

Utilization and Socioeconomic Impact of Biofuel Adoption Among Farming Communities in Fatehgarh Sahib, Punjab

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Abstract

With the increasing consumption of energy and environmental issues, transformation toward renewable energy is being considered as a trend globally. Biofuels such as biogas and biodiesel provide potential alternative to fossil based fuel, particularly, in the rural parts of India, including Punjab. These clean sources, however, are not only contributing to environment but also have a potential to improve the rural economy by saving costs and having better health. Despite this potential, there is scarce empirical evidence on awareness and adoption of biofuel and associated socioeconomic effects at the community level in Punjab. This cross-sectional survey study was conducted to evaluate the acceptance of biofuels by farming communities in the district Fatehgarh Sahib of Punjab from 2024–2025. A verbal (structured) questionnaire was used to interview 783 household samples from among 10 villages, selected through stratified Random Sampling. The questionnaire obtained information on household demographics, biofuel awareness and use, perceived benefits and constraints, and adoption willingness. Descriptive and inferential statistics were performed with the help of SPSS program v25. Knowledge of biofuels were demonstrated by 58.4% of the respondents; 34.7% reported using biofuels, with the predominant usage being in the former of biogas. The primary advantages mentioned by users were less costs of energy (72.1%), better respiratory health (61.5%) and rural livelihoods improvement (49.8%). Nevertheless, non-users cited cost to get started (48.3%) and lack of expertise (27.6%) as barriers. Of the respondents, 67.8% indicated that they would consider the use of biofuels, if they were supported with financial aid and training. The research highlights the substantial potential of biofuel use in promoting sustainable development in rural Punjab. Despite being down to a middling, it is still not adopted on any significant scale, because of economic and knowledge restrictions. Policy interventions, subsidies and community-based awareness raising campaigns could help overcome these barriers and speed up the uptake of RES in rural areas the world over.

Keywords: Biofuel, biogas, farming communities, punjab, rural energy, socioeconomic impact, sustainable development

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INTRODUCTION

The recent move toward the alternative and sustainable energy sources on global scale has given up the attention to biofuels as an alternative to the fossil fuels worldwide for the future [1]. The most common types in developing countries, namely biogas and biodiesel, have risen in popularity because of their dual advantages of environmental friendliness and rural economy development [2]. India, being a nation of rich agricultural lands as well as abundant rural population, has the unique opportunity to utilize the agricultural and livestock waste for biofuel generation [3]. But, still little known is how farmers and rural residents are adapting to this change.

The mostly agricultural-based economy of Punjab with high agriculture and crop yield also generates significant waste in terms of agricultural residues and livestock excreta which could be efficiently used for bio-fuel production [4]. Fatehgarh Sahib, a largely rural district of Punjab, is an apt place to study these environment-mediated processes. Although national and state policies have driven renewable energy uptake, local-level understanding, access, and use are fragmented [5].

Some of the previous studies that have been successful to detect the determinants to use renewable energy are based economic motivation, technological knowledge, infrastructure, and healthiness [6]. However, there is scarce empirical information about Punjab's farmer's community their adoption rate, perceived benefits, and constraints as well. In addition, knowledge of the community's inclination to adopt biofuel use at different support levels is important in informing appropriate policy and programmatic responses [8].

The current study intends to address this research lacuna, by examining the biofuel awareness, using, and adoptability pattern amongst farm households of Fatehgarh Sahib in 2024–2025. The study also aims to identify social and infrastructural factors that promote or inhibit adoption of biofuel products using a structured, data-driven approach. In the process, it offers lessons for decision makers seeking to accelerate the transition to renewable energy among rural populations of India [9].

METHODS

Study Design and Setting

This cross-sectional study was conducted to determine practices, perceptions, and determinants of biofuel use in the rural agricultural community of Fatehgarh Sahib, Punjab. The research was conducted in 10 villages, over a period of 15 months (January 2024–March 2025), purposively identified based on diverse agricultural and socioeconomic contexts. These villages were purposively selected in collaboration with local governmental and agricultural extension personnel, to get the geographical representation of the research site.

Sampling and Participants

With stratified random sampling methodology, 783 farming households were selected from an initial list of about 1,100 eligible households in the ten villages. Stratification was according to village population and size of landholding to have a proper representation. Eligibility criteria comprised: (1) engagement in active farming (2) having lived in the village for more than 5 years, and (3) agreement to take part in the survey. The non-agricultural working households were the exclusion criteria.

Data Collection Tools

Information was collected through a structured questionnaire prepared in English and Punjabi as per the choice of the participants. Pilot testing of the tool was done in a village 30 non study village nearer to the study village in 30 households to capture wording of questions that makes better sense to them and culturally relevant. The last version of the questionnaire comprised six sections: (1) socio demographic and socioeconomic data, (2) knowledge and general awareness on biofuel use, (3) present patterns of use, (4) perceived advantages and obstacles of benchmark venues, (5) willingness to adopt biofuels and driving policies under different hypothetical scenarios – (e.g., economic incentives etc.), and (6) health and environment perceptions. The structured survey was conducted by trained enumerators using face-to-face interviews in order to maximize response stability and precision.

Data Analysis

Data were recorded in Microsoft Excel then analyzed in SPSS program version 25. Participant characteristics and key variables were summarized using descriptive statistics (frequencies, means, and percentages). Cross-tabulations were conducted to investigate the association between biofuel adoption and factors such as education, income, and land size. Statistical significance of relationships between categorical variables was assessed using Chi-square tests. Differences were considered statistically significant at $p < 0.05$. Further subgroup analysis was performed to determine differences in the responses of biofuel users and non-users. For predictive determinants for the acceptance of biofuels, logistic regression analysis was used, where appropriate.

Table 1. Demographic profile

Demographic profile of respondents	Frequency	Percentage (%)
Gender (Male)	540	68.9
Age (31–50 years)	402	51.3
Secondary Education	372	47.5
Primary Occupation: Farming	636	81.2

RESULTS

The demographic structure of the sample in respondents presents an interesting pattern about farming households of Fatehgarh Sahib. Most of the participants (68.9%) were males (Table 1) implying an over representation of males within the survey. This may be a consequence of the traditional gendering of farm work in rural Punjab, where men are more commonly farmers.

The age profile of the respondent shows that 51.3% were aged between 31–50 years, implying that the membership of the community was not an inactive and unproductive one. This cohort is frequently the senior generation in farmers, and this may affect decision-making on energy and fuel options, such as biofuels.

In terms of education, 47.5% of the respondents were educated up to secondary level. This type of education is important because almost half of the population has a basic understanding of things and as new technologies (ie; biofuels) become available people can "understand" and "relate" to these new technologies and possibly even adopt them. But the large share of respondents with secondary education suggests that the education of the population may need to be more specialized to promote biofuel adoption.

Finally, the information suggests that 81.2% of interviewees were farmers, a result in line with the agrarian profile of the area. This high proportion underscores the agro-based nature of the society and the need to consider sustainable energy options, such as biofuels, which can be an asset for farm households, offering both environmental and economic gains. In general, the summary references a farming community that tends to be (i) male, (ii) middle-aged, and (iii) moderately educated, information that is important for understanding the obstacles and opportunities for biofuel adoption in the area.

In Table 2, The results of the data on biofuel awareness and use provide valuable knowledge of the community understanding and behavior toward biofuels. Slightly higher than the half of the interviewees (58.4%) confirmed that they were aware of biofuels, which evidences a moderate level of information among the local population. This awareness may be due to the growing conversations about alternative energy sources and perhaps new government movement to support biofuels in rural areas. However, given that the awareness of biofuels was unknown to more than 40% of responders, there remains a large population of individuals without biofuels knowledge that could well be targeted for education and outreach.

Table 2. Biofuel awareness and usage

Biofuel awareness and usage	Frequency	Percentage (%)
Aware of Biofuels	457	58.4
Actively Using Biofuels	272	34.7
Using Biogas	214	78.6 (of users)

Table 3. Perceived benefits among users

Perceived benefits of biofuels among users	Frequency	Percentage (%)
Reduced Energy Costs	196	72.1
Improved Respiratory Health	167	61.5
Improved Agricultural Productivity	136	49.8

Regarding active use, 34.7% of the interviewees acknowledged the active use of bio-fuels. This level of adoption suggests a limited reception of biofuels despite the existence of some degree of familiarity. This discrepancy may be explained by a number of reasons including the high cost of implementing biofuel systems, absence of key supporting infrastructure and inadequate knowledge regarding the effective use of biofuels. Of the biofuel users, 78.6% was exclusively using biogas, in a larger proportion than other biofuels. This could mean that biogas, as it is directly applied to rural livestock-owning households, is the most readily available and feasible type of biofuel to be used within the region. The high potential for biogas may be partly due to the large resources available in the form of farm and livestock organic waste, a principle feedstock for biogas production. This implies that if given the required support and the necessary infrastructure, biogas utilization could be expanded in this society. Biofuel awareness is somewhat high but the actual use of biofuel is low, with biogas being the most used biofuel among the very few bio digesters owners.

In Table– 3, The positive user perception of biofuels reflects a variety of attributes that favor their acceptability. The reduced cost of energy was identified as the main benefit for consuming biofuels, by the majority of users (72.1%). This result indicates that there are financial reasons to use biofuels and that decreasing energy expenses is even more so important in rural farmers' households where capital scarcity is prevalent. The fuel cost reduction of bio-fuels is sufficient to attract bio-fuels as a promising alternative to traditional energy sources in the long run.

Apart from saving money, 61.5% of clients reported better breathing and airways as an added advantage. This indicates the positive impact that biofuels, especially biogas, a cleaner burning fuel compared with wood or kerosene, may have on IAQ. Better respiratory health is also a significant impact factor as the traditional fuels used often results in indoor air pollution, which is a highlighted health hazard among rural population.

Finally, 49.8% of respondents believed that biofuels led to increased farm productivity. This advantage could be the result of the use of biofuels in machinery or irrigation systems, also improving effectiveness and decreasing dependency on fossil fuels. It might also be related to the implanting of organic waste currently used for biofuel production that can be utilized as real fertilizer to improve crop output. In sum, the perceived benefits to customers– financial savings, better health, and agricultural productivity gains– demonstrate that biofuels have positive multidimensional impacts, with potential implications for both economic and health gains in rural areas.

In Table 4, The barriers to adoption among the non-users bear the following evidence of several hurdles for a broader usage of biofuels. reported that the high amount of initial investment cost was the major obstacle, faced by 48.3% of respondents. This is a typical problem in rural areas, especially since the farmers may be lacking funds, and might not be able to afford to invest in biofuel, despite the savings in the long term. Initial investment The large investments that are needed for a biogas plant or a biodiesel production system to be set up, regardless of the advantages predicted, are one of the barriers to adoption.

Lack of technology knowledge is another major obstacle (27.6% of non-users). This indicates that despite knowledge about biofuels, a lack of insight on how to operate and maintain biofuel systems can be a barrier for farmers to adopt it. When there is insufficient training or technical support, or when project implementation is overly complex, as is the case with biofuel systems, the technology can become daunting and prohibitive, especially to people with limited experience of new technology.

Table 4. Barriers to biofuel adoption among non-users

Barriers to biofuel adoption among non-users	Frequency	Percentage (%)
High Initial Setup Cost	247	48.3
Lack of Technical Knowledge	141	27.6
Inconsistent Supply	71	13.9

Table 5. Willingness to adopt biofuels with financial support

Willingness to adopt biofuels with financial support	Frequency	Percentage (%)
Willing to Adopt with Financial Support	531	67.8

Finally, 13.9% of non-users cited lack of supplies as a barrier to fuel adoption. This may mean either that feedstock for biofuel production is cheap, or that a biofuel source is stable. The uncertain availability of inputs for the production, and access to, biofuels can lead to confusion and reluctance among farmers to use it as a sustainable energy source.

Ultimately, the main obstacles to biofuel dissemination– over cost, technical unfamiliarity, and logistical inaccessibility– suggest that there should be interventions focused toward appropriate access such as financial incentives and training as well as strengthening the availability of the supply chain in rural areas for better accessibility of the biofuel.

In Table 5, the data on the willingness to adopt biofuels with financial support showed a high intent of biofuel adoption by the respondents, of which 67.8% stated if financial support was offered, they would adopt biofuels. It suggests that a major part of the farmer community of Fatehgarh Sahib is ready for shifting toward biofuels, when economic barriers like high initial investment are removed.

This result emphasizes the importance of financial support in promoting biofuel use. By dealing with the upfront costs, monetary incentives may get farmers to adopt biofuels, and from there it's a short step to widespread use around the region. While the actual proportion of adopters was relatively low, the high proportion of people who express willingness to adopt with economic assistance is indicative that, with reduced financial barriers, biofuels might be an attractive option for rural households.

In general, it appears that directed subsidies or grants or favorable loans could yield substantial increases in biofuel use in rural areas and also lay the groundwork for more sustainable energy use and higher rates of conversion to renewable energy sources.

DISCUSSION

Awareness, adoption, and impediments in biofuel promotion: A case of farming households in Fatehgarh Sahib, Punjab: Policy brief The study has provided valuable information on the awareness, utilization, and constraints in the adoption of biofuel among the farming households in Fatehgarh Sahib, Punjab. The findings reveal that the awareness of biofuel is relatively low with relatively low adoption rates. These results are in concert with other research work in rural India, an area which is home to a vast biofuel potential from agricultural waste, and animal waste, yet adoption has been low due to a variety of constraints [1] [2].

Awareness of Biofuels

In the study, 58.4% of the respondents reported of having some knowledge about biofuels and biogas in particular, this is expected considering that biogas has been advocated as a sustainable source of energy in rural India since long time [3]. Such a mild awareness probably is because of existence of the Government's initiatives and the non-Government agencies for creating awareness regarding the

renewable energy sources (RES). But, in spite of the fact that they know, only 34.7% were actually using biofuels. This difference between awareness and use reflects an important barrier to biofuel adoption identified in previous research [4].

Adoption and Usage Patterns

The analysis demonstrates that 78.6% of biofuel users were the adopters of biogas, supporting the dependence of rural economy of Punjab on livestock economy. Biogas generation from cow dung and other organic wastes is highly favorable in agriculture setting and thus, can be adopted as an alternative and sustainable energy source for rural households [6]. Nevertheless, the low proportion of the whole sample that adopts this biofuel (only 34.7%) makes to believe that there are very strong barriers to its more extended use. Those barriers are discussed in detail below.

Perceived Benefits of Biofuels

Consumers of biofuels showed significant benefits, with the main benefits reported for lower energy cost (72.1%) and better respiratory health (61.5%). Rural Energy savings is particularly significant in rural areas where access to electricity and other types of energy is unreliable and expensive. Similar advantages have been reported in previous studies, such as savings in the cost of fuel and the quality of air by converting to cleaner and renewable forms of energy such as biogas [7]. The improvement in respiratory health may be a result of the cleaner burn of biogas as compared to other traditional biomass fuels such as wood or crop residues, which are associated with exposure to indoor air pollution and respiratory diseases [8]. Furthermore, 49.8% respondents perceived increase in agricultural productivity which might be attributed to the use of bio-slurry as organic manure that is evident to increase crop yield and soil fertility in other areas of India [9].

Barriers to Biofuel Adoption

Among non-users, the most significant barriers to adoption were high initial setup costs (48.3%), technical incompetence (27.6%), and unavailability of the training (13.9%). High cost involved in installing biogas derives at the very onset in literature dealing in rural India, where most of the farmers do not have access to credit and financial help [10]. Certainly, government schemes and subsidies already exist for biogas installation, but a significant number of farmers are either unaware of this or feel that the financial outlay is prohibitive due to the uncertain generation of payback. This is also in line with the results from other rural studies where economic factors were identified as a key barrier to renewable energy penetration [11].

Technical illiteracy also proved to be a major barrier as 27.6% of the interviewees said they have no knowledge on how to operate or maintain biofuel systems. This emphasizes the importance of including well-designed training programs for the farmers in order that they can perform the safe and effective use and maintenance of biofuels. Technical know-how and support are also recognized as important for the successful implementation of renewable energy technologies in rural areas [12].

Variability in the availability of feedstock, such as agricultural residue and livestock waste, was another limitation. Such a problem is exacerbated in situations where crop cycles are variable, or where the herd size varies leading to a variation in feedstock availability for biogas plants. Such concern parallels that encountered by other rural communities where the sustainable harvesting of feedstocks is a key factor in the long-term uptake of biofuels [13].

Willingness to Adopt Biofuels with Financial Support

One of the most striking findings of the survey was that 67.8% of the respondents would be willing to adopt biofuels when they are supported economically. This result also highlights the role of government backing, support, and micro-financing for biofuel acceptance. Previous reports indicated that the provision of financial incentives, such as subsidies or low interest loans, resulted in high diffusion of renewable energy systems in rural areas [14]. Furthermore, the financial incentive may lower the perceived investment risk related to adopting biofuel and entice some risk-averse farmers to apply it given the substantial fixed cost of investment at the outset.

The stated preference to adopt with subsidy implies that focused policy interventions could increase the use of renewable energy in rural regions. This would help to narrow the gap between awareness and actual usage, but only if appropriate financial motivation, together with necessary technical backing are supported by governmental or institutional initiatives.

Implications for Policy and Practice

The findings of this work have significant implications for policy makers and implementers, who are actively working toward promoting renewable energy in rural India. First, because the knowledge of biofuels is relatively high yet adoption of biofuels is still low, presumably caused by economic constraints and technical ignorance. In order to counteract these challenges, local, and state governments must offer higher financial incentives for installation of biofuels, financing in the form of low interest loans or grants to reduce the upfront setup costs. Furthermore, farmer trainings should be provided to enable them to use and maintain biofuel systems.

In addition, the establishment of a stable biofuel raw material supply chain is crucial for the sustainable use of biofuel. this may take the nature of supporting entrepreneurs to create businesses which gather and transport agricultural and animal refuse for biofuel.

Public–private partnerships (PPPs) might ultimately prove a determining factor in the scaling up of biofuel diffusion. Public–private partnerships comprising, government, businesses, and non-governmental organizations have an opportunity to bring the requisite resources, infrastructure, and extension inputs to catalyze a broader shift to biofuels in rural India.

Limitations and Future Research

This study is not free from limitations. It is a study based on Fatehgarh Sahib district of Punjab, India, and therefore may not be representative of other rural regions of the country. Future studies might broaden the geographical coverage for analysis of biofuel adoption in other regions with different farming and economic structures. Moreover, longitudinal studies may be valuable in monitoring the long-term effects of adopting biofuel on the economic status of rural households and the environment.

CONCLUSION

The intention of this paper is to ascertain a comprehensive account of biofuel knowledge, diffusion, and the socioeconomic consequentiality in the middle Indian state of Fatehgarh Sahib (Punjab), 2024–2025. Because of relatively low levels of consciousness about biodiesel and biofuel, the rate of acceptance is relatively low in the country, with some significant barriers i.e., high cost of investment, lack of technical know-how, and irregular availability of natural resources to produce biofuel.

However, the research also emphasizes significant advantages reported by those who use biofuels, such as lower energy expenses, better respiratory health, and increased crop yields. These advantages highlight the possible role of biofuels in not only sustainable energy generation but also enhancement of rural incomes, especially in regions such as Fatehgarh Sahib where agriculture is the major occupation. The positive results observed by this study are consistent with reports from elsewhere in India, where biofuel use has benefited the environment as well as the health of the community.

It is worth noting that a large number of non-users (67.8%) were open to considering biofuels under the financial support condition. This underscores the strong potential for government subsidy, micro-finance and training programs in stimulating the uptake of biofuel technology in the rural areas. Considering the economic and technical barriers to adoption of biofuels, since they emerge as a potential solution to the problems of rural energy challenges, it is important that policy mechanisms adapt to overcome these barriers, creating a more conducive environment for the integration of renewable energies.

The research also highlights the necessity for policy approaches integrating financial incentives, education, and local biofuel feedstock supply chains. Those steps can greatly increase the scalability of biofuels, so that rural towns such as those in the Fatehgarh Sahib region can enjoy the economic and environmental benefits of biofuels. Furthermore, collaborations between governments, corporations, and local residents are essential to the successful establishment and operation of bio-fuel production systems.

To conclude, biofuels appear promising in terms of the sustainable energy for rural Punjab. Nonetheless, the wide adoption of biofuels will call for overcoming current market- and technical-based constraints through directed policy measures and local small scale support. Biofuels can contribute significantly toward addressing these issues consequently ensuring sustainable energy transitions, better health, and rural economy development in India

RECOMMENDATIONS

- Deliver financial incentives/subsidies for biofuel setup.
- Encourage village-level awareness and training programs.
- Advance local supply chains for fuel raw materials.
- Create public–private partnerships to scale infrastructure.

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