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Integrating Artificial Intelligence and Mixed-Methods Research: A Framework for Enhancing Data Analysis and Interpretation in Environmental Science

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Abstract

It has been debated that to enhance data interpretation, and improve knowledge of environmental phenomena, Artificial Intelligence (AI) and Mixed Method Research (MMR) implementation and integration is of great value. However, not much is known about its actual use with environmental science data. Hence, the main aim of this study was to demonstrate how MMR and AI can improve environmental science data interpretation and analysis. The study adopted a case study titled "Willingness to Accept and Use Biogas Generated from Animal Manure and Agricultural Residue among University Students in Ghana" as the research that generated the data. A sequential explanatory MMR design was adopted. The survey collected data from (N= 231) and 5 in-depth interviews from Ghanaian University students. Through this study, it was found that majority of university students 112 (48.3%) are willing to install biogas in their future and homes and also 101(43.5%) are currently willing to use the energy. Again, the results showed that to integrate AI for a better understanding of environmental science research, researchers must first have a solid understanding of how to conduct MMR and obtain a reasonable picture of the main findings of the research conducted using statistical tools. Furthermore, the study found that AI was able to establish a relationship between both qualitative and quantitative data in an innovative way that provided answers to environmental issues, based on the results of the case study that was used. Additionally, the researcher must endeavor to supply appropriate prompts, the dataset, provide the framework that will guide the AI for enhanced data interpretation.

1. Introduction

Since its inception in 1956, artificial intelligence (AI) has become increasingly influential across various research methodologies [1]. The recent advancements in AI, particularly generative AI (Gen AI), offer innovative ways to streamline research processes, making studies efficient and accessible to a broader range of researcher [2]. While AI and Machine Learning (ML) are sometimes used interchangeably, ML refers explicitly to a subset of AI focused on statistical algorithms that enable systems to learn from data, identify patterns, and make decisions [3]. The broader field of AI encompasses ML and includes systems designed to simulate human intelligence. This distinction is relevant as environmental science researchers explore how AI can enhance MMR's capacity to analyze complex ecological datasets. In Sidney Dobrin's book, AI and Writing, the author espouse many benefits of AI and indicates that AI can provide services on research models and the opportunities for their application are diverse. Considerably, earlier systems of AI were syntax-based, modern AI applications have progressed to user-friendly interfaces, allowing researchers to engage more interactively with data. This ease of access brings

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a profound advantage to data interpretation, enabling faster and potentially more insightful analyses [4, 5]. Previous studies on AI use include Doorn [6]; Haupt, [7]; Oruganti et al. [8]; Rustam et al.[9];Van Wynsberghe,[10] mostly addressed the use of AI in waste management, sustainability, water management, earth observation, and the history of AI respectively. However, there are concerns regarding the increasing role of AI in research, especially in academic contexts. Scholars argue that AI's potential for producing irrelevant publications could overwhelm the educational landscape, diluting scientific integrity and prioritizing quantity over quality [11,12]. Meanwhile, AI systems frequently exhibit exceptionally high performance, but they are constrained in their capacity to offer insightful justifications for their judgments and choices [13,14]. Additionally, they are prone to biases and brittleness, which can have a detrimental effect on their perceived credibility[15, 12]. Consequently, as urbanization and socioeconomic growth accelerate, their environmental impacts become increasingly complex and multifaceted. Analysing these effects requires advanced data analysis techniques beyond conventional statistical tools, as ecological science research now generates vast and complex datasets[16]. In this context, Artificial Intelligence (AI) and Machine Learning (ML) offer powerful tools for processing and interpreting large-scale data, enabling researchers to make better-informed decisions for policy and environmental management [17]. Generally speaking, environmental science research aims to ensure the sustainability of natural resources, reduce over-exploitation, drive policy direction, contribute to decision-making, increase awareness, and make the environment safe. The combination of Mixed Methods Research (MMR) and AI stands a chance of contributing to discoveries in environmental science. Recent studies indicate a growing trend in using MMR across various fields, emphasizing its flexibility and comprehensiveness [18, 2].

Considering the vast benefits associated with the use of MMR, such as its ability to offer a firm structure for directing many multifaced issues in research, the potencies of one approach counterbalancing the weakness of the other, the innate ability of MMR answering questions that a single method cannot because one data source may be practically insufficient, the fact that this method offers interdisciplinary collaboration and the opportunity of gaining a more comprehensive and convincing evidence for a phenomenon [19]. Chae & Davidson, [20] asserts that AI's adaptability may complement MMR by offering tools for "prompt engineering," where experimenting with different prompts enhances AI's predictive capabilities, as seen in text classification tasks and this holds a promise for environmental science research. For instance, AI has already been employed in environmental research for weather prediction and disaster forecasting, demonstrating its utility in high-impact, data-driven applications [21, 22, 23]. Combining AI's data-processing power with MMR's methodological depth offers a unique opportunity to generate nuanced insights supporting evidence-based policy-making. Despite its promise, integrating AI and MMR in environmental science research is still emerging. Some foundational studies such as Barros et al., [11]; Combrinck, ; [2] Pack & Maloney, [24] give insights into its practicality for adoption in environmental science research.

Following this, the dynamic nature of environmental science research position AI as a complementing factor that cannot be neglected when considering the use of large data that requires insights to support decision-making and policy implementation. Seminal studies on this subject(AI and MMR research) include Combrinck,[2], who highlighted the importance of generative AI in synthesizing and analyzing accurate data (in Social sciences) from University students in South Africa and underlined that Generative AI outputs are reliable. Despite the declared benefits of AI such as (predicting water quality, weather conditions, etc.), there still exists a gap in the integration of AI in environmental science research (waste to energy). Additionally, available information suggests that limited studies have proposed a comprehensive framework that guides the integration of AI and MMR, via a detailed case study. Hence, this study seeks to provide a roadmap for implementing the adoption of AI to enhance qualitative and quantitative data interpretation in waste to energy research. Subsequently, the aims of this study will be achieved by finding answers to these research questions (i) Can AI-enhanced mixed methods research mitigate the effects of data quality in environmental science research? (ii) Does integrating AI-enhanced mixed methods research influence the identification of causal relationships in environmental science phenomena?

The framework described below illustrates how environmental science research can benefit from artificial intelligence and mixed methods

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research to improve data interpretation and analysis.

2. Research Conceptual Framework

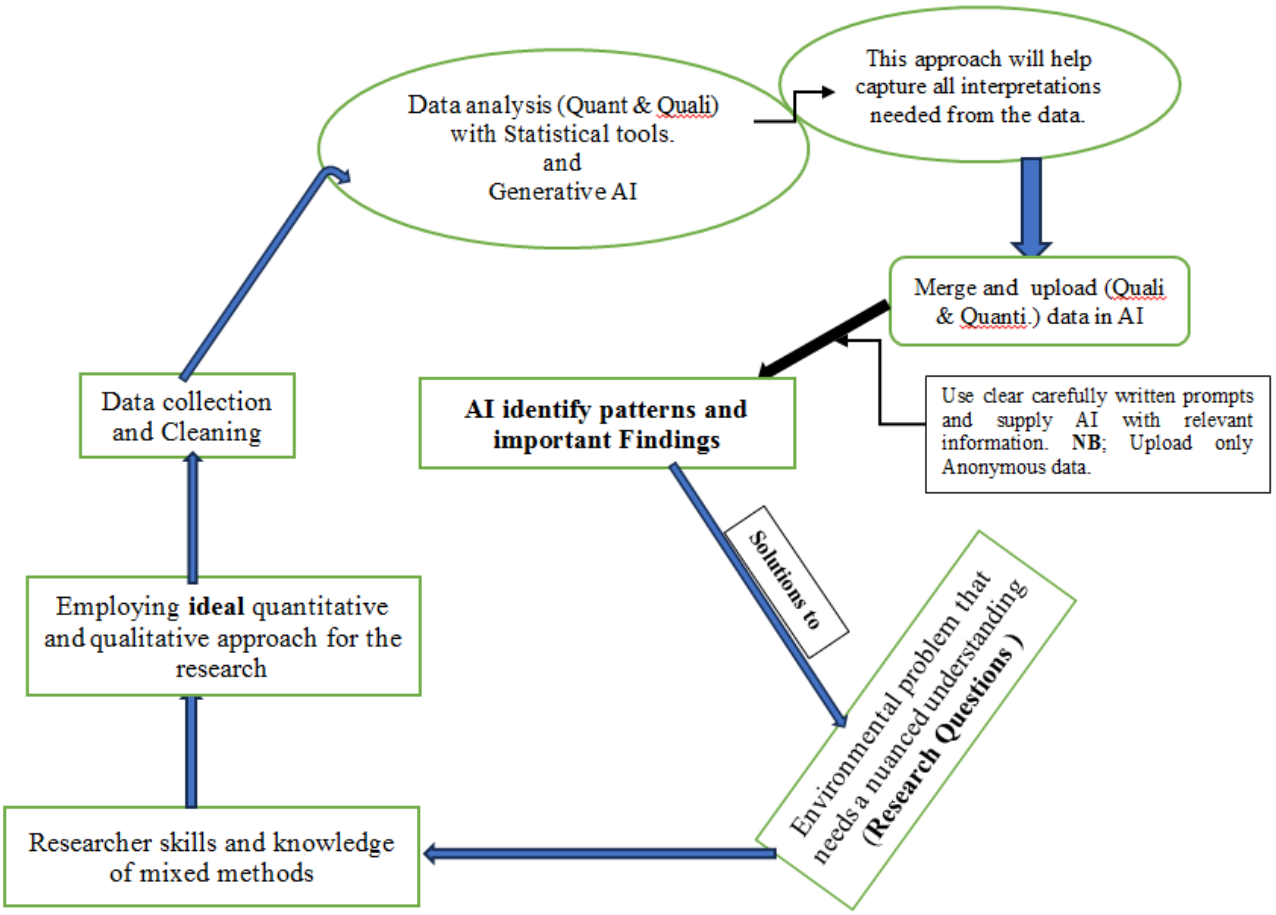


Figure 1. A framework for the integration of MMR and AI in Environmental Science research

According to this framework, an ecological issue or research topic may indicate the best method to gain a sophisticated understanding of the phenomenon. This framework emphasizes how crucial it is that the researcher has the know-how to carry out mixed methods research. The researcher also needs to independently analyze the data they have collected and look for trends. The researcher must transcribe all of the material to create themes from qualitative data. The researcher should, to the greatest extent feasible, provide detailed interpretations of the critical points in the data. The data is then presented to a generative AI after they have been composited for a more complex comprehension human intelligence might not have noticed. However, caution should be exercised in the use of responses submitted by AI; making sure it address the aim and objectives of the study. Hence, outputs should be thoroughly examined and carefully chosen.

3. Material and Methods

3.1. Research Design and Study Area

The data used in this study was obtained from a developed case study fashioned for this research titled "Willingness to Accept and Use Biogas Generated from Animal Manure and Agricultural Residue among University Students in Ghana." The research adopted a simple cross-sectional mixed-method approach for qualitative and quantitative data collection. At the same time, the MMR design adopted by this study was the sequential explanatory research design, which focuses on using qualitative data to explain quantitative findings of survey data [5]. This research sought to employ AI and MMR to enhance data analysis and interpretation in environmental science research(Waste to energy).

The study was conducted in Ghana. Ghana lies at the shore of the Gulf of Guinea in West Africa and occupies a total of 24 million (ha) with a population of 34.12 million. The country is divided into six ecological zones. In terms of education, the country has about 68 Universities

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which comprises of 16 public and 52 private Universities. In Ghana, only one in five persons (20.8%), 3 years and older have never attended school [25]. Currently, 40.7% of the population 18 years and older are currently attending tertiary education as the highest level attained and with a national literacy rate of 69.8%, [25]. Depicted below is the image of the study area adopted from Gumma et al.[27].

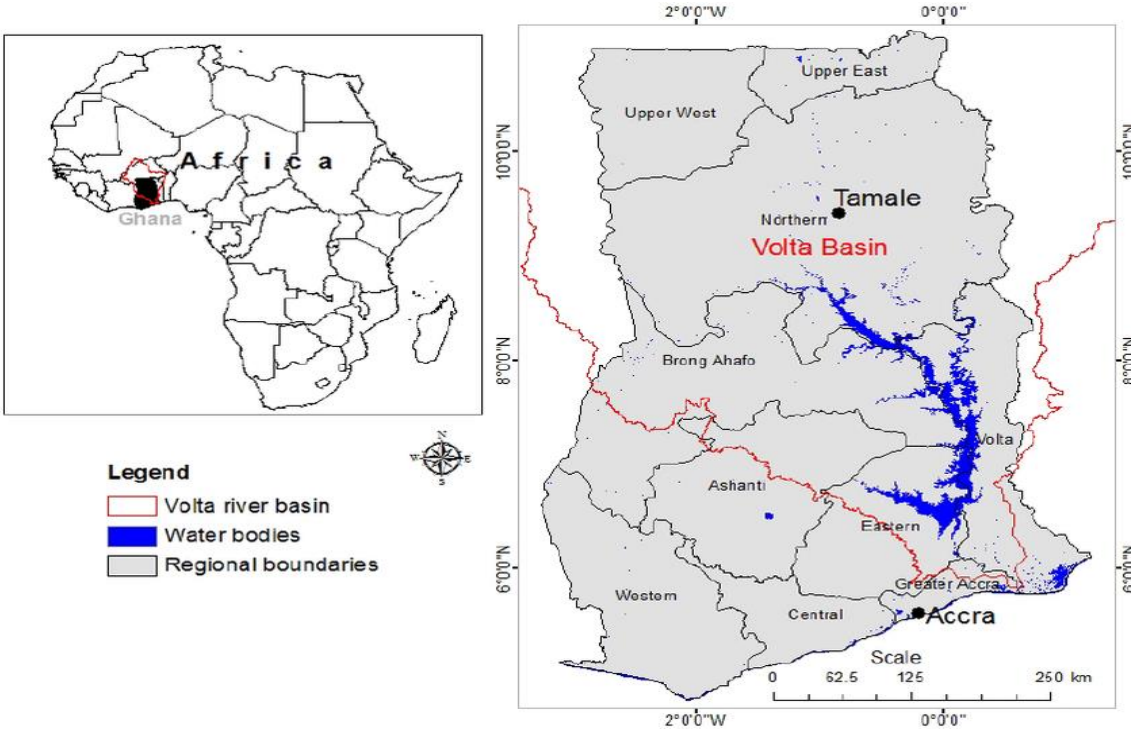


Figure 2: Map of Ghana (Adopted from Gumma et al. [27])

3.2. Sampling procedure and Sample size

The quantitative data were randomly collected from Ghanaian University students online nationwide. However, five (5) students participated in the in-depth interview using the snowballing sample technique. These students were from the University of Cape Coast. The reason for this selection was that students of the institution represented majority of the respondents and also because of their proximity to the researcher.

3.3. Data Collection

The quantitative data were collected using questionaries developed via a Google Forms survey which contained 14 closed-ended questions. They were shared online and contained sections on demographics, willingness to accept, and willingness to use biogas made from waste. The study collected 231 responses. The Qualitative data were collected using in-depth interviews for which the researcher designed a guide based on the quantitative data findings. The consent of participants was sought before they were included in the study. Five interviews were conducted using the interview questions below. The interviewees were 3 females and 2 males. These questions were based on patterns from the quantitative analysis in Tables 1-4. After transcription, the data was developed into four separate themes.

3.3.1. Interview Question

- Gender plays a significant role in determining willingness to use biogas. As a female, why do you think that is so?
- Many students from public universities like you believe that biogas energy can help offset gas expenditure. Why do you believe in this as a student?
- Would you support policies that promote the use of biogas because of its ability to prevent diseases? and why
- Can you suggest how biogas energy may be promoted among students in Ghana?

3.4. Data Analysis

The data quantitative data obtained from the case study research were cleaned and analyzed using SPSS (Statistical Package for Social

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Sciences) Version 21. Using inferential (Sperman's Rank coefficient, correlation, and Ordinal regression) and descriptive statistics. The qualitative data was transcribed using the Reflexive Thematic Analysis (RTA) [4]. This thematic analysis was selected because students' opinions on biogas may be multifaceted and influenced by factors such as religion, finance, and education, among others; hence, these complexities may be explained meaningfully using RTA. The final themes and write-up were then later completed by the researcher. The use of AI for the data analysis and interpretation was done according to [2] with modifications. An advanced data analysis chatbot called Chat GPT was used to perform some analysis. The data obtained after using the data analysis software were combined both qualitative and quantitative into a single-word document and uploaded to ChatGPT. Appropriate prompts to elicit the study goals and objectives were used to analyze the data.

4. Results

Results presented in the tables (1-4) below are descriptive and inferential analyses of qualitative and quantitative data gathered for this study on "Willingness to Accept and Use Biogas generated from Animal Manure and Agricultural residue among University students in Ghana." The study collected 231 responses from university students in Ghana. The reactions varied among students of different age groups in public and private universities. Out of the 231 respondents, 128 (55.3%) were female and while 103 (44.4%) were male. Majority of the participants of this study were within the ages of 21-25. They amounted to 110 (47.4%) out of the sampled population (Table 1). Whereas 59 (25.4%) were within the ages of 26-30 and the 16-20 years were also 36 (15.5%). Meanwhile, majority of respondents from this survey, were undergraduate students 176 (75.9%), where as 49(21.1%) were postgraduate students. Students from public institution reading science related programs were more than any other programs and the religion of that predominated the response landscape was Christianity. Students who were of science related background were 154(66.4%), with students from Social Sciences and Humanities accounted for 66 (28.4%). The public University students were 202 (87.1%), while private university students were 20 (8.6%). 227 (97.8%) of respondents were of Christian religion and 5 (2.2%) were of Islamic religion (Table 1).

Table 1. Demographics response of respondents

Category	Description	Percentage
Sex	Male	103 (44.4%)
	Female	128 (55.3%)
Age	16-20 years	36 (15.5%)
	21-25 years	110 (47.4%)
	26-30 years	59 (25.4%)
	Above 30years	27(11.6%)
Education	Undergraduate	176 (75.9%)
	Postgraduate	49 (21.1%)
Program of Study	Science Related	154(66.4%)
	Social Sciences and Humanities	66(28.4%)
	Business related	12 (5.2%)
University	Public University	202 (87.1%)
	Private University	20 (8.6%)
	Training Colleges	9 (3.9%)
Religion	Christianity	227 (97.8%)
	Islam	5 (2.2%)

Table two below shows the Spearman's rank correlation matrix developed for the data collected in this study. The values highlighted in red are significant. These values show a strong positive correlation among the variables of the study. The construct Biogas can offset gas expenditure was found to have a moderately strong correlation to another construct, such as Solid wastes_ environmentally hazardous, Willing to use such energy? Prevent public health-related diseases and Install biogas systems in future homes (Table 2). Students' willingness to use biogas energy was strongly positively correlated to understanding that the gas can prevent public health diseases and the desire to install the gas in future homes (Table 2).

From the cross-tabulation analysis of gender and willingness to use biogas, 128 respondents were females willing to use biogas with a Crammer's v = 0.255 and P-Value <0.05 = 0.000. From the cross-tabulation analysis, type of university and biogas can offset gas expenditure, 202 respondents were from public universities with a crammer's v = 0.224 and P-Value <0.05 = 0.000. From the cross-tabulation analysis, of type of university and biogas can prevent diseases of public health concern, 202 respondents were from public universities with a crammer's v = 0.219 and P-Value <0.05 = 0.00. Results in Table 2 below show the descriptive statistics gathered from respondents in the case study used for this study.

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The categories for measurement were if a student saw Solid wastes as environmentally hazardous, if they knew biogas energy could offset gas expenditure, what their gas expenditure was in a semester, their willingness to use the gas if they were available, and if they were willing to install this gas in their future home.

Table 2. Correlation matrix of biogas constructs and demographics

Variables	1	2	3	4	5	6	7	8	9	10	11	12
Education	1											
Program of study	0.131*	1										
University	-0.102	0.008	1									
Gas expenditure / semester	0.083	0.008	0.001	1								
Can biogas offset gas expenditure ?	-0.102	0.02	0.099	-0.13	1							
Solid wastes_ environmentally hazardous?	0.038	0.107	-0.01	-0.02	**0.328****	1						
Willing to use such energy?	-0.145	0.052	0.108	-0.06	**0.403****	**0.260****	1					
Prevent diseases of public health concern?	-0.13	-0.08	0.095	-0.11	**0.476****	**0.353****	**0.71****	1				
Install biogas system in future homes?	-0.043	0.015	0.057	-0.03	**0.360****	**0.162***	**0.61****	**0.528****	1			
Other benefits	0.001	-0.04	-0.00	0.072	0.076	-0.083	0.02	0.06	0.08	1		
Gender	0.076	0.021	-0.13	-0.10	-0.093	0.017	-0.15*	-0.107	-0.03	-0.03	1	
Age	0.451**	0.117	-0.11	0.07	-0.11	-0.051	-0.16*	-0.125	-0.03	-0.03	0.1*	1

**** P <0.01(2-tailed); *P < 0.05 (2-tailed) (N=231).**

Generally,s87(37.5%) and 63(27.2%) of respondents who were students from Ghanaian tertiary institutions agreed that Solid wastes are environmentally hazardous. However, 110(47.4%) and 104(44.8%) agreed that when these wastes are put to use, they prevent diseases of public health concern.

and that other benefits that could be derived from solid waste use were Fertilizer(227 (97.8%) (Table 3). Briquettes, Biochar and Construction materials (8 (0.5%). Majority of the participants agreed that when solid wastes are captured and treated, they are capable of offsetting gas expenditure. In numbers, 95(40.9%) and 107(46.1%) strongly agree and agreed to this assertion. When students were asked how much they spend in Ghana cedis on Gas, 91(39.2%) used < 200Ghc, while Ghc200-300, 60(25.9%) and > Ghc300 while 60(25.9%)(Table 3.0). Per, the response of the participants of this study, 101(43.5%) and 106 (45.7%) strongly agree and agree when asked if they were willing to use

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biogas energy. Meanwhile, many students agreed to Install biogas system in future homes. This was indicated by112(48.3%) and 114(49.1%) (Table 3).

Table 3. Descriptive statistics of Biogas constructs

Category	Description	Percentage
Solid wastes_ environmentally hazardous	Strongly Agree	63(27.2%)
	Agree	87(37.5%)
	Strongly Disagree	16(6.9%)
	Disagree	38(16.4%)
	Neutral	28 (12.1%)
Gas expenditure/semester	< 200Ghc	91(39.2%)
	200-300	81(34.9%)
	>300	60(25.9%)
Can biogas offset gas expenditure?	Strongly Agree	95(40.9%)
	Agree	107(46.1%)
	Strongly Disagree	3(1.3%)
	Disagree	4(1.7%)
	Neutral	23(9.9%)
Willing to use such energy?	Strongly Agree	101(43.5%)
	Agree	106 (45.7%)
	Strongly Disagree	13(5.6%)
	Disagree	2(0.9%)
	Neutral	10(4.3%)
Prevent diseases of public health concern.	Strongly Agree	110(47.4%)
	Agree	104(44.8%)
	Strongly Disagree	2(0.9%)
	Disagree	2(0.9%)
	Neutral	14(6.0%)
Install biogas system in future homes.	Strongly Agree	112(48.3%)
	Agree	114(49.1%)
	Strongly Disagree	5(2.2%)
	Disagree	1(0.4)
	Neutral	N/A
Other benefits	Fertilizer	227 (97.8%)
	Biogas	5 (2.2%)
	Briquettes, Biochar and Construction materials	8 (0.5%)
	Others/Don't Know	28(20.0%)

Demographics versus biogas construct ideas

From the cross-tabulation analysis of gender and willingness to use biogas, 128 respondents were females willing to use biogas with a Crammer's v = 0.255 and P-Value <0.05 = 0.000. From the cross-tabulation analysis, type of university and biogas can offset gas expenditure, 202 respondents were from public universities with a crammer's v = 0.224 and P-Value <0.05 = 0.000. From the cross-tabulation analysis, of type of university and biogas can prevent diseases of public health concern, 202 respondents were from public universities with a crammer's v = 0.219 and P-Value <0.05 = 0.00. Results in Table 2 below show the descriptive statistics gathered from respondents in the case study used for this study. The categories for measurement were if a student saw Solid wastes as environmentally hazardous, if they knew biogas energy could offset gas expenditure, what their gas expenditure was in a semester, their willingness to use the gas if they were available, and if they were willing to install this gas in their future home**.**

Qualitative findings

Theme 1: Kitchen responsibilities of women

Gender plays a significant role in determining the willingness of the use of biogas. The participants described that considering the whole construct, women spend much more time in the kitchen

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trying to fix food for themselves. At the same time, similar observation is seen in female students on campus than men. This desire make them more inclined towards energy or biogas to help them achieve this goal. "First of all, talking about biogas use, we have to go back to our homes when it comes to cooking and things that are in the kitchen and all this stuff. We say that women tend to have the upper hand.So I think that would be the reason ladies are more interested.Regarding our public universities, some guys do not even cook. So it doesn't bother them, but most of the time, the ladies are into cooking and all those type of things. That's why I think you got more response from the ladies than the guys" (Interview 2).

Theme 2: Cost Saving Means

Additionally, women perceive this alternate gas as beneficial, economical, and environmentally friendly. "Well, you can agree on that. When it comes to biogas, there are a lot of advantages over the normal gas. First of all, for money. Regarding what you have, I think the biogas will be much. It will be less expensive than the gas. And then, it's also environmentally friendly because what we use, we are renewing something to get another product from it." (Interview 2) "Students are more concerned about saving money. Biogas is obtained from natural waste, right? So if the person cooks and then they are left over on vegetables and whatever and the person can obtain gas from it, it's much better than taking and spending all your money on gas. Yes, that's what I think" (Interview 1). These responses feed into a construct that biogas energy can help offset gas expenditure.

Theme 3: Biogas improves sanitation

Another respondent highlighted that this whole narrative is firmly supported because "…I think the sanitation level here in public universities is low. I don't know, of private school However if we are able to collect all wastes in the environment, especially the organic substances in public universities into one point, trap the energy, then we may minimize the spread of contaminants from them…" (Interview 3). For example, another respondent indicates, "First, let's start with hygiene. Comparing public institutions to private sectors, I think they have more staff to take care of waste in their environment, but I just think we have a few when it comes to public aspects. Even those, that work there, they do it anyhow because there's no supervision…I think when you go to most of the public universities sanitation is sometimes a challenge because of the mass population. because there are no measures for them to comply when they go to the washroom. So I think that would be another." (interview 2 & 3).

Theme 4: Awareness creation program

Responses from participants indicate that biogas energy can be popular among Ghanaian students if efforts are made to"I think through conferences or webinars to tell them the benefits of using biogas and compare it with the gas we use to weigh the advantages. Yes, so through social media, we can go to the various programs and colleges to help them organize a conference" (Interview 3). Another respondent indicates similar to the other response: "…And then maybe we can even organize programs for them to come, and they will teach about it, give them the benefits and all that stuff. we can start from there…"(interview 5).

DATA ANALYSIS USING GEN A.I (CHAT GPT)

Prompt used: I have findings from a questionnaire and in-depth interviews. The results from the quantitative and qualitative analyses are attached. The results in words contain correlations and descriptive statistics. The Excel file includes results from ordinal regression of some constructs on the concept that biogas can offset energy and some on the willingness to use the biogas energy. Create a statistics-by-themes joint table that can be downloaded to Excel.

Table 4. Statistics by themes table generated from Gen A.I

Theme	Quantitative Findings	Qualitative Insights
Gender Influence on Biogas Willingness	There was a significant correlation ($r = -0.152$, $p < 0.05$) between gender and willingness to use biogas; female students showed higher inclination.	Women are more engaged in cooking and home management and are inclined towards biogas use.
Economic Benefits of Biogas	A significant correlation ($r=0.360$, $p<0.01$) between a belief that biogas offsets gas expenditure and future installation interest.	Students from public universities express a need for biogas due to cost savings and environmental concerns.
Health and Environmental	Significant correlations: Disease prevention	Biogas is perceived as a solution for

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Benefits	& willingness to use biogas (r = 0.476, p< 0.01); Disease prevention & future installation (r = 0.528, p < 0.01); solid waste hazard perception & willingness to use (r = 0.260, p< 0.01).	improving sanitation and preventing disease, especially in institutions with waste management challenges.
Public vs Private University Influence	Higher support among public university students for biogas offset gas costs and disease prevention (Cramér's V values of 0.224 and 0.219, p < 0.05).	Public university students emphasize sanitation issues, highlighting biogas's benefits in addressing waste and health concerns.
Awareness and Advocacy for Biogas	The survey shows high interest (89.2%) in biogas if awareness efforts are enhanced; qualitative themes suggest workshops, webinars, and social media as crucial strategies.	Students suggest targeted awareness campaigns using online platforms and campus events to promote biogas adoption.

MIXED METHODS RESEARCH WITH A.I (CHAT GPT)

Prompt used: I have findings from a questionnaire and in-depth interviews. The results from the quantitative and qualitative analyses are attached. The results in word document contain correlations and descriptive statistics. Please conduct a sequential explanatory analysis and help me identify patterns, achieve triangulation, and integrate the results. Write two pages based on your explanatory sequential analysis.

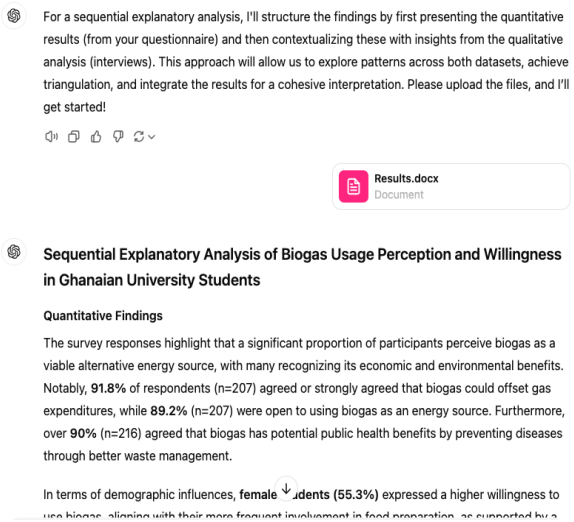


Figure 3. Image of Chat GPT conducting a Mixed Methods analysis based on compiled Quant and Quali data presented.

4. Discussion

The study used mixed-method research and artificial intelligence. As shown in Figure 3 above, the study employed a simplified methodology to investigate further the advantages of implementing the integration. One prominent finding from this study was that to fully comprehend the benefits of using AI and MMR, the researcher should thoroughly understand the phenomenon being studied, create suitable prompts, and examine the data independently using statistical tools. In the qualitative data, the investigator should extract specific patterns and themes relevant to the study's goals. Because the computer science adage "garbage in, garbage out" applies to using artificial intelligence (AI) to improve data processing [12]. Research by Combrinck, [2] advises that assisting AI with the necessary information specifics; the data, and its codebook most often generates the appropriate response. For instance, in this research, the researcher specified the exact analysis, the type of MMR to be used, and the content of the results in the prompts. The researcher modified the prompts' results and corroborated them with existing studies to meet the study objectives as described below.

The research survey outcomes show that a significant percentage of respondents believe biogas to be a feasible alternative energy source, with many acknowledging its financial and environmental advantages. Notably, 89.2% of respondents (n= 207) were receptive to employing biogas as an energy source, while 91.8% of respondents (n=207) agreed or strongly agreed that biogas might balance gas expenses (Table 2). Additionally, more than 90% of respondents (n=231) concurred that biogas may improve public health by reducing infections through improved waste management. Concerning demographic factors, a Cramér's V value of 0.255 (p < 0.05) indicated that female students (55.3%) (Table.1) were more eager to utilize biogas, which is consistent with their more frequent engagement in food preparation. This association implies that

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energy preferences are highly influenced by gender. This correlation suggests that gender significantly influences energy preferences. However, Gender and Biogas Willingness: Gender showed a negative but significant correlation with willingness to use biogas ($r = -0.152$, $p<0.05$), which was further explained by qualitative insights suggesting that female students are more inclined to adopt biogas for energy due to their roles in food preparation and home management. The findings of this research corroborate that of Van Aelst [27] they opine that in most countries, household chores are more inclined towards the female sex and even indicate that women are three times more involved than men. This pivotal role that they play as primary users tends to influence their sustainable transition towards energy saving in the household [29].

Females adopt cheaper or waste fuels to save household energy [29]. Nevertheless, students from public universities (87.1%) showed a greater belief in biogas's ability to offset gas expenditures (Cramér's $V= 0.224$, $p< 0.05$), potentially due to the more pronounced cost sensitivities or sanitation challenges in these institutions. The quantitative data also reveals positive correlations between beliefs in biogas's capacity to prevent diseases and willingness to use it ($r = 0.476$, $p< 0.01$), suggesting that the more participants see biogas as beneficial for health and the environment, the more willing they are to adopt it. This finding is in line with Arifin et al.[30]. The author asserts that using biogas reduces greenhouse gasses, prevents disease spread, and reduces unpleasant odors. This finding is further deepened by the strong positive correlation between belief in biogas's ability to prevent diseases and willingness to use biogas ($r = 0.476$, $p < 0.01$), confirming that health-related benefits influence students' attitudes toward biogas. This aligns with qualitative findings where students noted biogas's potential to enhance sanitation and reduce disease risks. Additionally, participants indicated a preference for future biogas installations in their homes, with 97.4% supporting this option.

On the concept of its public health benefits and future installation prowess in homes of students, the research indicates a strong positive correlation between belief in biogas's ability to prevent diseases and interest in future biogas installation ($r = 0.528$, $p< 0.01$); this reflects students' recognition of health benefits as a significant factor and its deeper meaning is further echoed in qualitative responses where students advocated for biogas's public health advantages, particularly in addressing sanitation issues in public universities. This willingness reflects strong support for biogas if it can mitigate financial burdens and environmental issues. Consequently, to the above, it was observed that a significant correlation was noted between the belief that biogas can offset gas expenditure and willingness to install a biogas system in future homes ($r = 0.360$, $p<0.01$), indicating that financial considerations strongly influence long-term support for biogas. This theme was reinforced by qualitative data, where students discussed biogas's cost-effectiveness as a critical motivator for adoption.

Overtly, the statistical analysis (Ordinal logistic regression) presented in table 5 and 6 below show the presence of a relationship between the dependent Variable (Biogas can offset as expenditure) and the combination of the independent variable (solid waste_ environmentally hazardous, willingness to use energy, installing biogas system in future homes, prevent disease of public health concern) which is significant at $\alpha=0.05$, $p \leq 0.001$ in complimentary Log-log link function. This assertion is explained below. From the statistical significance of the final models presented in Table 5, The-2LL with only intercept was 284.06 while the-2LL of the model with intercept and independent variables is 0.00 with a significant chi-square value of 92.386. A similar observation of the presence of a relationship is observed in Table 6 with a dependent Variable (willingness to use energy) and independent Variable (Installing a biogas system in future homes, preventing disease of public health concern)—considering, the deviance measure (lack of fit model and data) in Tables 5 and 6, The assumption is that a more significant deviance has a chi-square distribution with degrees of freedom equal to the estimated parameters [31]. The null hypothesis suggests that the data is fitted for the model and is accepted since $p = 1 > 0.05$ (Table 5) and $p = 0.079 > 0.05$ (Table 6).

Three of the four independent variables in Table 5. influenced students' understanding that biogas can offset gas as an expenditure. They include students understanding that solids waste is environmentally hazardous P= 0.009, 0.046 <0.05, their willingness to use the biogas P=0.034, 0.003 <0.05, and the understanding that biogas can prevent diseases of public health concern P=0.004 <0.05. In Table 6, the two independent variables (Installing a biogas system in future

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homes and biogas can prevent disease of public health concern) were found to influence the dependent variable (willingness to use biogas energy). since P= 0.000<0.05 was observed (Table 6).The null hypothesis states that the location parameters (slope coefficients) are the same across response categories. Inferring from this, the test for parallel lines indicated a significant P =1.00 > 0.05(Table 5 and 6), indicating no significant difference for the corresponding slope coefficients across the categories. This suggests that the model assumption of parallel lines was not defied with the complementary link because, as per Ombui et al. [31], the importance of the test is to make a judgment on the model adequacy.

Table 5. Ordinal logistic regression results for the construct biogas can offset gas expenditure

	Model Estimate	**Std. Error**	**Sig.**
Dependent Variable: Biogas can offset an expenditure			
[biogascanoffsetgasexpenditure = 1]	-1.517	2.033	0.455
[biogascanoffsetgasexpenditure = 2]	1.517	2.033	0.455
[biogascanoffsetgasexpenditure = 3]	1.665	2.034	0.413
[biogascanoffsetgasexpenditure = 4]	1.896	2.036	0.352
[Solidwastes_environmentallyhazardous=1]	-1.345	0.511	**0.009**
[Solidwastes_environmentallyhazardous=2]	-0.949	0.476	**0.046**
[Solidwastes_environmentallyhazardous=3]	0.123	0.648	0.849
[Solidwastes_environmentallyhazardous=4]	-0.644	0.524	0.219
[Solidwastes_environmentallyhazardous5]	0a	.	.
[willingtousesuchenergy=1]	-1.927	0.907	0.034
[willingtousesuchenergy=2]	-1.384	0.867	0.11
[willingtousesuchenergy=3]	-3.102	1.048	**0.003**
[willingtousesuchenergy=4]	-1.893	1.886	0.315
[willingtousesuchenergy=5]	0a	.	.
[installbiogassysteminfuturehomes=1]	2.596	2.215	0.241
[installbiogassysteminfuturehomes=2]	3.496	2.209	0.114
[installbiogassysteminfuturehomes=3]	2.722	2.347	0.246
[installbiogassysteminfuturehomes=4]	0a	.	.
[preventdiseasesofpublichealthconcern=1]	-2.205	0.76	**0.004**
[preventdiseasesofpublichealthconcern=2]	-1.105	0.691	0.11
[preventdiseasesofpublichealthconcern=3]	-0.266	1.542	0.863
[preventdiseasesofpublichealthconcern=4]	-0.201	1.814	0.912
Model Fitting Information			
	-2 Log Likelihood	**Chi-Square**	**Sig.**
Intercept	284.016		
	191.63	92.386	0
Pearson		221.76	0.109
Deviance		116.536	1
Test for parallel lines	191.63		1
Pseudo R-Square			
Cox and Snell	0.328		
Nagelkerke	0.372		
McFadden	0.185		

Dependent Variable: Biogas can be offset as an expenditure. **Threshold** (solid waste_ environmentally hazardous, willingness to use energy, installing biogas system in future homes, prevent disease of public health concern)

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Table 6. Ordinal logistic regression results for the construct Willingness to use Biogas energy

	Model Estimate	Std. Error	Sig.
Dependent Variable: Willingness to use Biogas energy			
[willingtousesuchenergy = 1]	-24.908	1.243	0
[willingtousesuchenergy = 2]	-20.453	1.212	0
[willingtousesuchenergy = 3]	-19.363	1.22	0
[willingtousesuchenergy = 4]	-19.105	1.226	**0**
[installbiogassysteminfuturehomes=1]	-21.989	1.159	**0**
[installbiogassysteminfuturehomes=2]	-19.796	1.153	**0**
[installbiogassysteminfuturehomes=3]	-21.646	0	.
[installbiogassysteminfuturehomes=4]	0a	.	.
[preventdiseasesofpublichealthconcern=1]	-4.995	0.709	**0**
[preventdiseasesofpublichealthconcern=2]	-2.249	0.61	**0**
[preventdiseasesofpublichealthconcern=3]	-1.01	1.469	0.492
[preventdiseasesofpublichealthconcern=4]	0.236	1.393	0.865
Model Fitting Information			
Model	**-2 Log Likelihood**	**Chi-Square**	**Sig.**
Intercept Only	269.384		
Final	83.376	186.008	0
Goodness-of-Fit			
	Chi-Square	**df**	**Sig.**
Pearson	694.424	37	0
Deviance	49.729	37	0.08
Test for parallel lines			1
Pseudo R-Square			
Cox and Snell	0.551		
Nagelkerke	0.627		
McFadden	0.379		

Dependent variable: willingness to use energy. **Threshold** (Installing biogas system in future homes, prevent disease of public health concern)

5. Recommendations

- The use of AI has come to stay in the current dispensation, as the growing population and urbanization are putting extreme stress on environmental resources. Obtaining actionable insights, fully understanding ecological science research, and adopting AI is an ideal step to sufficiently gather enough data for a nuanced understanding of environmental phenomena.
- This study suggests that, before AI is adopted in the analysis and interpretation of data, researcher(s) must endeavor to conduct independent research on the raw data using data analysis software.
- Using mixed methods in environmental science research is an avenue to secure appropriate conceptualization of ecological science research; hence, scientists in this field should consider employing the technique.
- While adopting AI Mixed methods research for data analysis and interpretation, researchers must adopt carefully planned prompts that situate into the research objectives. These prompts must be specific and provide Gen AI with frameworks, the data, and the type of analysis that should be conducted.

6. Conclusion

The main aim of this study was achieved—the adoption of AI and mixed methods research, which have contributed to the alignment between the quantitative and qualitative findings for the case study adopted in this research. This approach has underscored a comprehensive understanding of student perceptions toward biogas. The integration of both datasets reveals that gender and economic factors play pivotal roles in biogas acceptance. Female students, particularly public university students, see biogas as a dual solution to household energy needs and rising costs.

The benefits of sanitation intensify economic motivations as students acknowledge biogas's

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potential to address public health issues through improved waste management. Additionally, the quantitative and qualitative data collectively suggest that while awareness is relatively high, there is room for structured educational programs to deepen understanding of biogas's advantages. By leveraging biogas's appeal as an affordable and eco-friendly energy source, universities could foster greater student adoption and support. Consequently, a coordinated approach, integrating gender-sensitive strategies and targeted campaigns, may drive broader acceptance and contribute to a culture of sustainability on Ghanaian campuses.

The sequential explanatory analysis adopted in this study indicates that biogas energy holds strong potential for acceptance among university students in Ghana, primarily due to its perceived economic and health benefits. Gendered perspectives and institutional contexts play crucial roles in shaping attitudes, suggesting that tailored awareness efforts could significantly enhance biogas's appeal. Through targeted educational programs emphasizing cost savings and environmental impact, public universities can strategically promote biogas and foster an environmentally conscious student body.

6.1. Limitation of the Study

- The AI setting is a dynamic and ever-changing area [32] hence, this document will be limited to the time and space it has been developed, and some of the ideas may be outdated shortly. Notwithstanding, the study is still relevant because it will be one of the seminal studies conducted in environmental science.
- The data set used in this study came from a single case study, which focused on the usage of biogas by Ghanaian university students. It will be analyzed using only one Gen AI. (Chat GPT), it is said that AI systems are inherently biased and unfair. Researchers should be aware of how outputs are used, according to [29].

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