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REVIEW PAPER

A global perspective on sustainable pathways for biogas adoption

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ABSTRACT

Biogas technology has been developed worldwide in recent decades to provide affordable, secure, and clean energy in rural and developing regions. The technology presents various advantages, as it can be utilized for heating, generating power, and functioning as both a fuel and a raw material in the chemical manufacturing process. However, its widespread adoption remains hindered by complex social, economic, and environmental challenges. Local acceptance is increasingly becoming a critical factor for biogas projects and the transition to renewable energy. The objective of this systematic review is to explore and assess the diverse factors that contribute to the acceptance of biogas, utilizing publications from the Scopus, Web of Science, and PubMed databases for analysis. The study examined the connections among authors, disciplines, and geographic regions to contextualize the findings within the global framework. A visualization of similarities and Java-based software was utilized to map the trends in co-authorship, keyword co-occurrence, and thematic developments from 2013 to 2024. Adopting the preferred reporting items for systematic reviews and meta-analyses methodology, 1,358 studies were screened, resulting in 20 peer-reviewed publications meeting the inclusion criteria. A total of 248 factors influencing the acceptance of biogas were identified and clustered along the three sustainability dimensions. Biogas projects are influenced by social, environmental, and economic factors in distinct ways depending on the country or region. The weight scores within each dimension were normalized and the overall score of the studies were calculated, allowing for a comparability of the studies. The finding reveals that social factors are the most significant determinants of biogas adoption, including public trust, procedural justice, and community involvement, accounting for 45 percent of the total. Financial aspects, including incentives, operational costs, and market conditions represent 31 percent. The remaining 24 percent was comprised of environmental factors that received the lowest overall scores, including emission reduction, resource compatibility, and land use impacts. This indicates that the environmental drivers are less emphasized than the other two dimensions. The study emphasizes the critical significance of local governance, the engagement of stakeholders, and the implementation of strategic communication in facilitating the uptake of biogas. Perceived benefits, equity in decision-making, and accessible financial mechanisms emerged as key enablers, while barriers included mistrust, lack of awareness, uneven decision-making, and cost constraints. The significance of tailoring strategies to local conditions is highlighted by regional disparities. In Europe, the focus is on policy alignment, stakeholder governance, and sophisticated infrastructure, whereas developing regions emphasize affordability, education, and resource accessibility. The study highlights the necessity of an integrated approach that considers social, economic, and environmental dimensions, providing actionable insight to ensure equitable and sustainable biogas implementation.

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INTRODUCTION

Renewable energy sources have received increasing interest in recent years (Alberto Huerta-Reynoso et al., 2019; Venko, 2022) as the global fight against climate change, fossil fuel reduction, and the need for renewable energy sources (Razinkov et al., 2021). The development of biogas technology represents a significant advancement in the dual fields of waste management and biofuel production (Arthur et al., 2011; Achinas et al., 2017; Venko, 2022; IEA, 2023). The implementation of biogas technology enables energy generation and the creation of biofertilizers, while also delivering various social and environmental advantages (Ji-Quin and Nyns, 1996). Global demand for biogas and biomethane is expected to accelerate, and the International Energy Agency (IEA) estimates that it will increase by 30 percent (%) between 2024 and 2030 to reach 2,270 petajoule (PJ) per year by 2030 (IEA, 2024). When examining the distribution of biogas demand across countries and regions, the European Union (EU) ranks first, while China occupies the second position (IEA, 2024; European Biogas Association, 2024a). The combined production of biogas and biomethane was 21 billion cubic metres (bcm), according to 2022 data (European Commission, 2023). The updated European Biomethane map (European Biogas Association, 2024b) shows that 81% of biomethane capacity comes from plants in the EU, where growth has reached 37%. According to Eurostat data (Eurostat, 2024), 90% of the EU's natural gas demand was met by imports in 2023, but investment in biogas remains vital to reduce dependence on third parties. By tapping into the biogas potential of agriculture and livestock farming, the ALFA project facilitates the increased market uptake of Renewable Energy Systems. It assists livestock farmers in adopting biogas technology while helping to navigate the existing obstacles within the EU. A Decision Support Tool has been developed to calculate the potential benefits of biogas solutions tailored to the specifications of an individual's farm. The tool estimates the profitability, environmental, economic and social benefits of the farms (ALFA, 2024). The European Biomass Association has been producing annual Statistical Reports since 2007, providing an overview of the bioenergy situation in the EU Member States (European Biomass Association, 2017). Scarlat *et al.* (2015) outline the European Union's policy framework for renewable energy and analyze the biomass demand needed to meet the EU targets. Local acceptance is increasingly becoming a critical success factor for biogas projects and the transition to renewable energy. There is a rising volume of studies investigating the determinants of social and public acceptance regarding diverse energy technologies. Wüstenhagen *et al.* (2007) provide a definition for social acceptance that is relevant to this discussion. The study proposes a threefold perspective on social acceptance, integrating socio-political, community, and market considerations. It concluded that factors influencing socio-political and community acceptance are increasingly highlighted, and market acceptance has received the least attention. Wüstenhagen *et al.* (2007) highlighted that a successful policy requires the agreement of all stakeholders. According to Moula *et al.* (2013), it is important to consider social acceptance, which impacts the achievement of energy policy goals. The number of biogas plants is steadily increasing, especially in Asia (Mukeshimana *et al*., 2021). As noted by Xue *et al*. (2020), the biogas policy framework established in Europe offers an important model for the development of biogas in China and other countries across Asia. Compared to China, Indonesia is in a more difficult position to spread renewable energy technology (IESR, 2019). Situmeang *et al.* (2022) presented an overview of Indonesia's socio-technical and socio-economic barriers to biogas deployment. The most prevalent cause for the inability to establish biogas plants is the absence of financial resources, such as funding and loans. For a successful innovation strategy, it is imperative that government and businesses collaborate closely. Promoting biogas requires an increase in technical knowledge and the establishment of clear legislative objectives (Situmeang *et al.*, 2022). Despite biogas having a long history of use in various energy applications, as well as its potential for integration into biogas-based production, its overall contribution to the existing energy structure and its climate benefits remains modest, particularly in rural developing areas (Rahman *et al*., 2014; Surendra *et al*., 2014; Luo *et al*., 2024; Sumiyati *et al.,* 2024). A case study from India (Parikh and Parikh, 1977) examines the economic benefits of families using a biogas plant, the impact of adopting a biogas plant at the national level and the limiting factors. Insufficient governance, inadequate organizational

frameworks, and limited public engagement were recognized as factors contributing to the unsuccessful implementation. To address this, a uniform pricing policy for purchasing agricultural waste, gas, and fertilizer distribution was proposed (Parikh and Parikh, 1977). Gosling (1982) explored the potential of biogas production in Thailand to mitigate the effects of rising imported oil prices and deforestation due to the dual fuel crisis affecting rural populations. This study underscores the demand for cost-effective construction solutions and advocates for a greater focus on the application of biogas technology in rural settings, along with its integration into broader rural development initiatives.

Sustainability and socio-economic impact

Biogas production can reduce greenhouse gas emissions (Han *et al.,* 2008), reduce eutrophication and improve plant nutrient utilization (Lantz *et al.,* 2007). The study by Walekhwa *et al*. (2009) focused on identifying the factors that affect energy usage derived from biogas in households in Uganda. The results show that biogas adoption increases with decreasing the age of the household head, increasing household income, increasing the number of cattle, increasing household size, increasing male household heads, and increasing the cost of conventional fuels. Plieninger *et al*. (2006) examine bioenergy benefits for German farms. The production of bioenergy presents a fresh economic outlook, characterized by its seamless integration and the provision of various social advantages, including the generation of employment opportunities. At the same time, it pointed out that biomass production alone is not sustainable, and a complex sustainability assessment of different biomass technologies is needed. The advantages are contingent upon the scale of the biogas plant and the nature of biomass processing, whether centralized or decentralized (Domac, 2002). Nevertheless, advocates agree that it stimulates economic development in rural communities, facilitates job creation, and promotes innovative investment opportunities (Domac, 2002; Sims, 2003). Biogas can diversify agricultural production and provide farmers with a "livelihood" (Kromus *et al*., 2004). van der Horst (2007) examined the debate on the siting of renewable energy in the United Kingdom (UK) and identified the factors that need to be considered to understand why people are worried about new energy installations and how they express their concerns. Simultaneously, there exists a gap in understanding the dynamic and contextual relationships that affect public interest and the acceptance of renewable energy installations. The research simultaneously integrates equity theories into assessing factors influencing community acceptance of biogas projects. Several studies (Terwel *et al*., 2011; Mercer-Mapstone *et al.,* 2018) have found that trust is a social acceptance indicator. Soland *et al*. (2013) identify the factors that impact the local acceptance of biogas plants. The study revealed that local acceptance of biogas is quite strong in Switzerland. There is a significant relationship among the perceived benefits, associated costs, and the level of trust in the operator significantly influences the overall acceptance of the technology. The research highlighted that perceived outcomes and citizens' trust strongly influence local acceptance and that the perception of smog increases costs and reduces benefits and trust. An increasing number of researchers, notably Batel *et al*. (2013), are focusing on the social aspects of renewable energy technologies. However, social acceptability also includes environmental, economic and social aspects (Brohmann *et al.*, 2007). Alasti (2011) identified the socio-political, community and market acceptance as dimensions of social acceptance. The primary factors impacting this are inadequate information, uncertainties surrounding policies, the sustainability of bioenergy, the need for supply chain diversification, and competition from new sectors. Upham *et al*. (2015) presented an analytical framework for thinking about the social acceptance of energy technology. The energy technology adoptions were distinguished in the context-based classification framework: general (political, public, and stakeholder), community (local public, local stakeholder, and local political) and market (end-users, stakeholder, and political) acceptance. Numerous studies efforts have explored the inconsistency between advocating for renewable energy technologies and opposing energy initiatives within local communities. In the literature, this is referred to as the "not in my backyard" (NIMBY) syndrome (Wexler, 1996). The NIMBY is based on rational choice theory and assumes that citizens who support the switch to renewable energy do not have to face the impacts of renewable technology in their own "backyard" (Devine-Wright, 2005;

Devine-Wright, 2009; van der Horst, 2007; Soland *et al*., 2013). Devine-Wright (2005) reviewed existing research on public perceptions of wind energy, where public opposition is usually described by the NIMBY effect (Wexler, 1996). The investigation uncovered six determinants, such as socio-economic, communication, institutional, and political aspects, that shaped public perceptions regarding wind farms and renewable energy. The unavailability of multivariate statistical tools and cross-disciplinary frameworks hinders the systematic explanation of how these variables interrelate. The independent variables influencing public opinion on wind farms are not isolated but are linked through dynamic and context-dependent relationships.

Challenges and opportunities

Segreto *et al*. (2019) demonstrated the social acceptance of several bioenergy projects across the EU countries and identified and classified the main factors influencing public confidence. The study conducted by Dermont *et al*. (2017) delved into the political dimension of policymaking in relation to social acceptance, thereby providing further insights to the framework established by Wüstenhagen *et al.* (2007). Twyhues (2020) examined the factors influencing the general public's social acceptance of bioenergy. The data reveals that the level of awareness regarding bioenergy is somewhat limited in Germany and the Netherlands. Nevertheless, the German citizens are more informed and exhibit a more optimistic perspective on bioenergy, largely due to the implementation of effective policy initiatives. Researchers (Thanh Truc *et al*., 2016; Ortiz *et al*., 2017; Gabisa and Gheewala, 2019; Haseeb, 2019; Sarker *et al*., 2020) identified several factors that influence the acceptance and adoption of biogas technology. A notable research gap exists due to the lack of uniformity in digester design and the inadequate examination of economic incentives that impact the adoption of biogas in diverse settings. One key factor is the availability of government subsidies or financial support, which can help individuals and institutions overcome the initial cost barriers associated with acquiring biogas digesters or plants (Osei-Marfo *et al*., 2018). Furthermore, the uniformity in digester design, along with the availability of maintenance and monitoring assistance, plays a vital role in ensuring the ongoing performance and effectiveness of biogas systems (K House *et al*., 2007; Nathalie Bachmann, 2013; Nsair *et al*., 2020). Another important aspect is the market value of the byproducts, such as bio-fertilizers, which can further enhance the economic viability of biogas projects and incentivize their adoption (Miltner *et al*., 2017; Osei-Marfo *et al*., 2018; Velásquez Piñas *et al*., 2019; IEA, 2020). Public acceptance plays a vital role in the deployment of renewable energy technologies, and the introduction of new energy solutions is contingent upon the approval of the community (Bang *et al*., 2000; Kasperson and Ram, 2013). The uncertainty also plays a significant role in public opinion (Kasperson and Ram, 2013). Despite its significance, the impact of uncertainty and risk perception on the public's willingness to adopt renewable energy technologies is still not well-explored. It would be worthwhile to examine the ways in which uncertainty and perceived risks affect the public's acceptance of biogas initiatives. Indicators influencing public behavior are the availability of knowledge and information about new technologies, fear and concern about risks, perceptions of new technologies, and people's mindsets (Assefa and Frostell, 2007).

Social acceptance and strategic communication

Lack of communication with the local community is one of the main reasons for the public response to renewable energy development. There is a scarcity of studies examining the effect of communication strategies on the public acceptance of renewable energy initiatives (Kaldellis, 2005; McCormick, 2010; Fytili and Zabaniotou, 2017). The study additionally investigates the role of strategic communication in enhancing acceptance of biogas systems. However, the acceptance of new energy projects shows an increasing trend if the public is informed about the developments in time (Kaldellis, 2005). Fytili and Zabaniotou (2017) found that the lack of information and knowledge on bioenergy projects and fears of environmental concerns about emissions are responsible for low social acceptance. However, there is a limited understanding of how public awareness and knowledge influence the acceptance of bioenergy projects. The study emphasizes enhancing public awareness as a crucial factor in promoting the biogas adoption. Farstad *et al.* (2024) investigated the socio-cultural conditions for the social acceptance of the bioeconomy through a case study in Norway.

Various elements of this study are aligned with the triangle model adapted from Wüstenhagen *et al.* (2007). Identification of socio-cultural factors influencing the adoption of bioeconomy projects and insufficient knowledge of trust in public authorities. Additional investigation is required to explore the socio-cultural aspects, particularly emphasizing trust as a vital element influencing biogas adoption, which is connected to the current study. Social acceptance is also influenced by awareness of climate change and technologies and perceptions of the fairness of decision-making processes (Fytili and Zabaniotou, 2017). There are various approaches to the concept of acceptance in different disciplines. Gareiou *et al.* (2020) highlighted the social acceptance of renewable energy sources as a critical factor for developing and deploying the projects. Zabaniotou (2018) offered an extensive analysis of the environmental, economic, and social aspects of bioenergy, aligning with the three pillars of sustainability. Innovation in electricity generation should consider food waste and residues as a feedstock. In the first scenario, effective management of supply chains and logistics plays a crucial role, whereas the second systems seem to be more sustainable due to the ease of redesigning small-scale operations. The research shows that a multidisciplinary approach combining the technical, economic, and social dimensions of bioenergy projects is lacking. In a study by Meidiana *et al*. (2020), the adoption of biogas in rural communities was investigated. The results revealed that key factors affecting farmers' choices to adopt biogas plants include their age, the size of their families, land ownership details, ownership of cows, and their knowledge about the technology. Sharpton *et al*. (2020) concluded that the distance of renewable energy plants from respondents' homes strongly influenced acceptance, as did the importance of economic considerations, environmental sustainability, and supply security. Respondents highlighted the understanding of utility providers and policymakers as a key influencing element. To ensure a comprehensive analysis of biogas acceptance, it is essential to incorporate socio-political dimensions, particularly emphasizing the minimum level of socio-political acceptance. Farstad *et al*., 2024 found a high level of trust in the authorities as a key condition. Furthermore, socio-political acceptance is also determined by people's lack of courage. The results of van Dijk *et al.* (2024) indicate that the acceptance depends on the type of biomass feedstock and the efficiency of the contribution to the energy transition. A recommendation has been made to focus more on the particular types of biomass feedstock that should be incorporated into strategic communication. Concerns regarding environmental and health impacts often obstruct the social acceptance of biogas. Paolini *et al.* (2018) provided estimates of the emissions of major greenhouse gases based on case studies from around the world. Biogas production can significantly reduce greenhouse gas (GHG) emissions but the research also draws attention to other emissions (Paolini *et al*., 2018). Public sentiment towards energy projects can be marked by significant negative emotions and resistance. Perlaviciute *et al*. (2018) focused on appropriately managing these emotional reactions. It was concluded that a value-based approach can identify public concerns about new energy projects, which help them respond effectively and adaptively and make responsible decisions (Haidt, 2001; Roberts, 2001; Roeser, 2011). There is a diversity of perspectives among individuals regarding the characteristics of energy projects that they prioritize and the level of acceptability they assign to different energy initiatives (Bidwell, 2013; De Groot *et al*., 2013; Perlaviciute and Steg, 2015). Despite a steadily increasing number of literature and projects on biogas technology adoption, significant gaps remain in understanding the interaction between economic, social, and environmental factors within a comprehensive and multidimensional sustainability framework. Current studies are constrained in their ability to systematically investigate these dynamics due to the insufficient use of interdisciplinary and integrated approaches. While regional variations in acceptance and the role of governance and stakeholder engagement have been highlighted, the integration of localized socio-economic and cultural contexts with global policy implications is underexplored. This study seeks to explore the various multidimensional factors that influence the acceptance of biogas production, based on the observations presented. It categorizes them according to sustainability dimensions to provide an integrated approach to ensure equitable and sustainable implementation of biogas. The current study was carried out in Thailand in 2024.

METHODOLOGY

This systematic review analyzes the factors that contribute to the acceptance of biogas production. The study design followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (Moher *et al*., 2009; Page *et al*., 2021) to ensure methodological rigor and reproducibility (Soleas, 2021; Danya *et al*., 2024; Torres-Ceron *et al*., 2025). Three primary research questions guided the study: 1) What significant factors influence local acceptance of biogas production? 2) What research methods (qualitative or quantitative) are used to explore the social acceptance of planned and existing biogas projects? 3) How can the factors determining local acceptance be classified?

Data extraction and screening process

A comprehensive literature search was carried out in Scopus, Web of Science (WoS), and PubMed databases between August and October 2024 to ensure the scientific quality of the research. The search conducted in the database aimed to explore the elements that influence biogas acceptance, employing five specific keyword combinations: "biogas", "biomass energy", "influencing factors", "factors", and "acceptance", and using the "AND" and "OR" Boolean operators. All records were exported in a standardized tag format, specifically research information systems (RIS) into EndNote X9 software. Metadata, the 1,385 publications, contained authors' details, publication year, title, journal, publisher, DOI, keywords, abstract, language, and document type. The screening was implemented in a two-phase approach. In the first initial screening, 39 duplicates were removed from the EndNote library, and 1,346 records underwent title and abstract screening against predefined exclusion criteria, resulting in the exclusion of 1,319 records due to irrelevance, unavailable of the full-text, publication year and type (e.g., books or grey literature), or non-English language.

In the second comprehensive review of the texts, 24 ambiguous records were carefully evaluated, leading to the identification of 20 studies that satisfied the inclusion criteria were selected for factor analysis. The selection process is illustrated in a PRISMA flow diagram (Fig. 1). This methodical approach guaranteed that only studies pertinent to the study questions and objectives were incorporated.

Publications were selected or excluded based on specific criteria, including the type of publication, the significance of biogas acceptance factors, the focus on sustainability, and the methodological robustness. Table 1 outlines the specific criteria in detail. The influencing factors identified from the selected studies were aggregated and categorized into three sustainability dimensions. This framework of dimensions offered a coherent structure for assessing

Table 1: Inclusion and exclusion criteria

Category	Inclusion criteria	Exclusion Criteria
Publication type	Peer-reviewed journal articles and review articles to ensure quality and validity.	Books, book sections, and conference proceedings.
Publication date	Publications published after 2013.	Publications before 2013.
Topic relevance	Publications investigating factors influencing biogas acceptance, adaptation, or perception.	Publications not focused on factors influencing biogas acceptance or adaptation.
Driving and barrier factors	Publications identifying or analyzing driving (promoting), or barrier (inhibiting) factors related to biogas.	Publications not analyzing driving or barrier factors related to biogas.
Language	English to ensure accessibility.	Non-English publications, even with English abstracts.
Geographic scope	Global publications focusing on regions where biogas is relevant for sustainability.	Publications focusing on regions where biogas has limited relevance or sustainability applications.
Methodology	Empirical studies, case studies, systematic reviews, and bibliometric analyses.	Non-research publications lacking empirical or systematic analyses.
Sustainability	Publications categorizing factors in at least one of the three sustainability dimensions.	Publications not categorize factors in any sustainability dimension.

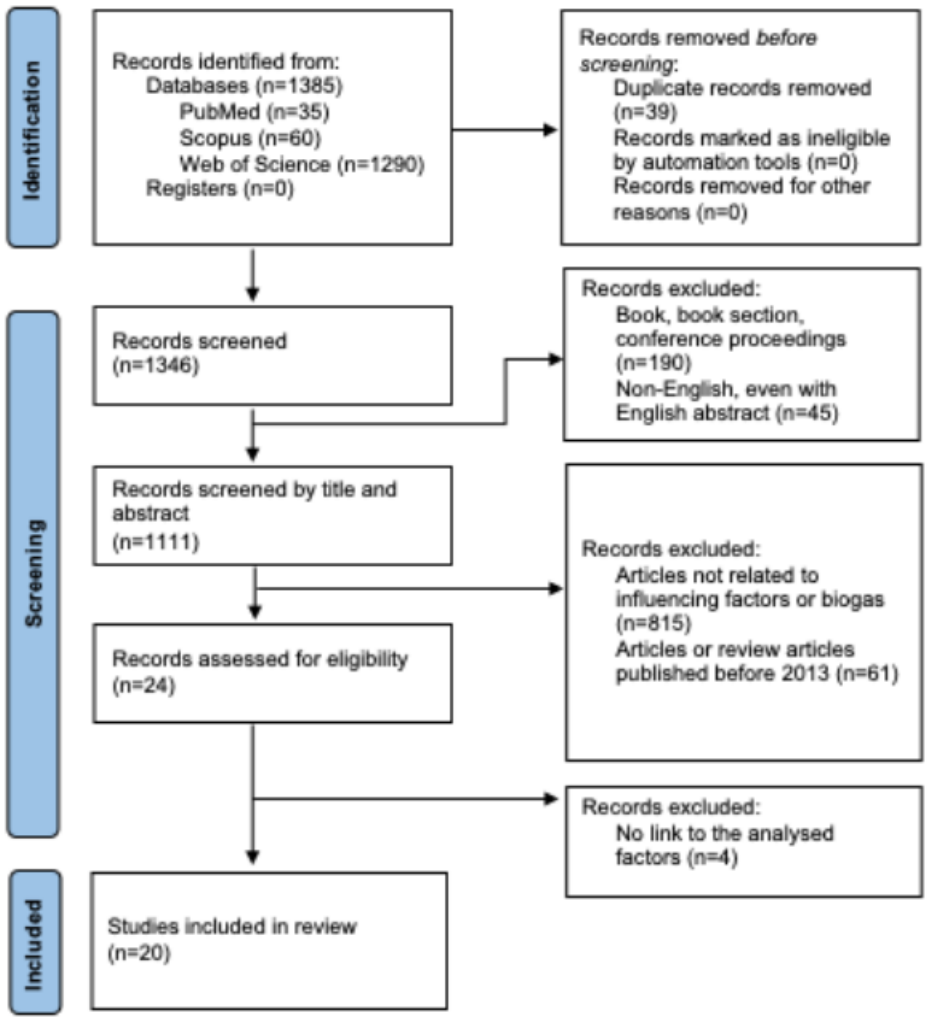

Fig. 1: PRISMA flow chart of the screening process to identify studies included in the review (Page *et al*., 2021)
Notes: The figure follows the PRISMA guidelines, detailing the steps of identification, screening, and inclusion, while also noting the reasons for study exclusions at each stage. A total of 1,385 records were retrieved from databases including PubMed, Scopus, and Web of Science. After removing duplicates (n=39) and applying inclusion criteria, 24 studies were assessed for eligibility. Ultimately, the analysis incorporated 20 studies that examined the various factors affecting the adoption of biogas technology.

the factors that impact biogas acceptance and their varying importance in different research contexts.

Bibliometric Analysis

Bibliometric analysis complemented the systematic review by using a visualization of similarities (VOS) Java-based software (VOSviewer) to construct and visualize bibliometric networks. The analysis shed light on trends in various disciplines, the geographic spread of research, and how research evaluation has changed over time. The study analyzed the interconnections among authors, various disciplines, and different geographic regions, including Europe, Asia, and America, to better understand the findings in a worldwide context. By integrating systematic review and bibliometric analysis, this study offers a comprehensive understanding of the sustainability dimensions shaping biogas acceptance and their regional and methodological variations. In order to clarify the significance of the factors involved, all studies were reviewed with respect to both the frequency and depth of their analytical approach.

Studies were assigned scores reflecting their methodological rigor and coverage of influencing factors:

- High weight (Score: 3): Studies employing comprehensive methods, such as multivariate or longitudinal analzses, and addressing multiple factors across all sustainability dimensions. These studies have explored the influencing factors and revealed a robust connection between the outcomes and the increased utilization of biogas.
- Medium weight (Score: 2): Studies using descriptive or single-method approaches (e.g., surveys, interviews) and addressing fewer factors.
- Low weight (Score: 1): Studies with limited focus, basic methods or a limited number of factors analyzed. Studies that concentrates on a narrow range of factors, such as solely social or environmental influences, or that depends on basic survey techniques without comprehensive statistical evaluation.

Normalization of the scores

To ensure that the studies could be compared effectively, the scores of the factors identified in the bibliometric analysis were normalized. This process allowed for an assessment of the weights of each sustainability dimension—environmental, economic, and social—relative to the maximum value found in the dataset. The normalization was performed using Eqs. 1 and 2 (Pollesch and Dale, 2016):

$$\text{Normalized score} = \frac{\text{Factor number}}{\text{Maximum factors in all studies}} \quad (1)$$

$$\begin{aligned}&\text{Overall normalized score} = \\ &\text{Normalized environmental score} + \\ &\text{Normalized economic score} + \\ &\text{Normalized social score}\end{aligned} \quad (2)$$

An elevated overall normalized score signifies a harmonious and meaningful contribution from the various sustainability dimensions, while a diminished overall normalized score points to a limited contribution across these dimensions.

RESULTS AND DISCUSSION

A total of 1,385 publications were identified in the comprehensive review. The search strategy identified 60 records in Scopus, 1,290 in Web of Science, and 35 in PubMed. After the selection process, the duplicates (n=39) were removed, and 1,326 publications were excluded based on the exclusion criteria. Finally, 20 publications were selected for the evaluation (Table 2). The first paper (Emmann *et al*., 2013) identifies the relevant influencing factors determining a biogas innovation's acceptability in 2013. In Fig. 2, the trend of publications and citations from 2013 to 2024 is presented. The bar graph illustrates the yearly number of publications, while the line graph tracks the corresponding citation counts.

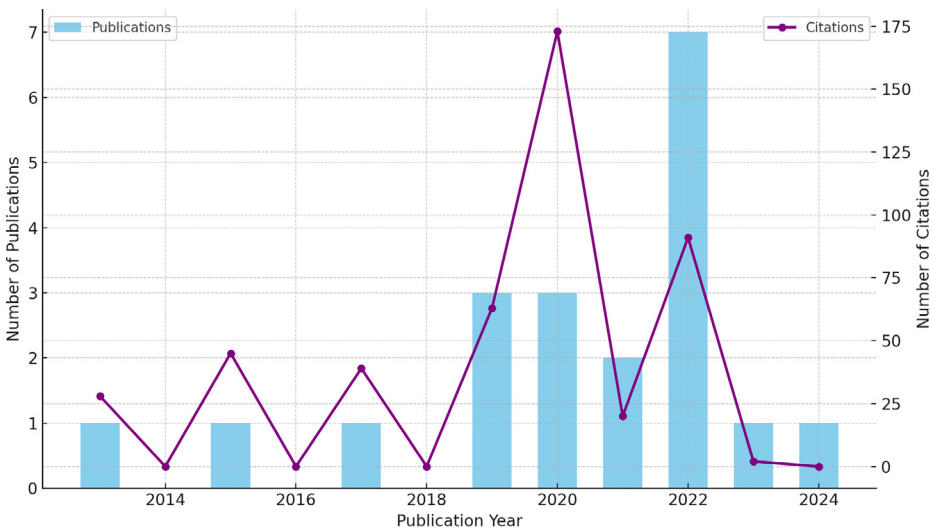

Fig. 2: Total publications and citations number (2013-2024)

Table 2: References focusing on identifying influencing factors of biogas acceptance

No.	Recruiting period	Objective	Factors			Unit of analysis	N	Method	Sources
			EN	EC	S				
1	Jun-July 2010	Determine factors influencing the acceptance of biogas innovation among farmers through causal analysis.	√	√	√	Households	180	Questionnaire survey	Emmann *et al.* (2013)
2	2009-2011	Analyze changes in public acceptance of biomass plants.	√	√	√	Households	423	Questionnaire survey	Kortsch *et al.* (2015)
3	Nov. 2014-Mar. 2015	Analyzing local acceptance of biogas plants in the Upper Rhine region and the influencing factors.	√	√	√	Households	433	Descriptive, multiple regression, GIS	Schumacher and Schultmann (2017)
4	July 2016-Feb. 2018	Examine the perspectives of biogas production stakeholders, identifying obstacles and levers for project development and exploring governance aspects of stakeholder interactions.	√	√	√	Stakeholders	55	Semi-structured interviews	Bourdin *et al.* (2019)
5	Dec. 2016	Analyze the relationship between spatial-economic variables and renewable energy source adoption in Poland.	√	√	√	Households	101	Statistical non-parametric: Spearman's rank correlation coefficient test	Hernik *et al.* (2019)
6	Sep.-Oct. 2013	Examine the public acceptance of hypothetical biogas plant (BGP) developments near residential areas in Germany.	√	√	√	Households	942	Questionnaire survey	Dobers (2019)
7	Oct. 2018	Assess household-based factors influencing the utilization of biogas generation technology.	√	√	√	Households	695	Descriptive and empirical; probit regression model-based estimations	Jabeen *et al.* (2020)
8	2003-2018	Analyse the success factors of anaerobic digestion projects in France.	√	√	√	Stakeholders	140	Quantitative: logit model (91); qualitative: semi-structured interviews (49)	Bourdin *et al.* (2020)
9	2001-2019	Assess factors affecting social acceptance of renewable energy systems in Europe.	√	√	√	Residents, stakeholders, experts	25	Comparative case studies	Segreto *et al.* (2020)
10	2018-2019	Argue for including the concept of naturalness in the social acceptance of renewable energy technology to address the social rejection of biogas technology.			√	Residents	607	Questionnaire survey and focus groups	Dumont *et al.* (2021)
11	NR	Establish key indicators for measuring green economy transition potential at the local level.	√	√	√	Residents	41	Domain-based approach, driving force–state–response (DSR) model, interviews (41)	Timonen *et al.* (2021)

Continued Table 2: References focusing on identifying influencing factors of biogas acceptance

No.	Recruiting period	Objective	Factors			Unit of analysis	N	Method	Sources
			EN	EC	S				
12	NR	Examine general and local acceptance of energy technologies by assessing public concerns, stakeholder trust, and attitudes.	√	√	√	Residents, stakeholders	1,247	Questionnaire survey	Baur *et al*. (2022)
13	2008-2020	Identifying critical challenges in realizing biogas projects.	√	√	√	Stakeholders	2,503	Multiple case studies (5), longitudinal analysis: documentum analyses (2,489), semi-7structured in8terviews (9)	Nielsen (2022)
14	2018-2021	Identify site-selection factors for biogas plants in Sweden under evolving conditions, emphasizing the need for spatially explicit analysis in decision-making processes.	√	√	√	Experts	34	Interviews (11), focus groups (2), reflexive thematic documentum analysis (21)	Feiz *et al*. (2022)
15	July 2021	Identifies factors influencing social acceptance of biogas plants.			√	NR	54	Systematic literature review	Mancini and Raggi (2022)
16	2008-2015	Identify critical non-technological success factors affecting centralized biogas project deployment.	√	√	√	Stakeholders	502	Longitudinal process analysis (1 case study, 408 documents), semi-structured interviews (3)	Nielsen *et al.* (2022)
17	NR	Examine household acceptance of bio-technology by categorizing driving and inhibitory factors.	√	√	√	Households	164	Questionnaire survey	Ahmed *et al*. (2022)
18	April-May 2018	Evaluate policy impacts and public perceptions of agricultural biogas plants in Slovakia, analyzing social acceptance in areas near residential zones.	√	√	√	Operators/experts, residents	239	Questionnaire survey (234) and interviews (5)	Kulla *et al.* (2022)
19	Sep.-Oct. 2022	Identify factors influencing household acceptance of biomethane generation technology in rural Pakistan.	√	√	√	Households	300	Logistic regression model, survey-based evaluation	Wu *et al.* (2023)
20	2012-2020	Explore regional factors influencing the establishment of biogas plants in 96 French regions.	√	√	√	Regional database	96	Empirical analysis	Coll-Martínez *et al*. (2024)

Notes: N: sample size; NR: not reported; EN: environmental; EC: economic; S: social.

The analysis shows changes in research productivity and academic engagement over the years, with distinct peaks observed in particular years. The graph depicts a temporal gap between the publication of works and their citation influence, indicating a slow process of gaining recognition. Overall, it indicates a shift in focus or interest within the academic field. From 2013 to 2018, the number of publications (Emmann *et al*., 2013; Kortsch *et al*., 2015; Schumacher and Schultmann, 2017) was consistently low, with no more than two publications each year. This timeframe signifies a phase of limited activity regarding the generation of new research findings. Throughout these years, citation levels remained low and inconsistent, experiencing modest increases in particular years, notably in 2015 and 2017. A slight rise in publications occurred from 2019, peaking significantly in 2022. Citations followed a fluctuating pattern with notable spinks in certain years. The rise in publications corresponds with the worldwide trend of increasing biogas production. A growing trend among countries is the investment in renewable energy sources, accompanied by efforts to diminish their dependence on fossil fuels. There is a significant rise in the trend across Europe and Asia, where agricultural byproducts and organic materials are being utilized to fulfill local energy needs.

The European Union greatly emphasizes biogas as it promotes sustainable agriculture and energy independence. Recently, China and India, two populous countries, have dedicated significant resources to the development of biogas infrastructure. China is now one of the world's largest biogas producers, primarily driven by agricultural and wastewater treatment projects. India is making significant strides in enhancing its biogas initiatives in rural regions to decrease reliance on firewood and fossil fuels. In the context of sustainability, advancing biogas production is among the climate and sustainability targets set by numerous countries. Subsidies and a favorable regulatory environment are helping biogas projects to take off, particularly in the European Union, where renewable energy sources are encouraged as part of energy policy objectives. Between 2019 and 2020, the number of publications nearly doubled (Bourdin *et al.* 2019; Hernik *et al*., 2019; Dobers, 2019; Jabeen *et al*., 2020; Bourdin *et al*., 2020; Segreto *et al*., 2020). The total number of citations jumped to 173 in 2020. This phenomenon indicates that research on biogas has had a significant impact and that biogas production is becoming an increasingly important renewable energy source, serving as a critical source of information for other research. The years 2020 and 2022 are notable for their significant citation and publication rates. These could be linked to groundbreaking research outcomes or areas that have unexpectedly surged in significance or interest among scientists.

Research areas

The publications on biogas acceptance identified in the Scopus, Web of Science, and PubMed databases cover nine disciplines, reflecting the multifaceted nature of the research topic. Investigations within this domain focus on the economic, environmental, social, and technological factors, thereby enriching the understanding of the various influences on public and institutional acceptance of biogas technology. Table 3 summarizes the primary research areas identified through the examination of publication trends, showcasing the interdisciplinary strategy essential for addressing the complex issues associated with biogas acceptance. "Environmental Science and Ecology" (40%) is the largest research area in biogas acceptance-related studies, highlighting the importance of ecological perspectives in understanding the technology's impacts and benefits. Studies within this domain analyze the impact of biogas adaptation on environmental sustainability, highlighting its contributions to lowering greenhouse gas emissions, improving waste management practices, and conserving valuable resources.

Representing 35%, the "energy and fuels" sector holds considerable importance, concentrating on the technical and operational features of biogas as a sustainable. Publications in this area usually assess the efficiency of biogas production, energy yield, and integration into existing energy systems. Also, "science and technology – other topics" (35%) represents an interdisciplinary approach to technological innovation. This field of study encompasses publications focused on new technologies, advancements in processes, and innovations across various sectors that improve the efficiency and viability of biogas production. "Business and Economics" (15%) plays a critical role in understanding the financial and market-driven aspects of biogas acceptance. Studies examine the cost-benefit ratios, market dynamics, and financial incentives

Table 3: Major research areas in references focusing on identifying influencing factors of biogas acceptance

Research area	TP	TP(%)
Environmental Sciences and Ecology	8	40%
Energy and Fuels	7	35%
Science and Technology - Other Topics	7	35%
Business and Economics	3	15%
Public Administration	2	10%
Public, Environmental and Occupational Health	2	10%
Geography	2	10%
Development Studies	1	5%
Engineering	1	5%

Notes: TP: total publications; TP(%): percentage of total publications.

that drive or hinder biogas adaptation. The selected publications analyze the economic viability of biogas-related projects from the perspective of households or businesses, shedding light on financial barriers and potential drivers that could increase adaptation rates. "Public Administration" (10%) deals with the policy and regulatory framework governing the introduction of biogas technology. Research emphasizes the importance of government initiatives in fostering biogas development by creating a supportive policy framework and implementing strategic regulatory actions. These studies underline the importance of policy coordination and administrative support in achieving widespread acceptance and operational success of biogas projects. "Public, Environmental and Occupational Health" (10%) examines the health implications of biogas production. Various publications analyze the health benefits linked to biogas, particularly its capacity to mitigate indoor air pollution resulting from standard cooking methods and the occupational health and safety issues faced by employees in biogas production plants. This field of study is crucial for recognizing and addressing health hazards, ensuring that biogas technology is both safe and advantageous for communities and individuals. "Geography" (10%) examines the spatial and regional factors influencing biogas acceptance, focusing on how geographical variables affect the uptake, implementation, and public perception of biogas projects. The researchers investigate the ways in which the presence of local resources, the density of the population, and land use patterns affect the practicality and acceptance of biogas technology in diverse areas. The geography studies provide valuable insights into regional differences in adoption, suggesting that biogas deployment strategies should consider local geographic characteristics to improve adoption rates. "Development Studies" (5%) examine the acceptance of biogas from a social development perspective, especially in low- and middle-income countries. This part focuses on the potential of biogas technology to contribute to sustainable development goals, particularly in terms of increasing energy accessibility in rural communities, bolstering economic resilience, and elevating quality of life standards. Researchers explore the role of biogas in supporting development initiatives by providing affordable, clean energy solutions for disadvantaged populations. Finally, "Engineering" (5%) deals with the technical design and infrastructure challenges related to biogas systems. Engineering research focuses on system design, optimization, and innovation and addresses practical issues related to the construction, efficiency, and maintenance of biogas plants. The study of engineering is essential for tackling the technical obstacles that hinder the scalability and reliability of biogas technologies, guaranteeing that biogas systems comply with both performance and safety requirements. The interdisciplinary nature of biogas acceptance highlights the complex interplay of environmental, technical, economic, social, and regulatory factors that influence acceptance by the public and institutions. Different fields of research contribute unique insights and solutions, emphasizing the importance of a unified approach that brings together diverse expertise to effectively address the multifaceted challenges related to the implementation of biogas technology.

Journals analysis

Studies on the acceptance of biogas span multiple scientific disciplines, with findings published in various esteemed journals that cater to diverse

yet interconnected research fields. The five most essential journals are listed in Table 4. Each journal presents a unique angle, underscoring the multifaceted nature of research related to biogas utilization. Each of the five journals represents 10% and accounts for 50% of the cumulative percentage, covering half of the journals under systematic review. As a top-tier journal in the field of energy research, Energy Policy is widely recognized for its focus on studies related to policy, regulatory structures, and governance matters. Publications in Energy Policy analyzes the political aspects of fostering the future implementation of biogas-based gas production, concluding that it is essential to advocate for biogas technology in a manner that is both sustainable and environmentally friendly (Dobers, 2019).

Policymakers should carefully evaluate the impact of biogas production targets on other industries to prevent any adverse effects on food production when planning for expansion (Emmann *et al*., 2012; Emmann *et al*., 2013). The Journal of Cleaner Production emphasizes sustainability and the management of environmental issues. The publications place biogas in the broader context of sustainable development and cleaner production practices. Studies emphasize the environmental benefits of biogas, including waste reduction, emission control, and contribution to the circular economy. The impressive h-index of 309 reflects the frequent citation of articles in this journal, emphasizing the critical role and relevance of sustainability-oriented research in the acceptance of renewable energy. Hernik *et al.* (2019) analysed the connection between spatial-economic factors and renewable energy storage. Feiz *et al.* (2022) examined the factors influencing the site selection of biogas plants. Renewable Energy has a 250 h-index with a Q1 ranking. Recognized as a leading publication in renewable energy, this journal features research on diverse energy sources, including biogas. Studies on biogas adaption focus on the technical, economic,

Table 4: Main journals focusing on the identification of factors influencing the acceptance of biogas in references

No.	Journals	TP	TP(%)	Cumulative frequency	Cumulative percentage	h-index	Quartiles
1	Energy Policy	2	10%	2	10%	272	Q1
2	Journal of Cleaner Production	2	10%	4	20%	309	Q1
3	Renewable Energy	2	10%	6	30%	250	Q1
4	Energy Research and Social Science	2	10%	8	40%	113	Q1
5	International Journal of Environmental Research and Public Health	2	10%	10	50%	198	Q2
6	Global Journal of Environmental Science and Management	1	5%	20	100%	33	Q1

Notes: TP: total publications; TP(%): percentage of total publications; h-index: Hirsch-index.

Table 5: Top-cited articles in references focusing on identifying influencing factors of biogas acceptance

No.	Total citations	Citation from this year	Countries\regions of the corresponding author	Sources
1	110	2013	Europe	Segreto *et al.* (2020)
2	52	2021	China	Jabeen *et al.* (2020)
3	45	2016	Germany	Kortsch *et al.* (2015)
4	40	2022	Germany	Baur *et al.* (2022)
5	39	2017	Germany	Schumacher and Schultmann (2017)
6	28	2014	Germany	Emmann *et al.* (2013)
7	23	2020	Germany	Dobers (2019)
8	21	2019	France	Bourdin *et al.* (2019)
9	19	2020	Poland	Hernik *et al.* (2019)
10	17	2022	Pakistan	Ahmed *et al.* (2022)

and environmental performance of biogas systems, exploring socioeconomics, infrastructural, and demographic factors, which are the critical factors of biogas generation technology utilization (Jabeen *et al*., 2020). The study by Kortsch *et al*. (2015) explored the various factors that impact public acceptance of biomass power plants, shedding light on the influences surrounding bioenergy project approval. Energy Research and Social Science represent 10% of the publications on factors influencing the acceptance of biogas, with a 113 h-index. The research explores the impact of social factors, including the level of public awareness, cultural acceptance, and community participation, on the adaptation processes of biogas plants (Dumont *et al*., 2021; Mancini and Raggi, 2022). Despite having a lower h-index compared to the aforementioned journals, its concentration on the social and human factors influencing renewable energy acceptance is essential for the effective implementation of biogas initiatives. The International Journal of Environmental Research and Public Health focuses on environmental and public health issues. In the context of biogas adoption, research in the journal focuses on the health benefits of biogas production, such as reduced indoor air pollution and improved public health, social equity (Timonen *et al*., 2021), as well as occupational health aspects for biogas plant workers. The journal's Q2 ranking and relatively high h-index (h-index=198) reflect its reputation for public health research, indicating that health-related factors are essential to biogas adoption research. The main journals - Energy Policy; Journal of Cleaner Production; Renewable Energy; Energy Research and Social Science; International Journal of Environmental Research and Public Health and Global Journal of Environmental Science and Management provide a unique perspective on the factors influencing the acceptance of biogas. Their high h-indexes and rankings in Q1 or Q2 reflect the substantial scientific contribution and diverse interdisciplinary nature of this research area. These journals highlight the multifaceted nature of biogas acceptance studies, including policy, social science, environmental impact, technical performance, and health aspects. This range illustrates the multifaceted challenges of biogas adoption, which depends on several key factors to facilitate its wider implementation in different sectors and communities.

Citations

In Table 5, the essential factors impacting biogas adoption are examined, including regional dynamics, household aspects, and social or territorial governance challenges, which represent the most commonly cited literature in the systematic review.

Segreto *et al.* (2020) analyzed the prevailing trends in accepting renewable energy in different European countries, including biogas. The evaluation focuses on the dynamics of social acceptance and details the cultural and political influences that shape the integration of renewable energy systems. Influencing factors include public perception, environmental benefits, economic incentives, policy frameworks, and community involvement. Additionally, the research examines the differences present among European countries, attributing these variations to regional policy differences, historical energy frameworks, and social influences, which collectively illustrate the acceptance of such impacts at both the societal and community levels. Jabeen *et al.* (2020) focused on household-based factors in Pakistan that influence the use of biogas production technology, particularly in the Punjab region. They underscore economic considerations such as income brackets, the accessibility of affordable biogas technologies, and the importance of education, and awareness. Factors such as social norms, family size, and the extent to which regions depend on conventional energy sources play a significant role in influence adoption. In addition, factors specific to Pakistan, such as infrastructural and political constraints, pose challenges to widespread adoption. The longitudinal study (Kortsch *et al.,* 2015) examined long-term trends in the acceptance of biomass, including biogas plants in Germany. The elements that play a role in this context include the economic benefits to the local community, the availability of employment, and worries about the potential environmental consequences. The study finds that adaption fluctuates with changes in policy incentives and the visibility of economic benefits to local communities. The findings underscore how continuous engagement with the community is crucial for fostering enduring acceptance (Kortsch *et al.,* 2015). Baur *et al.* (2022) examined social acceptance of energy technologies as part of the wider energy transition in Germany. Factors influencing the acceptance of biogas

include its environmental benefits, the perceived impact on national energy objectives, and local economic incentives. The study finds relatively high acceptance of biogas when the technology is in line with Germany's ambitious goals but also highlights the importance of addressing community concerns about environmental and economic impacts at the local level. A comparative study (Schumacher and Schultmann, 2017) investigated cross-border factors influencing the acceptance of biogas plants in the Upper Rhine region. Significant factors encompass the differences in regional policies, the environmental advantages, and the cultural views on renewable technologies. The inconsistencies in national energy policies, subsidy structures, and public participation methods have contributed to diverse levels of adaptation within the three countries of the region. Schumacher and Schultmann (2017) revealed the need for harmonized regional policies to improve adoption rates. Emmann *et al.* (2013) used a structural equation model to assess individual adoption of biogas innovation, focusing on psychological and social factors related to perceived simplicity of use, awareness of environmental benefits, and personal attitudes toward the technology. The results demonstrate that greater awareness and constructive social influences have significantly boosted engagement, highlighting the essential nature of educational campaigns and the impact of positive peer relationships. The research addresses spatial factors that influence the acceptance of biogas, such as the proximity of plants to residential areas and the impact on the local landscape. Dobers (2019) found that concerns about noise, odor, and visual impacts reduce the acceptance when plants are located near densely populated areas. Local cultural attachment to landscapes also influences acceptance, suggesting that strategic siting of plants and design changes can improve public perception. Bourdin *et al.* (2019) examined how territorial governance influences the proliferation of biogas production across various regions in different regions of France. Essential components consist of regional governance systems, participation of local stakeholders and administrative challenges. The findings of the study indicate that regions where governance is effectively coordinated to align local, regional, and national energy goals experience higher acceptance rates, underscoring the significance of strong governance in facilitating biogas deployment. Hernik *et al*. (2019), focusing on eastern Poland, identified the cultural and economic variables that affect the adaptation of renewable energy sources, including biogas. The adaptation rate is higher when the economic benefits, like reduced energy costs and local job creation, are obvious. Cultural attachment to traditional practices and limited knowledge of the benefits of renewable energy are challenging. To increase the acceptance of alternative energy solutions in regions with deep-rooted traditional energy practices, such as Poland, it is essential to implement community-driven approaches and educational programs. In the case of Pakistan, Ahmed *et al.* (2022) researched the acceptance of biogas technology using a diffusion of innovation framework, emphasizing factors such as economic viability, observed utility, social influence and compatibility of biogas with existing practice. Results indicate that adaptation is hindered by financial constraints, limited infrastructure, and low awareness, while expected benefits (cost savings and environmental impact) can stimulate adaptation if properly communicated (Ahmed *et al.*, 2022). The foremost ten publications emphasize the multifaceted interactions of elements that shape biogas adaptation, which encompass economic incentives (economic dimension), governance and policy considerations, community participation, and cultural (social dimension) aspects. Regional variations are significant, with household-level economic and social considerations prominent in areas such as Pakistan, while European studies focus on policy harmonization and territorial governance. Areas related to biogas deployment that require further investigation include enhanced policy frameworks and innovative technologies. Specific contributions include new insights into policy harmonization or the impact of community-led initiatives. As noted by Wüstenhagen *et al*. (2007), the adoption of biogas is significantly bolstered by local ownership and collaborative decision-making, especially in the context of wind energy projects. Their research highlights that financial involvement from residents can foster greater community trust and improve the viability of such initiatives (Wüstenhagen *et al.*, 2007). The gap between national renewable energy targets and local project implementation needs to be addressed through an adaptive policy. France's new policy framework has led to an increase in wind

energy capacity. An essential component of the measures was the reassignment of administrative responsibilities for granting authorization for wind farm projects to the regional subdivisions and municipal authorities (Nadaï, 2007). Planning, siting and permitting policy framework of renewable energy are key factors in local policy. While social acceptance responds to issues and processes related to site selection, policy measures tend to focus on planning issues (Nadaï, 2007).

Bibliometric analyses

By importing the RIS files extracted from the EndNote library, the VOSviewer software was used to create network visualization maps describing co-authorship and co-occurrence links in the biogas-related literature. To depict the connections, two visualization methods were utilized: network visualization and overlay visualization, similar to the techniques described by Maphosa and Maphosa (2022). The visualization map usually contains one type of link, and each link has a strength indicated by a positive numeric value. A higher value indicates a stronger link (van Eck and Waltman, 2018). The "link strength" indicates, for example, how many links the five publications have in common (bibliographic linkage links), how many publications have been co-authored by five researchers (co-authorship links), how many publications in which five terms occur together (co-occurrence links). The articles are categorized into clusters, which correspond to items found on the map. It is essential to understand that each element is limited to a single cluster and does not necessarily address every aspects of the map.

Countries

The studies reviewed in the literature analysis focus on public and social acceptance, territorial decision-making, policy impacts, and success factors of projects in different countries and regions (Table 6). In Europe, the emphasis of studies has largely been on the acceptance by the public, the impacts at the regional level, and the governance of territories related to renewable energy projects. The case studies in Pakistan and South Africa focus on household and community acceptance, particularly socio-economic and cultural factors. In the Nordic region, which encompasses Denmark, Sweden, and Finland, investigations are centered on the challenges of settlement, the determinants of site selection, and the prospects of the green economy at various levels, including local and national.

Germany has the highest percentage of publications, followed by France, Pakistan, and Denmark. This distribution illustrates the key focus areas across different countries, with a notable emphasis on Germany, France, and Pakistan. This indicates that these countries are proactively investigating the adoption and integration of renewable energy technologies, especially in the realm of biogas. Each publication emphasizes the importance of social, economic and political dimensions in the adoption and uptake of biogas and renewable energy technologies tailored to the specific needs of each country or region.

Co-authorship analyses

The co-authorship visualization map of the selected 20 documents was performed using VOSviewer. This

Table 6: National or regional areas of the publications

Country/ region	TP	TP(%)	Publication
Germany	5	25	Dobers (2019)
Pakistan	3	15	Kortsch, *et al.* (2015)
Denmark	2	10	Baur *et al.* (2022)
Finland	1	5	Emmann *et al.* (2013)
France	3	15	Schumacher and Schultmann (2017)
South Africa	1	5	Wu *et al.* (2023)
Slovakia	1	5	Jabeen *et al.* (2020)
Poland	1	5	Ahmed *et al.* (2022)
Sweden	1	5	Nielsen (2022)
Europe (Regional)	1	5	Nielsen *et al.* (2022)
Global	1	5	Timonen *et al.* (2021)

Notes: TP: total publications; TP(%): percentage of total publications.

network map depicts the collaborative relationships among 11 authors in the biogas sector, focusing on their co-authorship connections. Each node represents an author, with larger nodes indicating authors with higher collaborative influence. The relationships between the nodes are depicted by lines, where thicker lines signify a greater degree or frequency of co-authorship. The total 62 number authors in my network are not connected. The largest set of connected authors consisted of 11 authors therefore this set of authors was visualized and divided into three distinct clusters, color-coded (Fig. 3). Ahmad *et al*. (2022) demonstrate strong ties to multiple clusters. The interactions between Ahmad *et al*. (2022) and authors from various clusters, including red and green, imply that they functioned as a link, promoting collaboration across different research teams.

Keyword co-occurrence analyses

Keywords are grouped into clusters based on their co-occurrence patterns, indicated by their positions and connected lines. From a total of 225 keywords, 20 have satisfied the criteria in the bibliometric analysis, as shown in Fig. 4, and represent three thematic domains. This keyword co-occurrences network visualization map highlights the interdisciplinary nature of biogas research and the importance of integrating the three dimensions for a comprehensive understanding. Table 7 illustrates the overall strength of the co-occurrence links for each of the 20 keywords. The keywords with the greatest total link strength were selected. The three clusters are the “environment and energy” (central area, red color), the “social acceptance and policy” (left side of the network, green color), and the “technical and scientific systems” (right side of the network, blue color). There are intersections among the clusters; for example, the topic of acceptance is examined in both environmental and economic settings, as well as within social and political realms, demonstrating a multidisciplinary approach to the studies on renewable energy. This may indicate the need to integrate social, technical, and political considerations in energy adaption and sustainability debates.

The “Environment and energy” related cluster focuses on cross-cutting issues in environmental sciences and renewable energies, focusing on adapting and understanding biogas, renewable and wind energy. Additionally, it covers the economic considerations linked to the adaptation and business implications of these technologies. The keywords

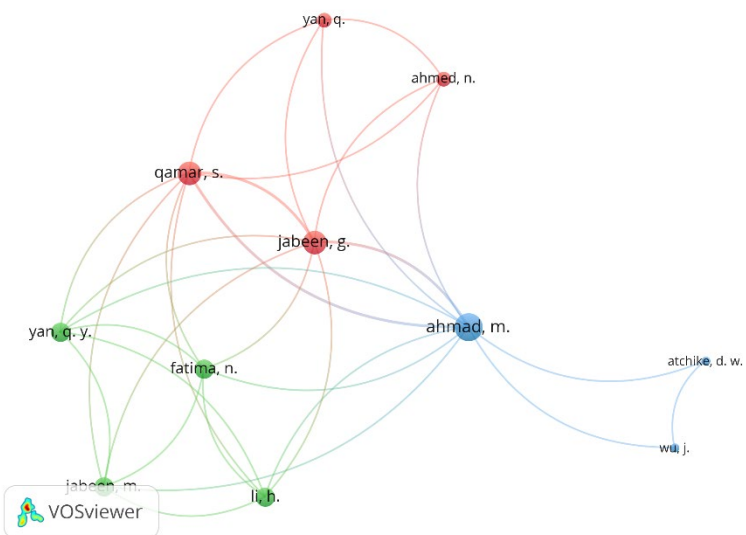

Fig. 3: Co-authorship collaboration network visualization to uncover the existing collaborations between authors contributing to biogas-related research minimum number of publications: 1)

Notes: red cluster: forms a tightly connected subgroup emphasizing specific themes in biogas research; green cluster: highlights another group with strong collaborative ties; blue cluster: centers on Ahmad et al. as a key bridging author linking diverse clusters.

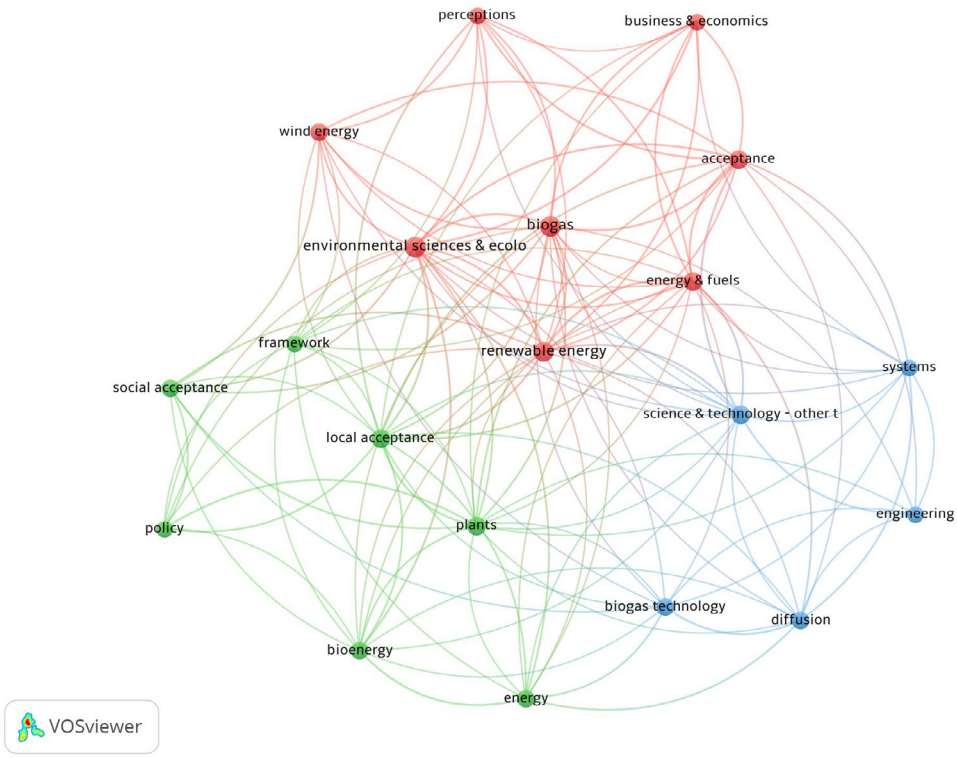

Fig. 4: Keyword co-occurrences network visualization illustrates the relationships between keywords used in biogas adoption studies (minimum number of occurencces of a keyword: 3)

Notes: The map groups keywords into three thematic clusters: (1) environment and energy (red) which focuses on renewable energy and environmental sciences; (2) social acceptance and policy (green) emphasizing social acceptance, frameworks, and policy; and (3) technical and scientific system (blue) covering engineering, diffusion, and biogas technology. The thickness of lines between nodes indicates the strength of co-occurrence between keywords, while proximity reflects thematic connections.

Table 7: Co-occurrences keywords and clusters (n=20)

Cluster No.	Thematic area	Keyword	Occurrences	Total link strength
1	Environment and energy	environmental sciences and ecology	8	36
		biogas	8	30
		renewable energy	7	29
		acceptance	6	30
		energy and fuels	6	28
		wind energy	4	16
		perception	3	17
		business and economics	3	15
2	Social acceptance and policy	local acceptance	6	30
		plants	6	26
		bioenergy	4	19
		energy	4	17
		social acceptance	4	15
		policy	3	12
		framework	3	11
3	Technical and scientific systems	science and technology – other topics	6	22
		diffusion	4	17
		biogas technology	4	15
		systems	3	13
		engineering	3	8

in cluster 1 refer to the general interest in the environmental and economic aspects of renewable energy, emphasizing social acceptance. This cluster, titled "Social acceptance and policy," is centered on the social acceptance and the policy frameworks that govern renewable energy and bioenergy. These keywords highlight the importance of social acceptance and policy. The studies examine the social and regulatory frameworks affecting the acceptance of renewable energy. The "Engineering and scientific systems" focuses on the scientific and technological aspects of renewable energy, with an emphasis on the technical challenges and advancements associated with biogas systems.

In conclusion, the keywords that co-occurrences refer to show patterns of how renewable energy research is interlinked. The key themes and relationships can be identified by analyzing which terms appear together frequently, such as the need for technological progress, social acceptance, and supportive policy frameworks for effective renewable energy adoption. The visualization of the co-occurrence network (Fig. 5) produced by VOSviewer demonstrates the frequency with which keywords appear together in publications related to biogas. The network map is color-coded according to the timeline of publications from 2019 to 2022, represented by a gradient color bar at the bottom of the image.

The network is presented in a chronological gradient, with colours ranging from purple (2019) to yellow (2022), showing when each topic came to the fore. Older themes (shades of purple/blue) are "perception", "business and economics" and "acceptance", indicating early debates focusing on social and economic impacts. More recent themes (shades of yellow) like "systems", "engineering", "diffusion" and "plants" indicate recent areas of interest in engineering and scientific research, reflecting a shift towards engineering-focused studies of renewable energy systems in later years. The co-occurrences network offers a glimpse into the relationships among related renewable energy themes, showcasing the ways in which social acceptance, environmental science, and engineering interact and affect each other. The chronological gradient highlights a transition in priorities: while initial studies primarily addressed social dimensions, there has been a recent trend towards a heightened interest in engineering and scientific progress.

Factors influencing biogas acceptance

In this study, a total of 248 factors have been selected and clustered according to the three dimensions of sustainability. Social, environmental, and economic

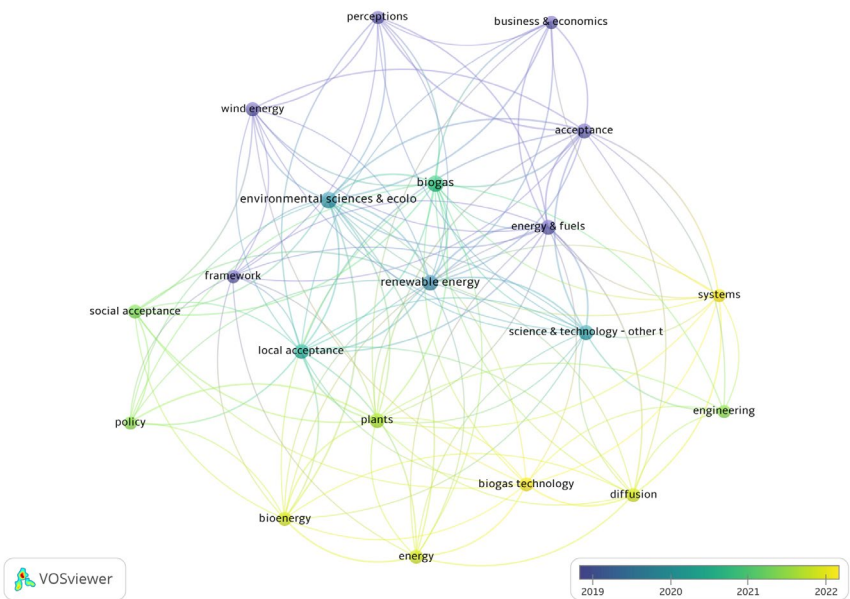

Fig. 5: Keyword co-occurrences overlay visualization (2019-2022)

factors affect the biogas project differently, depending on the country and region. The study conducted by Mukeshimana *et al*. (2021) focused on the barriers to biogas adoption in Rwanda, revealing that social acceptance is the foremost non-technical challenge facing the development of bioenergy initiatives. Rwanda has made significant efforts to promote biogas, particularly to meet rural energy needs and reduce dependence on conventional biomass. The key social factors were public awareness campaigns and educational programs. However, adoption has been hampered by cultural attitudes towards waste as a resource. While government subsidies have helped lower the initial financial burden for low-income families, the substantial maintenance costs still present a considerable obstacle. Biogas systems have contributed to better environmental and health conditions by decreasing deforestation and indoor air pollution. The rise in biogas production has been particularly notable in rural areas, where community-oriented strategies have built trust and promoted active participation among residents (Mukeshimana *et al.*, 2021). Mancini and Raggi (2022) concluded the same result and highlighted three critical factors for social acceptance, which can provide valuable insights into underrepresented regions like South America. Social trust is paramount, particularly in high-income regions, where community acceptance hinges on transparent communication, equitable benefit distribution, and localized governance. In low- and middle-income countries, the interplay of educational and socio-cultural factors, including the living conditions of women, plays a crucial role in determining levels of acceptance. This underscores the need to integrate educational campaigns and gender-sensitive approaches to foster support for biogas projects in rural areas. Biogas acceptance is highly dependent on local contexts. By embedding localized life cycle analysis and adapting project designs to cater to distinct regional demands, the likelihood of project adoption can be significantly increased (Mancini and Raggi, 2022). Mühl and de Oliveira (2022) identified three key dimensions influencing the development of anaerobic digestion (AD) technology in Brazil's agricultural sector: 1) Technological adaptation: Most AD plants in Brazil are small-scale, producing less than 500,000 normal cubic meter (Nm^3) of biogas per year. Tailored technological solutions that accommodate the small-scale nature of these units and their specific biogas applications, such as electricity generation, are crucial; (2) The biogas market is experiencing significant growth; however, there is an absence of cohesive policies and financial incentives to bolster the industry. Current regulations and subsidies are insufficient to drive large-scale adoption; (3) Regional and sectoral characteristics: The distribution of AD plants is concentrated in certain regions, particularly in the Southeast and South, highlighting the need for regional strategies and infrastructure development to expand AD's reach. The agricultural sector, despite its significant contribution to waste generation, produces only 11% of the total biogas, suggesting untapped potential (Mühl and de Oliveira, 2022). Oliveira *et al.* (2024) assessed biogas potential in Brazil, underscoring the sustainability of anaerobic digestion. Environmentally, AD offers significant benefits, including reduced emissions and enhanced waste management, particularly from cattle manure, food waste, and sugarcane residues. The economic analysis indicates a significant potential for renewable energy production, which could reduce natural gas demand by 10–22% and generate biofertilizers that exceed local agricultural requirements. Biogas production contributes to rural development by bolstering small-scale producers and cooperatives, thereby enhancing energy security and promoting sustainability in regions with dense populations. These findings emphasize the need for policy enhancements to unlock the region's biogas potential fully (Oliveira *et al.*, 2024). The development of biogas production in Colombia highlights critical socio-economic, technological and environmental dimensions (Rocha-Meneses *et al.*, 2023). From a socio-economic standpoint, it supports rural livelihoods, fosters job creation, and enhances energy independence, thereby encouraging sustainable growth. From a technological perspective, advances in anaerobic digestion and centralized biorefineries are increasing efficiency, although challenges such as high costs and limited infrastructure remain. From an environmental standpoint, the generation of biogas helps to decrease GHG emissions, supports sustainable waste management solutions, and presents environmentally-friendly alternatives, including organic fertilizers (Rocha-Meneses *et al.*, 2023). To determine which factors have had the highest impact on the acceptance of biogas, factors

that recur frequently in several studies within each dimension of sustainability were explored. The factors were structured into the three dimensions of sustainability to identify the most commonly emphasized dimensions. Fig. 6 illustrates the complexity of biogas deployment according to the key influencing factors identified along the three dimensions. Each category highlights essential elements necessary for sustainable and fair decision-making. The environmental factors emphasize the location of biogas plants, the associated environmental advantages and risks, such as pollution and odors, as well as the ecosystem resilience. These considerations underline the importance of assessing ecological impacts, like forest loss, emission levels, and the compatibility of projects with environmental policies and spatial planning rules. Other factors, such as heritage conservation and the availability of sustainable resources, underline the need to ensure environmental sustainability and long-term resource management.

The role of social factors underscores the significance of public endorsement, trust in governmental institutions, and the concepts of and procedural and distributive justice. Stakeholder engagement through community involvement, education, and transparent communication is critical to fostering social acceptance. Moreover, securing socio-political support, performing comprehensive risk evaluations, and ensuring just decision-making practices are vital for building trust and encouraging acceptance by local communities. Economic factors address the financial viability and economic benefits of projects. Key considerations include cost and profitability, energy market dynamics, and infrastructure feasibility. The importance of financing, subsidies, and resource efficiency cannot be overstated in achieving operational sustainability.

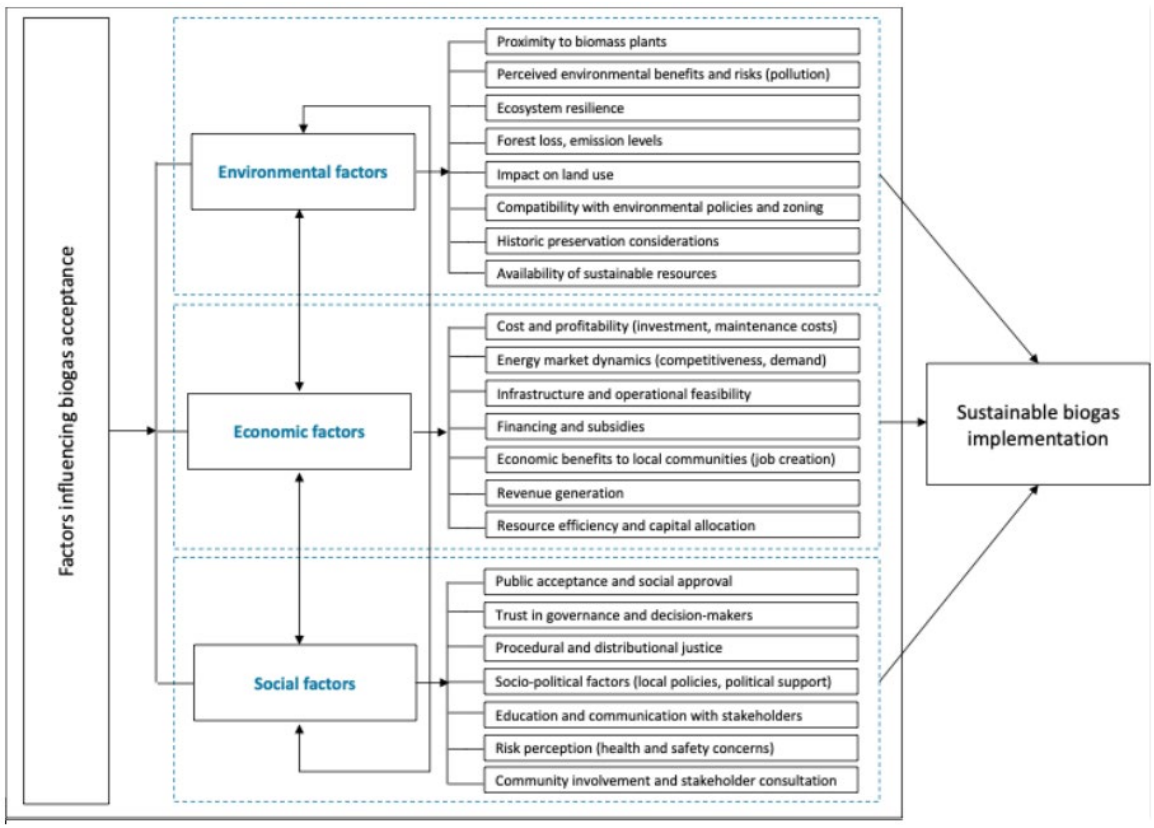

Fig. 6: Multidimensional model of biogas adoption and the relationship among the identified key influencing factors

Table 8: Ranking of key factors influencing biogas acceptance based on weighted analysis

Considerations of sustainability impact	Indicator No.	Methods	Weight	Weight score	Sources
Factors affecting success/failure of biogas projects	10	Quantitative and qualitative analysis	High	3	Bourdin *et al.* (2020)
Key factors in site selection for biogas plants	12	Interviews, focus groups, doc. analyses	High	3	Feiz *et al.* (2022)
Spatial-economic variables and renewable energy sources	21	Spearman's rank correlation	High	3	Hernik *et al.* (2019)
Diffusion of innovation factors for biogas acceptance	21	Questionnaire survey	High	3	Ahmed *et al.* (2022)
Success factors in centralized biogas project's lifecycle	30	Process analysis, interviews	High	3	Nielsen *et al.* (2022)
Regional determinants for biogas production setup	11	Empirical analysis	High	3	Coll-Martínez *et al.* (2024)
Longitudinal analysis of public acceptance of biomass plants	9	Questionnaire survey	High	3	Kortsch *et al.* (2015)
Territorial governance impacts on biogas projects	5	Semi-structured interviews	High	3	Bourdin *et al.* (2019)
Challenges and drivers for centralized biogas plants	18	Case studies, semi-structured interviews	High	3	Nielsen (2022)
Factors affecting biomethane technology acceptance	24	Logistic regression model	High	3	Wu *et al.* (2023)
Indicators for green economy and social acceptance	9	DSR model, interviews	Medium	2	Timonen *et al.* (2021)
Local acceptance in cross-national study	7	Multiple regression, GIS	Medium	2	Schumacher and Schultmann (2017)
Individual acceptance of biogas innovation	6	Structural equation model	Medium	2	Emmann *et al.* (2013)
Global factors influencing social acceptance of biogas	14	Systematic literature review	Medium	2	Mancini and Raggi (2022)
Household-based factors for biogas technology utilization	15	Probit regression model	Medium	2	Jabeen *et al.* (2020)
Public perception and policy impacts on biogas	11	Interviews	Medium	2	Kulla *et al.* (2022)
Social acceptance of energy technologies	10	Questionnaire survey	Medium	2	Baur *et al.* (2022)
Social acceptance and public involvement in Europe	8	Comparative case studies	Medium	2	Segreto *et al.* (2020)
Impact of spatial factors on biogas plant acceptance	6	Questionnaire survey	Medium	2	Dobers (2019)
Naturalness and social rejection factors	1	Questionnaire survey, focus groups	Low	1	Dumont et *al.* (2021)

Furthermore, economic benefits, including the creation of jobs and the generation of revenue, are vital for promoting community development. Integrating these factors emphasizes the importance of balancing short-term feasibility with long-term economic benefits. Table 8 presents an analysis of the factors frequently mentioned within each category. The studies are ranked according to their weight, with those marked "High" at the top. The weighted score is determined by the frequency and significance of the factors emphasized in each study, which are used to evaluate the quality of the publications. For the weighted analysis of the factors influencing the biogas acceptance, weighted scores were assigned based on how often each factor was mentioned in the studies, resulting in publications weighted by a score of 1 to 3. Factors that are mentioned more frequently were given a higher score. The assigned weight for publications indicates the overall quality and the rigor of the methodology employed in each study. The weight scores within each sustainability dimension were normalised, and the overall normalised score for the studies were calculated (Table 9) to allow a balanced comparison of studies.

The normalized score serves as an aggregate measure of the influence of all dimensions for each study, presented on a consistent scale. Figs. 7 and 8 illustrate a thorough comparison of how each study affects sustainability factors. In the case of Nielsen *et al.* (2022), four, and Wu *et al.* (2023), two "other" factors were also included in their study. The "other" factors include the "variety of size and continuity of use across seasons" or the "cooking time and fuel utilization". However, the present study focuses only on the environmental (EN), economic (EC), and social (S) factors; only the total normalized score obtained from these three aspects was calculated.

Fig. 7 highlights the contribution of environmental, economic, and social factors by authors. Nielsen *et al.* (2022) show a higher contribution in all dimensions, especially for environmental (EN) and economic (EC) factors. Certain scholars, including Mancini and Raggi (2022), concentrate on specific aspects, providing important insights into social factors. Fig. 8 illustrates the authors' overall normalized score. Nielsen *et al.* (2022) have the highest overall score, indicating a balanced and significant contribution across dimensions. Dumont *et al*. (2021) have a minimal

Table 9. Normalized comparison of sustainability dimensions across studies

N	EN	EC	S	Norm EN	Norm EC	Norm S	Overall norm	Sources
30	5	11	10	0.08	0.15	0.09	0.33	Nielsen *et al.* (2022)
24	2	5	15	0.03	0.07	0.14	0.24	Wu *et al.* (2023)
21	5	7	9	0.08	0.09	0.08	0.26	Ahmed *et al.* (2022)
21	10	9	2	0.17	0.12	0.02	0.31	Hernik *et al.* (2019)
18	3	7	8	0.05	0.09	0.07	0.22	Nielsen (2022)
15	2	6	7	0.03	0.08	0.06	0.18	Jabeen *et al.* (2020)
14	0	0	14	0.00	0.00	0.13	0.13	Mancini and Raggi (2022)
12	3	6	3	0.05	0.08	0.03	0.16	Feiz *et al.* (2022)
11	4	4	3	0.07	0.05	0.03	0.15	Coll-Martínez *et al.* (2024)
11	6	2	3	0.10	0.03	0.03	0.16	Kulla *et al.* (2022)
10	3	2	5	0.05	0.03	0.05	0.12	Baur *et al.* (2022)
10	1	3	6	0.02	0.04	0.06	0.11	Bourdin *et al.* (2020)
9	2	3	4	0.03	0.04	0.04	0.11	Kortsch *et al.* (2015)
9	4	1	4	0.07	0.01	0.04	0.12	Timonen *et al.* (2021)
8	2	1	5	0.03	0.01	0.05	0.09	Segreto *et al.* (2020)
7	2	2	3	0.03	0.03	0.03	0.09	Schumacher and Schultmann (2017)
6	3	1	2	0.05	0.01	0.02	0.08	Dobers (2019)
6	1	2	3	0.02	0.03	0.03	0.07	Emmann *et al.* (2013)
5	1	2	2	0.02	0.03	0.02	0.06	Bourdin *et al.* (2019)
1	0	0	1	0.00	0.00	0.01	0.01	Dumont *et al.* (2021)
248	59	74	109	-	-	-	-	

Notes: Factor counts: N (Total), EN (Environmental), EC (Economic), S (Social); Normalized scores: Norm_EN, Norm_EC, Norm_S, Overall Norm Score. In the case of Nielsen *et al.* (2022) four and Wu *et al.* (2023) two "other" factors were included in their study, but since the present study focuses only on the EN, EC, and S factors, only the total normalized score obtained from these three aspects was calculated.

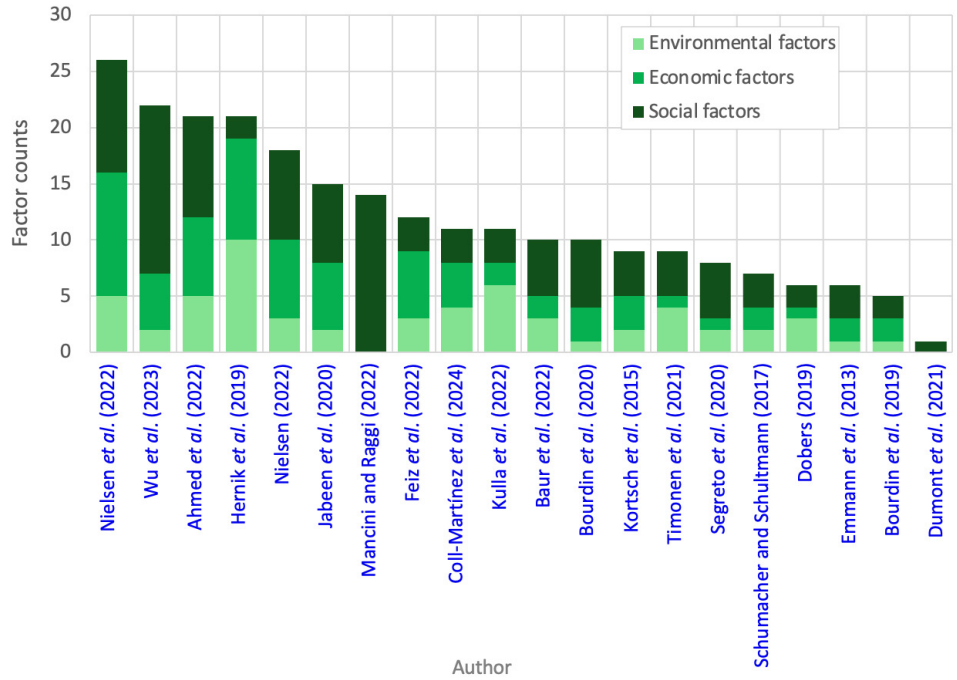

Fig. 7: Factor contribution by authors

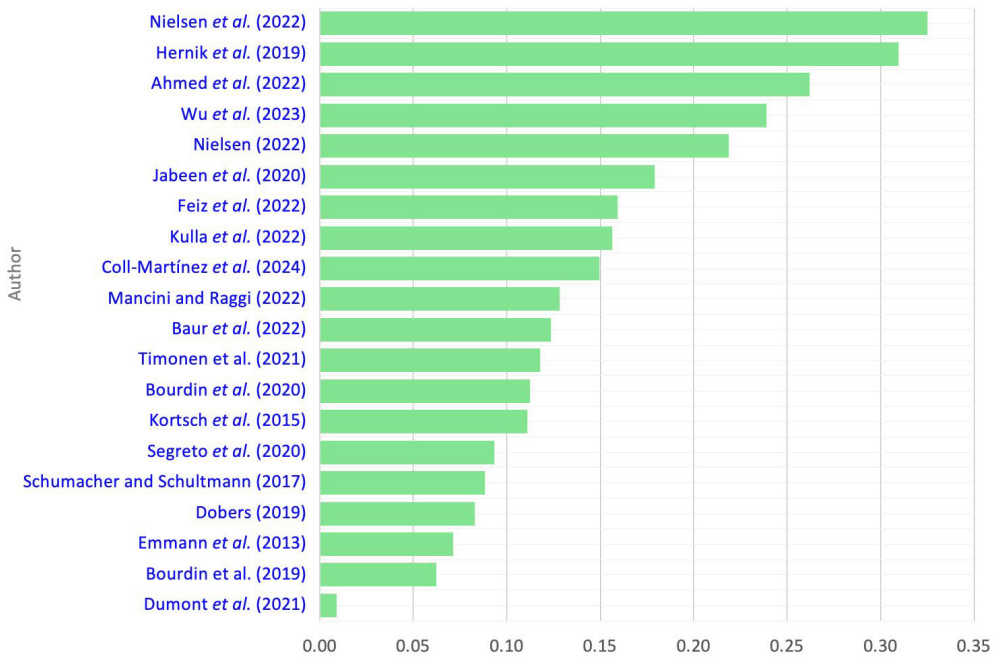

Fig. 8: Overall normalized scores by authors

Table 10: Distribution of the influencing factors in biogas adoption

Factors	Total No.	%	Max	Min	Average	Median	Standard deviation (SD)
Environmental	59	24.4	10	0	2.95	2.5	2.33
Economic	74	30.6	11	0	3.7	2.5	3.08
Social	109	45	15	1	5.45	4	3.95

overall normalized score, as their contribution across dimensions is low.

Many authors highlight a crucial trend where environmental and economic factors play a leading role. Social contributions are more variable, with some studies focusing on this aspect (Mancini and Raggi, 2022). The distribution of factors influencing the acceptance of biogas according to the three dimensions of sustainability shows that social factors dominate with 45%, followed by economic factors (31%), while environmental factors (24%) are the least prominent (Table 10). Although biogas production greatly diminishes GHG emissions relative to fossil fuels, it also introduces important ecological trade-offs that necessitate careful assessment to guarantee sustainable results. A large amount of fugitive methane (CH_4) is emitted from the biogas supply chain, during feedstock handling, anaerobic digestion, feedstock storage, and distribution can undermine its environmental benefits (IEA Bioenergy, 2019; Nisbet *et al.,* 2020). The digestate stage generated the most methane () which has a 27.2 ± 11 times greater global warming potential (GWP) than carbon dioxide (CO_2) over the 100-year horizon (IPCC, 2021). Methane emissions from the biogas supply chain surpass those from fossil fuels. Scheutz and Fredenslund (2019) conducted measurements of total methane emissions across 23 biogas plants located in Denmark. It was found that methane emission is between 0.4 and 15%, and the average emission from agricultural biogas plants is 2.4%. Biogas production could require substantial land for feedstock cultivation, storage, and infrastructure (Patinvoh and Taherzadeh, 2019; Jameel *et al.,* 2024). Focusing on the cultivation of specific energy crops for biogas may create competition with food production, contribute to deforestation, and threaten biodiversity. Furthermore, the use of digestate, which is produced through anaerobic digestion, as a fertilizer carries both benefits and potential risks (Chojnacka and Moustakas, 2024). While it enriches soil with nutrients, excessive or improper application can lead to nutrient runoff and water contamination. Biogas projects contribute to ecosystem services by reducing organic waste in landfills, mitigating landfill methane emissions, and recovering valuable resources (Obaideen *et al.,* 2022). These projects need to be thoughtfully crafted to ensure they are in harmony with local ecological conditions and to mitigate potential negative effects, such as habitat disruption or over-extraction of biomass resources. Integrated planning that considers regional ecological sensitivities can optimize the environmental benefits of biogas systems. Economic factors show a slightly higher spread (standard deviation) than environmental factors, which implies that there is more variability in how they are identified in different publications. Environmental factors have the lowest overall average (mean) and total count, indicating that they are less emphasized than the other two dimensions.

Social factors have a higher maximum (15) than environmental factors (10), reflecting greater focus in certain studies. The minimum value for social factors is 1, while environmental factors have a minimum of 0, suggesting that some studies entirely omit environmental considerations. Social factors, with an average of 5.45, are notably more emphasized than environmental factors, which have an average of 2.95. This indicates a consistent trend of greater focus on social factors in various studies. The standard deviation for social factors is 3.95, surpassing the 2.33 standard deviation observed for environmental factors. This suggests that the identification of social factors varies more significantly across studies. Social factors dominate consistently in all metrics, showcasing a more substantial and widespread focus in research on biogas acceptance. Environmental factors are less frequently emphasized, with lower averages and a more minor total count, though their variability is narrower.

Recommendations and future direction

Biogas is increasingly becoming a key component of global renewable energy sources, therefore addressing the multidimensional challenges is essential to ensure its widespread deployment and long-term sustainability. By merging technological innovations, socio-economic aspects, and a solid policy framework, we can create an opportunity to boost the implementation of biogas technology. This requires tailored strategies that take into account local cultural, environmental and economic contexts while building on lessons learned from successful implementations worldwide. The following recommendations and future directions outline key actions and innovative approaches to maximize the uptake of biogas, optimize the environmental and social benefits and minimize the associated challenges. These strategies are designed to offer policymakers, stakeholders, and researchers valuable insights that can guide the evolution of biogas initiatives moving forward. Standardized requirements for biogas projects can reduce uncertainties in permitting processes and limit discretionary decisions that increase development risks. It is essential to recognize that the location and approval of renewable energy initiatives cannot be governed by a singular policy framework, as regional disparities in cultural, political, social, and environmental attributes exist. To address these challenges, a centralized "one-stop shop" permitting system is recommended to streamline approval processes. Clear guidelines for community participation are essential to incorporate local input into project siting and design phases, ensuring projects align with community needs and priorities. The role of governments is crucial in defining standards and ensuring that local ordinances do not impede or restrict the progress of project development. Having transparent permitting schedules and consistent deadlines can streamline the review and approval process, ultimately improving the chances of project success. Early community engagement and consistent communication are key to addressing local resistance, which often stems from concerns about land use and visual impacts. Direct, on-the-ground engagement with local communities fosters trust and mutual understanding, enabling companies to identify and address concerns during the flexible stages of project planning. From an ecological standpoint, it is crucial to formulate and execute robust methane reduction strategies at all levels of the biogas supply chain. Prioritizing the use of agricultural residues, organic waste, and manure as feedstock minimizes land-use conflicts and aligns with the principles of a circular economy. Policies should emphasize the use of non-food biomass to reduce ecological pressures. Investigating optimal practices for digestate management and the associated regulatory frameworks is crucial for reconciling the agricultural benefits of digestate with the possible environmental hazards. The ecological trade-offs of biogas adoption, such as methane leakage, land-use conflicts, water contamination, and resource over-extraction, require careful management to maximize benefits while minimizing harm. Addressing these challenges demands advanced technologies, robust policy frameworks, and proactive stakeholder engagement to achieve long-term ecological balance. Recognizing regional variations in adoption barriers, future strategies should integrate cultural, social, and economic contexts into global policy frameworks to create region-specific solutions. Recognizing the critical role of social factors, the implementation of participatory governance models is suggested to ensure that all stakeholders are fairly represented, which in turn promotes trust and acceptance of the project. Research should focus on innovative financial solutions such as community-based financing models, public-private partnerships, and subsidy optimization tailored to resource-constrained regions. Future studies should also examine the long-term impacts of stakeholder governance, particularly the role of third-party organizations, in building trust and ensuring equitable outcomes in biogas deployment. These coordinated initiatives will enhance the sustainable advancement of biogas as an effective renewable energy solution.

CONCLUSION

This study conducts a thorough analysis of the determinants impacting the acceptance of biogas, employing a systematic literature review and bibliometric analysis to highlight the sustainability dimensions of environmental, economic, and social factors. The results demonstrate the multidimensional complexity of biogas technology adoption, emphasizing the interplay between technical, social, and policy factors. Social factors are the most significant determinants of biogas adoption,

based on trust in governance, procedural equity, public involvement, and community-level benefits. Procedural equity emphasizes the importance of fairness in the decision-making procedures, ensuring that all relevant stakeholders have an equal opportunity to participate and articulate their concerns. Community-level advantages pertain to the beneficial impacts that biogas initiatives can provide to local populations. These benefits may include job creation during project construction, operation and maintenance and increased demand for local goods and services; improved access to clean and reliable energy that can increase energy independence and reduce dependence on fossil fuels; reducing air pollution and GHG emissions, which can lead to improved public health and environmental conditions in the community; community members can receive training in biogas technologies, leading to skills development and long-term career development; the improved infrastructure, such as roads or transmission lines, built as part of a project can benefit the wider community. The role of economic factors, such as financial incentives, subsidies, and operational costs, is vital in mitigating adoption barriers, especially in rural and developing regions. Financial incentives in biogas projects are designed to encourage development and deployment by reducing upfront costs, improving profitability, and ensuring long-term sustainability. Governments can provide direct financial support to cover a portion of the project's costs, like the equipment, construction, or infrastructure costs. Tax incentives facilitate the reduction of taxable income by allowing the deduction of investment costs or can provide tax benefits based on the quantity of energy produced from biogas. Fixed payments for biogas energy fed into the grid, ensuring a steady revenue stream. Government-backed or subsidized loans provide favorable terms for financing biogas projects, reducing financial risks for developers. Biogas projects that reduce GHG emissions can gain carbon credits on international or regional carbon markets and sell them for additional revenue. Incentive programs for energy efficiency recognize biogas initiatives for their contributions to lowering total energy usage or enhancing the effectiveness of waste-to-energy operations. Public-private partnerships (PPPs), can be set up to work with governments or other organizations to share costs, reduce risks and provide long-term support for project operations. Although less pronounced, environmental considerations play a pivotal role in assessing the ecological benefits of biogas, including emission reduction, waste management efficiency, and compatibility with environmental policies. Regional differences highlight the importance of adapting strategies to local circumstances. In Europe, policy harmonization, stakeholder governance, and advanced infrastructure dominate, while affordability, education, and access to resources are priorities in developing regions. Stakeholder management encompasses the proactive engagement of all pertinent stakeholders, including community members, government entities, developers, and external organizations, throughout the decision-making, project design, and implementation phases. The analysis underlines that the successful deployment of biogas depends on a balanced approach that integrates all three dimensions of sustainability. The systematic review and bibliometric analysis identify several critical factors, including transparent communication, participatory governance, and targeted financial mechanisms, as critical to promoting uptake. Conversely, barriers such as mistrust, lack of awareness, and uneven decision-making processes must be systematically addressed to achieve widespread adoption. In conclusion, biogas holds great promise as a sustainable energy alternative, as long as the strategies for its implementation are crafted to be inclusive, contextually suitable, and consistent with the tenets of environmental sustainability, economic viability, and social equity. Future research should focus on longitudinal and interdisciplinary studies to better understand evolving societal perceptions, economic trends, and environmental impacts, thereby ensuring that biogas systems contribute meaningfully to global renewable energy goals.

AUTHOR CONTRIBUTIONS

K. Biró was responsible for conceptualizing the draft, searching the bibliography, selecting the relevant references, coding the references, writing the initial manuscript draft, synthesizing the manuscript, and revising the final manuscript version. K.S. Woon was responsible for reviewing the whole manuscript and validating it. W. Ounsaneha was responsible for the project administration and resources. C. Rattanapan was responsible for reviewing the whole manuscript,

supervising the research, and responsible for the funding acquisition.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy, have been completely witnessed by the authors.

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ABBREVIATIONS

%	Percent
AD	Anaerobic digestion
AEBIOM	European Biomass Association
ALFA	Scaling up the market uptake of Renewable Energy Systems by unlocking the biogas potential of Agriculture and Livestock FArming
bcm	Billion cubic metres
CH_4	Methane
CO_2	Carbon dioxide
DST	Decision Support Tool
EBA	European Biogas Association
EC	Economic
e.g.	Exempli gratia/for example
EN	Environmental
Eq.	Equation
EU	European Union
Fig.	Figure
GHG	Greenhouse gas
GWP	Global warming potential
h-index	Hirsch-index
IEA	International Energy Agency
IESR	Institute for Essential Services Reform
IPCC	Intergovernmental Panel on Climate Change
NIMBY	Not in my back yard
Nm^3	Normal cubic meter
NR	Not reported
PJ	Petajoule
PRSIMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PPS	Public-private partnership
RES	Renewable Energy Systems
RIS	Research Information Systems
SD	Standard deviation
S	Social
TP	Total publications
UK	United Kingdom
VOS	Visualization of similarities
WoS	Web of Science

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