A Study on the Influencing Factors and Development Strategies of Biomass Energy Utilization in Chongqing

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Abstract: Against the backdrop of global climate governance and China's national carbon neutrality and emissions reduction strategy, biomass energy—as a renewable energy source that can be stored and transported—plays a critical role in optimizing the energy structure and promoting sustainable development. This study takes Chongqing as the research area, breaks through the traditional macro perspective, and focuses on the behavioral decisions of micro-level actors such as farmers and enterprises. It innovatively constructs a three-dimensional analytical framework of "administrative agency-enterprise-farmer," and, based on the Technology Acceptance Model (TAM) and Structural Equation Modeling (SEM), combines multi-stage mixed sampling with multivariate data analysis to systematically explore the influencing factors and impact pathways of biomass energy development and utilization. The results reveal that perceived usefulness and perceived ease of use are the most significant drivers of usage intention, with functional value and social value showing synergistic enhancement effects. The study further proposes differentiated development strategies, such as reducing production costs through technological R&D, improving the industrial chain collaboration model of "enterprise + cooperative + farmer", to enhance the willingness of micro-level actors to partici-pate. This research provides a reference for promoting regional green energy transformation and offers significant practical value for similar regions across China.

Keywords: Biomass Energy; Technology Acceptance Model; Structural Equation Model; Influencing Factors; Development Strategies

1. Introduction

Under the dual context of accelerating global climate governance and the policy requirements of China's carbon neutrality goals, biomass energy, as the only renewable energy that can be stored and transported, has become a strategic pivot in the transformation of China's energy structure. As the only municipality directly under the central administrative agency in western China, Chongqing faced an external energy dependence rate of 46.7% in 2022, with energy consumption per unit of GDP 18% higher than the national average. The region is challenged by a pronounced dual urban-rural energy consumption structure (with rural coal usage exceeding 40%), emission reduction pressure in ecologically sensitive zones, and rigidly growing energy demand in the Chengdu-Chongqing economic circle.

In this context, a regionally adapted biomass energy development system has emerged through differentiated layouts: municipal waste incineration power generation in the metropolitan core (adding 300MW installed capacity), agroforestry biomass cogeneration in the Three Gorges Reservoir area of northeastern Chongqing, and distributed biogas projects in the Wuling Mountain area of southeastern Chongqing. For example, the calorific value of forestry residues in Yubei District reaches 16.8 MJ/kg; annual straw production in Tongliang District exceeds 500,000 tons; and the biogas potential from livestock and poultry waste in Nanchuan District reaches 210 million m^3/year, forming distinctive regional resource advantages.

From a techno-economic perspective, the production cost of biomass briquettes in Chongqing has dropped to 320 yuan/ton (a 41% decrease since 2015), and gasification power generation efficiency has exceeded 28%, though further improvement remains possible. The establishment of 42 straw collection and storage centers under the “enterprise + cooperative + farmer” model not only increased farmers’ income by 120 yuan per mu but also reduced raw material collection radii to within 15 km. The application of IoT technology has reduced equipment operation and maintenance costs by 30%, while blockchain trials in carbon footprint tracing have created environmental benefits of 12.8 yuan/MWh—demonstrating the development potential of a technology-economic-social synergistic innovation model.

Scholars at home and abroad have explored biomass energy from multiple perspectives. Chen [1] and Wang [2] affirmed the renewable attributes and resource sources of biomass energy, emphasizing its strategic role in energy transition. Zhang [3] and Li [4] discussed diversified development paths such as incineration and anaerobic digestion, underscoring their practical value in rural energy supply and waste management. Wang [5] and Yang [6] further revealed the comprehensive benefits of biomass energy in optimizing the energy structure and supporting rural sustainable development. In the research on influencing factors, Zhang [7], Peng Yuanchun [8], and Mao Jiabin (2018) analyzed the key constraints of biomass energy promotion from the perspectives of individual psychology and demographic characteristics. Wang Qiang [9] (2022), Liu Haibo (2021), and others examined it from the economic policy dimension. Wang Jian (2021), Li Zhiqiang (2020), and others analyzed it from the technical environment aspect.

The TAM model (F. Davis [10]) has been introduced into relevant studies, with Wang Yao and Mi Feng [11] (2015) validating the influence mechanisms of perceived usefulness and ease of use on technology acceptance. This study selects Chongqing as a case and shifts from the traditional macro perspective to focus on the usage intentions of micro-level actors—such as farmers and enterprises—in biomass energy development. It innovatively constructs a “administrative agency-enterprise-farmer” tripartite analytical framework based on the Technology Acceptance Model (TAM), and, considering Chong-qing’s energy structure, consumption habits, and policy orientation, adopts a combination of questionnaire surveys, structural equation modeling (AMOS), and multiple linear regression to systematically analyze key influencing factors and their pathways.

This study emphasizes both theoretical model innovation and deep coupling with local practical scenarios, aiming to provide a systematic solution featuring “micro-level perspective, model innovation, and policy adaptation” for energy transition in mountain-ous cities, and to offer theoretical references and practical paradigms for similar regions across the country.

2. Data Sources and Sample Characteristics

The data in this study originate from a hybrid survey conducted among biomass energy developers and users in Chongqing from 2024 to 2025. A multi-stage mixed sampling method was employed, guided by the “One Core, Two Belts” regional development strategy. The survey covered the metropolitan core area (Yubei District, Shapingba District), the northeastern urban agglomeration (Wanzhou District, Kaizhou District), the southeastern ecological zone (Qianjiang District, Youyang County), and special functional zones (Liangjiang New Area). A total of 1,400 households from seven districts and counties were sampled.

By combining stratified sampling, probability proportional to size (PPS) sampling, and simple random sampling, a four-tier sampling framework—municipality, district/county, sub-district, and community—was constructed to ensure the representativeness of the sample. The sample included respondents from diverse contexts such as industrial and commercial zones, agricultural regions, and ecological protection areas. Among the respondents, 38% were energy developers and 62% were end-users.

After pre-survey optimization and quality control, 751 valid questionnaires were collected (see Table 1), yielding a 93% effective response rate. Reliability and validity tests showed that Cronbach's α values for all variables were greater than 0.7, the KMO value exceeded 0.6, and the cumulative variance explained by factor analysis surpassed 84%, indicating the data quality was sufficient for analysis. Abnormal values were cleaned using Python, and missing data were addressed using imputation methods to ensure the reliability of analytical results.

Table 1. Survey Sample Basic Characteristics

variable	Stats	Number of people (persons)	Proportion (%)
Educational background	High school and below	243	32.34%
	Junior college	112	14.97%
	Undergraduate course	330	43.91%
	Master degree or above	66	8.78%
occupation	Pupil	273	36.33%
	administrative agency/public institution staff	91	12.18%
	Enterprise staff	123	16.37%
	freelancer	91	12.18%
	other	173	22.95%
Per capita disposable monthly household income	Less than 1500 yuan	115	15.37%
	1500-3000 yuan	172	22.95%
	3000 to 4500 yuan	214	28.54%
	Over 4500 yuan	250	33.13%

3. Research Hypotheses and Structural Equation Model Construction

3.1 Theoretical Basis and Research Hypotheses

The Technology Acceptance Model (TAM), developed by Davis in 1989, is based on the Theory of Reasoned Action (TRA) and the Theory of Planned Behavior (TPB). Its core constructs include Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Subsequent research (Venkatesh V et al., 2000; Chang I et al., 2007) expanded the theoretical framework by incorporating external variables such as Social Influence (SI) and Facilitating Conditions (FC), significantly enhancing the model's explanatory power regarding the adoption behaviors of emerging technologies. Domestic scholars, such as He Ke et al [12]. (2013), successfully revealed the behavioral decision-making mechanisms of farmers in the carbon reduction utilization of biomass resources using an improved TAM model. This study will be based on the expanded Technology Acceptance Model to construct an analytical framework for the adoption behaviors of biomass energy development and utilization suitable for the Chongqing region (see Table 2). It aims to systematically explore the key factors influencing the Use Intention (UI) of relevant parties and their pathways of influence.

Perceived usefulness (PU) refers to the subjective perception of relevant stakeholders regarding the benefits that can be gained from using biomass energy. The use of biomass energy can bring multiple benefits, including economically increasing income, such as participating in the collection, transportation, and production of biomass raw materials; environmentally reducing pollution and alleviating the energy crisis; and socially responding to the "dual carbon" goals to gain social recognition. If relevant stakeholders believe that the use of biomass energy helps enhance economic, environmental, and social benefits, their intention to use it will strengthen. Based on this, we propose Hypothesis 1: The stronger the perceived usefulness, the stronger the stakeholders' intention to use biomass energy.

Table 2. Variable Design Table

Perceived usefulness	Code	Questionnaire item description
Social value	SV1	The use of biomass energy is easy to be accepted and recogni-zed by

	SV2 SV3 SV4	society Using biomass energy can save resources, reduce pollution and alleviate energy crisis Developing straw bio-mass energy indus-try can improve the local ecological envi-ronment Using biomass energy can respond to the "two-carbon" goal
Sentimental value	EV1 EV2 EV3	The use of biomass energy can reflect a green and environmen-tally friendly lifestyle
Functional value	FV1 FV2 FV3 FV4	The process of using biomass energy is safe and renewable
Perceived ease of use	Code	Using biomass energy gives me a clean and hygienic experience
self-efficacy	SE1 SE2 SE3 SE4 SE5	Participate in the collec-tion, transporta-tion and production of biomass energy raw materials to bring eco-nomic income
Instrumental cognition	UT1 UT2	Using biomass boilers to generate electricity is more energy efficient
Attitudinal willingness	Code	Using biomass boilers to generate electricity is cleaner and more envi-ronmentally friendly
Hold an attitude	AUT1 AUT2 AUT3	Questionnaire question type description
Willingness to use	AU1 AU2 AU3 AU4	I am interested in biomass energy

Perceived ease of use (PEOU) refers to the subjective perception of relevant stakeholders regarding the effort required to use biomass energy, including the difficulty of understanding biomass energy technology and the availability of technical support. Beyond expectations of benefits, the ease of participation also impacts the intention to use, and perceived ease of use can influence perceived usefulness (Zhou et al., 2014) and, consequently, the intention to use. Therefore, we propose Hypothesis 2: Perceived ease of use has a positive effect on both perceived usefulness and the stakeholders' intention to use.

Attitude (AT) refers to the overall evaluation and emotional tendency of individuals toward a specific object. Within the framework of the Technology Acceptance Model (TAM), attitude is seen as a mediating variable between perceived usefulness (PU) and perceived ease of use (PEOU) and the intention to use (UI). This study is based on the practical context of biomass energy development and utilization in Chongqing and combines TAM theory to propose the hypothesis that attitude has a direct influence on the intention to use, while exploring its relationship with perceived usefulness and perceived ease of use.

Intention to use (UI) refers to the willingness of relevant stakeholders to use biomass energy. In Chongqing, the models for biomass energy development and utilization mainly include: one, a business-centered approach, such as certain agricultural enterprises that purchase straw and other biomass raw materials to process into biomass fuels for sale; and two, a pilot project led by administrative agencies that promote biogas projects in rural areas to provide clean energy for farmers. This study focuses on the intention to use biomass energy by relevant stakeholders in its development and utilization, covering both energy developers and users' acceptance and willingness to apply biomass energy.

3.2 Structural Equation Model Construction

The Structural Equation Model (SEM) is a statistical method that simultaneously handles multiple dependent variables and is suitable for analyzing complex relationships among latent variables in fields such as psychology, sociology, and economics. SEM includes two components:

- Measurement Model:

$$Y = \Lambda y \eta + \varepsilon, \quad X = \Lambda x \xi + \delta \quad (1)$$

- Structural Model:

$$\eta = \Gamma\xi + B\eta + \zeta \quad (2)$$

Where:

- Y and X are vectors of endogenous and exogenous observed variables;
- η and ξ are endogenous and exogenous latent variables;
- Λ is the factor loading matrix;
- Γ and B are the influence coefficient matrices;
- ε, δ, and ζ represent measurement error and residual terms.

Following the TAM framework, this study identifies four core latent variables: perceived usefulness, perceived ease of use, attitude, and use intention, measured using 25 observed variables. These form the foundation for the questionnaire design and subsequent data analysis.

4. Model Testing and Data Analysis

4.1 Reliability and Validity Testing

Reliability testing evaluates the stability and internal consistency of the measurement tools. In this study, Cronbach's Alpha was used for reliability analysis. The overall Cronbach's Alpha for the model was 0.93, indicating excellent reliability. Each latent variable also had an Alpha coefficient exceeding 0.7, further confirming the consistency and robustness of the measurement instrument.

Validity testing assesses whether the instrument accurately measures the intended constructs. Confirmatory Factor Analysis (CFA) was conducted to evaluate both convergent and discriminant validity:

- Convergent validity: The Average Variance Extracted (AVE) values for all latent variables were greater than 0.5, indicating that the observed indicators well reflect the latent constructs.
- Discriminant validity: The square root of the AVE for each latent variable exceeded 0.70 and was greater than its correlations with other latent variables, indicating good differentiation among constructs.

4.2 Hypothesis Testing and Model Estimation

Using AMOS 17.0, the structural equation model was estimated and optimized. The final path diagram demonstrated that 11 out of 12 hypotheses were supported ($p < 0.05$) (See Figure 1). All significant path coefficients were positive, indicating a strong and positive influence of the five latent variables on use intention. The only insignificant path was from self-efficacy to functional value, suggesting that users' self-efficacy does not directly affect their perception of functional value.

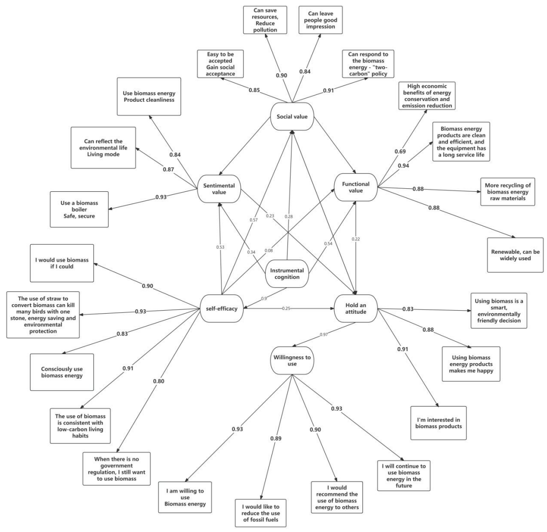

Figure 1. Structural Equation Model

The results highlight that:

- Users' attitude toward biomass energy has a decisive impact on their use intention.
- Perceived usefulness and perceived ease of use significantly and positively influence both attitude and use intention.
- There is a mutual influence between perceived usefulness and perceived ease of use.

Overall, the model demonstrated good fit across all key indices, confirming that the theoretical framework is well-aligned with the empirical data. Thus, the factors affecting use intention of biomass energy are validated and can be further used for strategic recommendations (see Table 3).

Table 3. Overall Model Fit Test

Exponential type	Fitting index	Threshold value	Results of this study	Whether the result conforms to
	CMIN/DF	0-5	4.271	Conform to
Absolute fit index	RMR	<0.05	0.045	Conform to
	RMSEA	<0.10	0.081	Conform to
	GFI	>0.85	0.86	Conform to
	NFI	>0.90	0.928	Conform to
	RFI	>0.90	0.917	Conform to
Relative fit index	IFI	>0.90	0.944	Conform to
	TLI	>0.90	0.936	Conform to
	CFI	>0.90	0.944	Conform to
	PGFI	>0.05	0.661	Conform to

Reduced fit index	PNFI	>0.05	0.808	Conform to
	PCFI	>0.05	0.821	Conform to

5. Research Conclusions and Recommendations

5.1 Research Conclusions

This study conducted a comprehensive investigation into the current state and influencing factors of biomass energy utilization in Chong-qing, offering valuable insights for future promotion and application.

In terms of influencing factors, the use intention of both biomass energy developers and users was found to be positively correlated with perceived usefulness, perceived ease of use, social value, emotional value, and functional value. Among these, perceived usefulness (coefficient = 0.973) and perceived ease of use (coefficient = 0.489) were the most significant. Improvements in biomass energy's effects—such as resource conservation and pollution reduction—enhanced users' perception of usefulness, while users' initial understanding of the technology and operational convenience contributed to perceived ease of use.

The results also showed a synergistic effect between social value and functional value. When biomass energy projects performed well in environmental protection and gained social recognition, they also tended to yield better economic benefits and employment opportunities—and vice versa—forming a reinforcing feedback loop that improved the overall value of the project.

To sum up, in order to promote the adoption of biomass energy more effectively, stakeholders should focus on enhancing both perceived usefulness and ease of use, and fully leverage its economic and social benefits. administrative agencies and enterprises are encouraged to invest more in technology R&D, policy support, and public awareness campaigns to accelerate the widespread application of biomass energy, thus contributing to energy structure optimization and sustainable development goals.

5.2 Recommendations for Biomass Energy Promotion

5.2.1 Strengthen institutional support – the role of administrative agency is crucial

A sound institutional framework is essential for effective policy implementation. In addition to favorable policies, supporting mechanisms play a key role in delivering real impact.

(1) Support the development of environmentally friendly enterprises: administrative agency should increase financial and policy support for biomass energy R&D and production enterprises, offering tax incentives or low-/zero-interest loans to help overcome technical challenges and encourage innovation.

(2) Implement price subsidy policies: Price subsidies, tax relief, and green credit mechanisms can be used to lower the usage costs for farmers and enterprises, thereby increasing their participation.

5.2.2 Improve strategic planning – build a shared development vision

During the formulation of macro strategies and policy targets for biomass energy development, it is important to include diverse stakeholders in the process—such as local administrative agencies, industry associations, corporate representatives, research institutions, environmental organizations, and the general public—to form a broad-based consensus.

5.2.3 Raise public awareness – improve societal recognition of biomass energy

The success of biomass energy development depends heavily on public awareness and support. The administrative agency should invest in public communication by launching dedicated websites, producing public service announcements, and organizing lectures, exhibitions, and forums to improve public understanding.

Surveys showed that many enterprises value technology and community relations, and are willing to cooperate with farmers. Strengthening enterprise-farmer coordination could lead to a vertically integrated value chain. Enterprises should also listen to public opinion, diversify communication channels, establish feedback mechanisms, and increase transparency to gain public trust and support for biomass energy.

Additionally, local administrative agencies should:

- Accelerate outreach through village committees and local representatives;
- Increase subsidies for raw material collection;
- Provide training to community staff;

- Optimize waste collection and logistics to prevent straw overstock or direct burning.

5.2.4 Strengthen R&D efforts – explore new “industry-academia-research” cooperation models

To effectively promote biomass energy in Chongqing, talent development and platform building must be prioritized. Regular technical training programs can be jointly conducted with local universities, inviting domestic and international experts to improve both theoretical knowledge and practical skills.

Close collaboration between research institutes, higher education institutions, and enterprises is encouraged to create a resource-sharing and complementary innovation ecosystem. This could be supported through administrative agency such as tax relief and funding programs that incentivize R&D and promote shared achievements.

Under the "industry-academia-research" model, students can help disseminate biomass energy policies in their hometowns after learning relevant knowledge at school, thereby laying a strong social foundation for policy implementation. Schools and communities are also encouraged to host science outreach events on biomass energy to further improve public understanding and support.

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