understanding of biogas plants can increase the degree of consumer satisfaction	8.9
	ATSM6	There is a shortage of knowledge and comprehension regarding the operation of biogas facilities, their benefits, and the amount of energy they produce	14.6

Table 10 (continued)

Variables	Items	Interrogations	%
Intention to Adopt biogas technology	ITABT1	The rural investor and common farmers have reservations about embracing biogas technology	23.4
	ITABT2	The government can approve the biogas dealer and information service, provider	22.5
	ITABT3	A biogas plant is ideal for farmers looking to lower their energy expenditures and energy scarcity	14.3
	ITABT4	By using biogas technology, farmers can conveniently and affordably execute their duties	18.8
	ITABT5	Farmers in rural areas must embrace biogas technology to utilize animal poo cake	9.5
	ITABT6	In rural areas, there is a shortage of information about biogas technology to accept and enjoy its benefits	11.3

Declarations

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