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Research article

From manure to megawatts: Navigating the sustainable innovation solution through biogas production from livestock waste for harnessing green energy for green economy

Mohsen Brahmi [a,*], Bruna Bruno [b], Karambir Singh Dhayal [c], Luca Esposito [b,d], Anna Parziale [e]

[a] Department of Economic Sciences, University of Sfax, Tunisia
[b] Department of Economics and Statistics, University of Salerno, Italy
[c] Department of Economics and Finance, Birla Institute of Technology and Science (BITS), Pilani, Rajasthan, India
[d] Karelian Institute, University of Eastern Finland, Joensuu, Finland
[e] Department of Business Sciences - Management & Innovation Systems/DISA-MIS, University of Salerno, Italy

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ABSTRACT

This article aims to provide a systematic review of the literature on animal biomass and biogas plants through an analysis of externalities and benefits in economic, social, and environmental terms. In recent years, the spread of biogas plants has played an important role, especially in rural areas, generating benefits not only for the individual farm but for entire communities, contributing to the reduction of energy poverty and, at the same time, promoting the production of energy and organic manure. In light of the findings, the study argues that: (a) more public subsidies are needed; (b) the deployment of an appropriate policy mix would encourage the spread of small and medium-sized plants, with a reduction in road transport; and (c) targeted and diversified investments are needed on a geographic-by-geographic basis.

1. Introduction

Environmental issues and sustainable growth have become essential topics when it comes to innovation and technological development [1,2]. However, the term sustainable often has a vague meaning and an unspecified contextualization in relation to the technology or application in question [3]. A process can be defined as sustainable if it uses natural resources at such a rate that they can be regenerated naturally. For years now, scientific evidence has indicated that humanity is living in an unsustainable way, consuming the Earth's limited natural resources faster than it is able to regenerate them. In essence, humanity has followed and is still following the path of development that ensures the satisfaction of the needs of the present generation but irreversibly compromises the possibility of future generations realising their own [4–6]. It is necessary to change the model and, probably, the concept of development. Another problem closely related to the irrational exploitation of resources is the production of enormous quantities of waste and the transformation of products into waste too quickly. Technological and scientific development should not only encourage but also prevent and bring solutions to this situation. The technological scenario is closely connected with the sustainability of production

* Corresponding author.
E-mail addresses: brahmi.mohsen@gmail.com (M. Brahmi), brbruna@unisa.it, lucaesposito1@unisa.it (B. Bruno), karambirsinghdhayal@gmail.com (K.S. Dhayal), luca.esposito@uef.fi (L. Esposito), aparziale@unisa.it (A. Parziale).

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processes and human actions in general, strongly influencing the impacts they have on the ecological system. In this context, the use of energy sources assumes an enormously important role. Putting these two aspects together, it is clear that, in addition to minimising the production of waste, from the perspective of a sustainable economy, it is necessary to consider waste as a resource with potential yet to be used. Often, this potential is an energy potential [1,7]. The production of biogas starting from organic matrices that can be subjected to the anaerobic digestion process fits perfectly into this context, enabling the development of green energy and the promotion of the green economy [8,9]. The organic matrices that can be used are of various types: agricultural biomass, agricultural by-products, industrial waste, sewage sludge, organic fractions of municipal solid waste, and various by-products of animal and/or vegetable origin. The construction of biogas production plants, both agricultural and industrial, makes it possible to achieve numerous advantages, especially in the energy and environmental fields, through the valorization of matrices that often represent environmental problems for their disposal. If well designed and well built, a biogas plant can operate at high levels of efficiency and energy yield, making the investment worthwhile. However, it is logical to ask when a biogas plant is truly sustainable, according to the considerations previously set out. Without wanting to go into too much technical detail, the construction of biogas plants is justified if they use waste materials from other processes or organic waste, while those plants that use agricultural biomass consisting of silage from specially cultivated plants (crop energy). The incentives for biogas plants also reward the use of matrices other than dedicated agricultural ones, providing greater incentives for the use of by-products [2,10].

Energy from biogas therefore represents one of the most widely used alternative sources to fossil energy. The big advantage is the possibility of reusing waste materials, giving them economic, environmental, and social value. It is possible to produce electricity from biogas using this energy resource in specific thermoelectric plants. Furthermore, biogas energies have zero environmental impact; in fact, biogas emissions can be considered net zero, i.e., no new carbon dioxide is released into the atmosphere compared to that previously absorbed by plants. Thanks to the high calorific value of biogas, it is easily converted into electricity and heat. Among the other characteristics of biogas is the absence of odour, while the solid and liquid fractions deriving from anaerobic digestion (digestate) have an important agronomic value [11]. For these reasons, biogas is considered an essential resource for the transition towards a 100 % green, renewable, and sustainable energy system [12].

The energy crisis made clear the need to move towards an increasingly renewable and sustainable generation of energy and also pushed the strategic choice to encourage the production of biogas and on the path towards sustainability, energy efficiency, and the circular economy [13,14]. Added to this is the possibility of "exploiting all the existing production potential to renew other production chains as well. And among these potentially "carbon negative" supply chains, the agricultural one is not lacking, which is particularly useful for developing countries, especially in rural areas, with regard to biogas production from livestock manure [15,16]. Although biogas systems cost less than some other technologies, providing them is often still a challenge for low-income households in developing countries, especially rural areas [17–19]. Many of these families need financial and technical assistance to build them. Both governments and non-governmental organisations can step in to help in this area [20]. However, once people have biogas systems in place with minimal system maintenance, they can live healthier and more comfortable lives while reducing their impact on the environment.

The present study holds significance because most of the review studies on this topic have been centered on a particular country or region. For example, China [21–26], Iran [27,28], Italy [29,30], the Canary Islands [31], Europe [32,33], Bangladesh [34,35], Sub-Saharan Africa [36,37], Nigeria [38,39], Taiwan [40,41], and India [42,43].

The present study has done a comprehensive review of all the research domains with a time period up to 2023, which makes it exhaustive. Moreover, the article discusses the role of biogas in combating climate change through reduced fossil fuel consumption to attain sustainable development goals. Biogas production from livestock manure not only reduces dependence on renewable energy sources, but it is also related to the mitigation of climate change problems and eventually results in sustainable development. In this framework, we conduct a literature review with the aim of synthesising the main results of economic research, deriving conditions for policy intervention, and assessing the relative efficacy of different kinds of interventions.

The methodology employed is [44–46]. This methodology consists of five operational steps, as described in Table 2. Considering the results, the study argues that more public subsidies are needed for the diffusion of biogas plants, and the important role of the policy mix would favour the spread of small and medium-sized plants with a reduction in road transport. Another interesting aspect is related to investments and incentives that should be provided according to the characteristics of individual geographic areas.

This paper provides a valuable contribution by offering a comprehensive review of the economic and environmental research on biogas production from livestock manure. Through the analysis of existing literature, the paper outlines a clear framework for understanding the advantages and disadvantages of biogas production, as well as the main policy interventions that have been implemented to promote its adoption. The paper also classifies these interventions according to their relative efficacy in achieving specific targets, providing important insights for policymakers and researchers.

This project will attempt to provide an answer to the following research questions.

1 A quantitative assessment of the research domain through publication trend, document classification, top countries, and the use of top keywords.
2 A qualitative assessment of the research domain is needed to identify the major areas of future research.

Specifically, the Data Finding section will respond to RQ1, and the Discussion section will respond to RQ2. The paper is structured as follows: i) literature background; ii) methodology; iii) data findings; iv) discussion; v) conclusions; vi) limitations and future research.

2. Literature background

Biogas production from livestock manure is a subject of interest for economic and environmental studies (Table 1). Biogas is a renewable energy source produced by the anaerobic digestion of organic matter, such as livestock manure [3,15]. The growing demand for animal products is driving a large volume of biodegradable waste in the form of livestock manure suitable for biogas generation worldwide. However, this has remained an untapped potential for years [47,48]. Building a biogas plant for a rural house is much easier than building other types of plants [49]. The benefits of biogas production from livestock manure are numerous, including reducing greenhouse gas emissions, reducing dependence on fossil fuels, and improving the economic viability of livestock farming. We can classify the main advantages into macro-environmental advantages and microeconomic advantages for farmers.

From the macroenvironmental perspective, the first and more straightforward advantage, as we have already mentioned above, is that biogas production from livestock manure can also help to reduce the dependence on fossil fuels and to create an energy surplus, implying a displacement of fossil fuels [11,65,66] and consequently the dependence on imported sources of energy [4,7,49]. Furthermore, considering that biogas can be used to generate electricity and heat, it can reduce the demand for electricity and natural gas from the grid.

From an environmental perspective, production from livestock manure can help mitigate climate change because, unlike fossil fuels, it is permanently renewable [11,13,67–72]. Anaerobic digestion systems are beneficial to developing countries because they are low-cost compared to other technologies, low-tech, low-maintenance, and safe. They provide reliable fuel and improve public health and sanitation. It should be noted that biogas from livestock manure facilities themselves can produce unintended gas emissions that could undercut the environmental benefits of these technologies, which requires appropriate facility design and management to fully harness their benefits [47,73–75]. They also save people the work of collecting large quantities of firewood, freeing them up for other tasks [16]. Therefore, livestock-manure-based energy systems can contribute to rural development. Biogas for rural areas has other environmental benefits [4]. It reduces the need to burn wood for domestic use, slowing down deforestation and eliminating emissions that would otherwise be produced. Many advances in biogas production have been explored, taking into account that different manure management modes can be used [76] and that different technical processes can improve biogas production through co-digestion [3,11, 77–80]. Biogas plants can involve both high-tech and low-tech digesters, ranging from industrial-scale plants to small farms and even households [81]. They represent an alternative for the decentralised production of bioenergy in rural areas. Indeed, the biogas produced can be used in stoves, engines, cogeneration units, and even kitchens at home [10]. Nevertheless, digesters are considered a sustainable technology capable of improving the living conditions of farmers by covering energy needs and stimulating nutrient recycling [4]. Thanks to their technical, socio-economic, and environmental advantages, rural biogas plants have spread throughout the world since the 1970s, with a large focus on agricultural and domestic systems. There are several opportunities to introduce rural biogas plants to small and medium populations using wastewater, agricultural waste, and organic municipal solid waste. However, several challenges still need to be overcome to improve the technology, financial viability, and uptake [19,34,49,82].

From the microeconomic perspective, benefits for farmers in employing biogas plants are in the additional income they can generate from their livestock operations [19,72,83–86] and in the reduced cost of manure management, especially for labour and

Table 1
Overview of other literature review studies on biogas.

Source	Outcome/Significance of the study
(Kougias & Angelidaki, 2018) [50]	It gave perspectives on the biogas production from anaerobic digestion.
(Balat & Balat, 2009) [51]	It reviews the role of biogas as an alternative energy source.
(Paolini et al., 2018) [52]	Biogas benefits are being discussed along with their impact on the environment.
(Jiang et al., 2011) [53]	Biogas energy production for the rural environment of the China is being discussed.
(Raven & Gregersen, 2007) [54]	It describes the success and the failure of biogas plants in Denmark.
(Kapoor et al., 2019) [55]	Review of the advanced technologies is done which are useful to upgrade the existing biogas plants.
(Mittal et al., 2018) [56]	Several barriers were identified which act as hindrance for the dissemination of biogas in India.
(Chen et al., 2023) [57]	It provides a comprehensive examination of the alkaline hydrolysis (AH) of livestock manure during AD.
(Sakar et al., 2009) [58]	Review of the performance of the different anaerobic process configurations and operational conditions used in poultry and livestock waste treatment.
(Lu et al., 2021) [24]	China's biogas production and development in rural areas is being discussed.
(Nasir et al., 2012) [59]	It reviews the potential of anaerobic digestion (AD) for biogas production from livestock manure wastes and compares the operating and performance data for various anaerobic process configurations.
(Tauseef, S. M. et al., 2013) [60]	A review of the traditional ways of methane capture used in India, China, and other developing countries for providing energy to the rural poor, and of methane capture from livestock manure in developed countries.
(Zhang et al., 2020) [18]	It aims to provide a comprehensive understanding on the opportunities and challenges of membrane processes in the concentration of digested effluent for their further implementation.
(Magrí et al., 2013) [61]	It provides an overview of published studies on ANR. Specific issues related to the applicability of the process for treating manure digestates are discussed.
(Wang et al., 2021) [62]	It investigates the current status of the livestock industry in China and assesses the potential for biogas production from anaerobically digested livestock manure.
(Shi et al., 2018) [63]	Technologies focused on nutrient recovery from digestate are reviewed and compared, and challenges are deliberated.
(Yang et al., 2022) [64]	A review of research implications and a new avenues in the field of bioenergy conversion of livestock manure from a perspective of fates and conversion of antibiotics.

Table 2
Operational process for systematic literature.

Stage	Procedure	Objective
1	Database selection	Selection of Suitable Databases for Research Papers on the Chosen Topic
2	Keywords	Identifying Optimal Keywords for Retrieving Relevant Research Papers on our Desired Topics
3	Filter specification	Selecting Appropriate Filters to Exclude Low-Quality or Irrelevant Work from the Entire Sample for our Purpose
4	Selecting articles	Choosing Alternative Methods to Ensure Significant Relevance and Pertinence of the Selected Papers
5	Refine	Reviewing the Abstract, Introduction, and Conclusion of the Selected Articles, Considering Journal Relevance and Citation Count to Eliminate Potential False Positives

energy costs [15,87–90]. Furthermore, farmers can obtain high-quality fertilisers to consequently increase crop yields [71]. Also, better living standards can be observed in farms adopting these technologies [91]. A debate on the potential advantages of biogas production is focused on the farm dimension, which is better conducive to environmental and economic plant efficiency. For some authors, the development of larger-scale farms enhances reaching environmental gains with more positive externalities [92]. Other authors underline that biogas production can be efficient and productive on small farms [81,86,93] according to the social and economic conditions in the area [94].

Biogas also helps farmers drastically reduce the negative externalities of their activities and allows them to recycle organic nutrients and restore soil fertility and is a crucial resource for the present and future of rural areas. Biogas plants allow many farmers to convert their conventional activities into sustainable agriculture to provide the bioeconomy [95]. To adapt to changing markets, many farmers have been driven to plant oil, lignocellulosic, herbaceous, and tree crops in addition to starch and sugar crops. However, the growth of these crops has decreased soil carbon sequestration and increased the use of herbicides, creating additional obstacles for biodiversity, food security, and environmental preservation. New methods centered on cover crops and crop rotation, however, are showing to be successful approaches to these problems. Crop rotations must be continuously researched, funded, and supported by consulting services in order to be adjusted to various climatic and geographical conditions. These farmers stand to gain not just from the digestate produced by the biogas plant but also from lower waste and disposal expenses and a contribution to the aims of renewable energy. The production of biogas is an excellent way to comply with national and international regulations, which are always more restrictive in this sector, and to use organic biomass from the agricultural and livestock sectors and it also implies a lower use of water. Even compared to other biofuels, biogas has some advantages. One of the main advantages of biogas production is the capacity to convert waste into a useful resource by using it as a substrate for anaerobic digestion. Anaerobic digestion also requires less process water [16,81]. The development and deployment of renewable energy systems, such as biogas from anaerobic digestion, based on national and regional biomass resources, enables each country to improve its national energy supply while reducing its dependence on fuel imports.

It additionally allows for job development because the generation of biogas from anaerobic digestion requires labor for the production, assembling, and transportation of raw materials, the manufacture of technical equipment, and the construction, operation, and maintenance of biogas plants [11].

A biogas plant not only produces electricity, but the digested substrate, known as digestate, is a beneficial soil fertilizer rich in nitrogen, phosphorous, potassium, and micronutrients that can be applied to soils using the same equipment as liquid manure [15,81]. And, as we said, it's not just a matter of purely energy implications but also positive repercussions on the use of the soil, on crops, on the local economic system, and in terms of employment [4].

The pandemic and the energy crisis, with their repercussions on the economic system, have highlighted the leading role of the agricultural sector in the efficient production of energy. There are numerous experiences that demonstrate how many and which advantages can derive from the use of bioenergy [36,96]. The many companies that today produce energy from solid, liquid, and gaseous biomass are proof of how it is possible to use this type of plant with complete environmental and territorial compatibility. Clearly, in the past, the lack of regulatory rules has permitted the construction of energy production plants that are incompatible with the concept of sustainability.

Despite all these advantages, however, potential disadvantages related to biogas production could emerge. From a farmers' economic perspective, biogas production requires a significant investment in infrastructure, such as biogas digesters and gas storage plans. From a farmers' economic perspective, biogas production requires a considerable investment in infrastructure, such as biogas digesters and gas storage plants. Therefore, the use of biogas as a fuel source may not always be economically advantageous, especially if the cost of producing biogas is higher than traditional fossil fuels. Biogas production can also be labor-intensive, putting an additional strain on farmers, particularly those with limited labor resources. This suggests that government action may be required to assist farmers not just with the installation of biogas plants, but also with their economic functioning.

In conclusion, the development of biogas, obtained by maximizing the energy recovery of agricultural organic residues, is strategic for the growth of a circular economy, and its production within rural businesses represents a strong point towards improving sustainability and it is crucial for the competitiveness of businesses. On the other hand, the availability of renewable resources to replace oil will ensure sustained industrial activity, economic progress and job creation [2]. The need to encourage the replacement of non-renewable energy sources with renewable alternatives is therefore underlined [97]. Accordingly, policy interventions may help promote more sustainable management behaviors. Policymakers may implement different policy interventions according to the main objectives of their actions. Policy interventions include subsidies and tax incentives, as well as regulations and mandates. Incentives for farmers include tax credits or subsidies for the purchase of biogas equipment, as well as easier access to credit and financial services [42,74,98]. Different policy mixes can be evaluated [99–101], and the choice of single versus multiple policies may be relevant [102]. As to regulations and mandates, various forms of intervention can be designed. As an example Governments can implement Renewable Portfolio Standards (RPS) by seeking certain percentages of electricity or heat generated by renewable sources or by enforcing environmental regulations that limit greenhouse gas emissions from livestock operations. Carbon credits are a market-based approach to reducing greenhouse gas emissions. Producers of biogas from livestock manure can earn carbon credits by reducing greenhouse gas emissions using renewable energy sources. Also, many agricultural policies, such as those related to land use, soil health, and conservation, can have an impact on the adoption of biogas production from livestock manure. These policies can incentivize the adoption of biogas systems by promoting sustainable agricultural practices, biotechnological innovation [2], and providing support for renewable energy projects and promoting the spread of green energy and the widespread development of the green economy [8,9] through the implementation of circular economy models.

3. Methodology

This section explains the research methodology used to conduct the systematic literature review. For this study, the technique developed by Refs. [44–46] was used. All articles were selected through the Scopus database, and the presence of top-ranked journals in various subject areas makes this database a reliable tool for academic literature. The methodology [44–46] consists of five

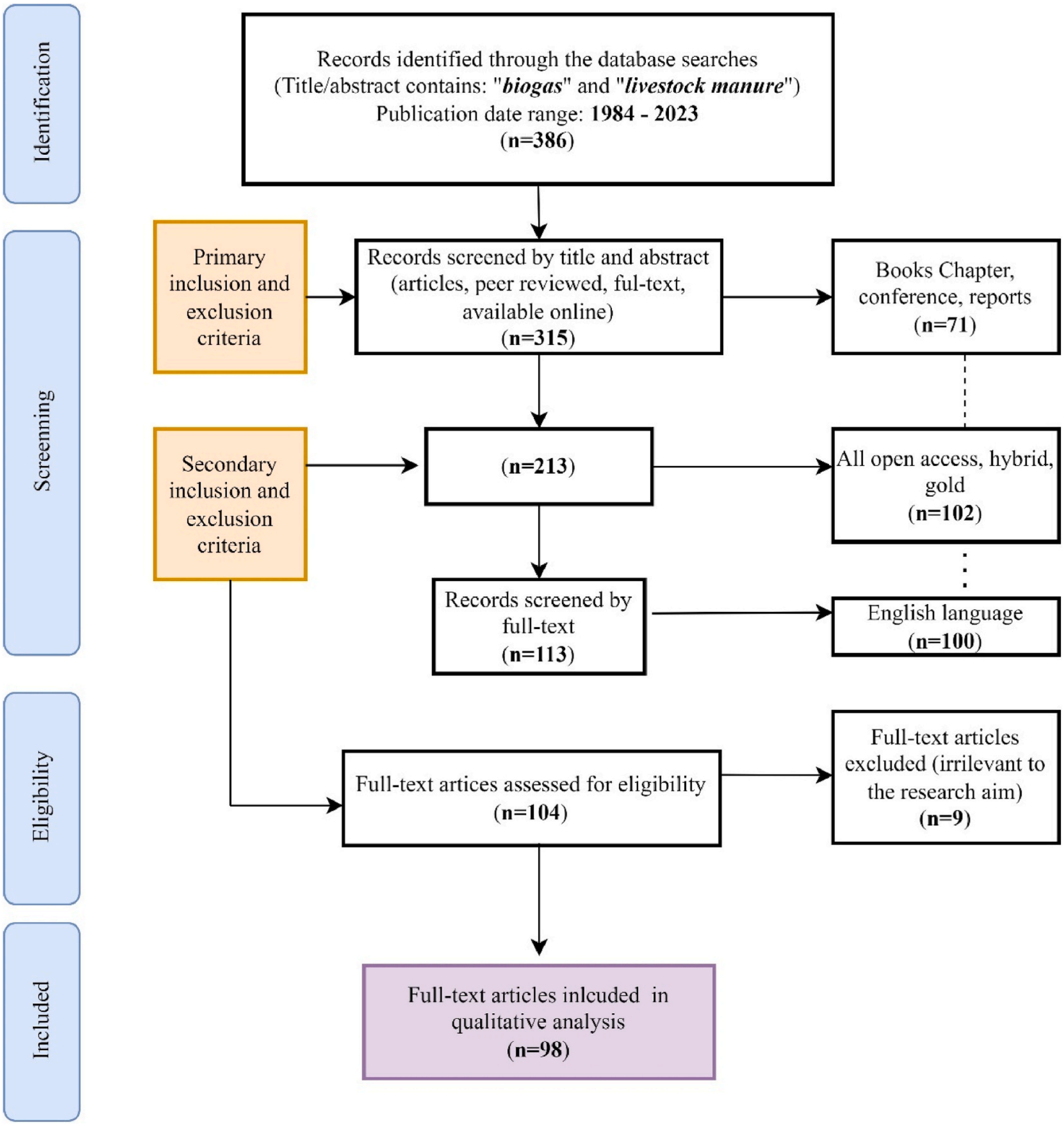

Fig. 1. Article selection procedure.

operational steps, as described in Table 2. In the first step, the reference database used to implement the analysis must be selected. Next, a suitable selection of keywords is needed to conduct the search on potential articles to be included in the analysis. The keywords (biogas) and (livestock manure) were searched within the fields "Article Title," "Abstract," and "Article Keywords" in the Scopus database (Fig. 1).

The present study deploys a systematic literature review (SLR) research methodology to comprehensively investigate, synthesise, and understand the extant research availability in the domain of biogas production from livestock manure. Although there are many review studies on biogas production (refer to Table 1), they have been targeted at a particular research gap only, which leaves ample scope for future researchers. Moreover, as the domain of biogas has been growing widely, the research avenues in this area have expanded at a vast pace. There are other review studies also, which are limited to a certain technological aspect [58,59], innovation dissemination [103,104], successful case studies [105,106], and also highlight the good practices in a particular country [25,28,53]. Therefore, a need was felt to look at this research domain to further identify the existing research gaps.

The present study has explicitly studied the role of biogas production from livestock manure from a general perspective, and therefore it did not specifically target certain countries. This study has followed the steps as per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure the transparency, replicability, and scientific rigour involved in the process [107–109].

The screening of the research articles involved several steps for capturing relevant publications of high quality. Initially, the titles and abstracts of the articles were skimmed through as per the inclusion and exclusion criteria. Only the articles that met the central theme of the intersection between "biogas" and "livestock manure" were included. Secondly, the full texts of these articles were thoroughly scanned and reviewed to confirm the suitability of the included articles. Thus, by implementing a very stringent screening process and further conducting the content analysis, the present review study has ensured the reliability of the synthesised information, which aided in synthesising the evidence between biogas and livestock manure. Now, the content analysis was conducted on the selected papers, which were systematically reviewed, and their particular major key themes related to the optimisation of biogas production from livestock manure, socio-economic and environmental impacts, and economic viability were identified. The resulting analysis provides a much more detailed and comprehensive overview of the current state of knowledge in the field.

The research foundation of this present review article is based upon a meticulously developed research protocol that outlines the research questions, inclusion and exclusion criteria, information sources, search strategy, and data extraction procedures as per the PRISMA framework [107] (refer to Fig. 1).

Scopus has been used primarily for the search engine database due to several considerations, like its extensive interdisciplinary coverage across several fields, which enhances its breadth and depth. Moreover, its corpus of research articles is far more extensive than other datasets. Mostly, researchers make use of two commonly used datasets, namely Scopus and Web of Science, for conducting literature reviews [109,110]. But since scopus covers the majority of the published scholarly articles, having far more extensive coverage of articles, it becomes the favourable option [108].

Simultaneously with the inclusion and exclusion criteria (Table 3), we also screened out the articles based on their titles and abstracts, which helped in determining their relevance for the research idea. This helped in avoiding the presence of any possible discrepancies in the selection process. Moreover, the data extraction was carried out systematically, and their key information has been represented through various graphical figures, tables, and content analysis. The resulting synthesis from the research findings of these articles will aim to provide a comprehensive overview of the state-of-the-art in biogas production from livestock manure. With regards to the methodologies of the reviewed articles, it has been found that there is a predominance of quantitative studies, followed by mixed methods, case-based approaches, and literature review articles.

An exhaustive search was conducted across the Scopus database from the time frame 1984 to 2023 using the relevant keywords and boolean operators as such: "biogas" and "livestock manure." This search strategy yielded 386 results, which were reduced to 104 articles after applying various inclusion and exclusion criteria. This list was even further finalised for only 98 articles after further removing 6 more articles which were from low-impact factor journals.

A total of 386 papers were obtained. The limited number of articles made it possible to thoroughly examine the various publications and, by means of inclusion and exclusion criteria (Table 3), to select the most relevant articles to conduct this analysis. At a later stage, the inclusion of further filters in the screening phase, aimed at eliminating books, chapters, conferences, proceedings, editorials, reports, and articles not in English, further reduced our sample. This brought the number of 315 articles to be analysed. Since the research focuses on the economic and environmental impacts of biogas plants, it was restricted to the following subject areas: 'Agriculture; Decision Science; Environment; Social Sciences; Business; Economics; and Multidisciplinary Research'. This brought the number of articles for analysis to 213 (Fig. 1). However, a careful reading of the abstracts, introduction, and conclusion of the articles allowed us to exclude false positives from our analysis and select only the articles in English. With this, 104 articles were selected based

Table 3
Inclusion exclusion Criteria's.

Inclusion	Exclusion
Only articles and reviews	Open access, hybrid, gold access were excluded
Subject was limited to Economics, social science, environmental science, and business management	Subject areas like mathematics, chemistry, material science, chemical engineering etc.
Source type: journal	All conference proceedings, books, trade journals etc.
Publication stage: Final	Articles in languages other than English; Article in press.

on the relevance of the journals, the number of citations received, and the publications of the authors. At the end of the procedure, a further six articles were excluded (since they were from low-impact factor journals), resulting in a total of 98 articles examined (Fig. 1). The economic and environmental advantages of the biogas production process are outlined, as are new technologies and methods for the proper disposal of animal manure. Suggestions are made for policymakers who often act under conditions of uncertainty and are a critical reflection on externalities and the role of bioenergy in achieving climate targets and in the energy transition process.

4. Data findings

Fig. 2 shows the year-wise publication trend in the given research domain. It can be seen that the articles have been consistently published since 1984, and there has been quite a surge in them since the year 2010. The first article was published by Ref. [111], which discussed the economic feasibility of utilising livestock manure fermentation for biogas generation. This visualisation of publications is quite useful to identify trends and shifts in the research focus over time. Further, it also helps to discern the evolution of knowledge in that particular field by helping us to distinguish the periods of extensive research publication activities and identify the potential gaps in the existing literature. Fig. 2 shows that there has been significant research interest among the scholarly community to explore the harvesting of renewable energy in the form of biogas production from livestock manure for a sustainable future.

Fig. 3 displays the document classification in terms of research articles and review studies. It can be seen that there are 86 research articles and 12 review studies. But those review studies have been quite narrow, either in terms of a particular technology, country, benefits, etc. Some of the notable ones include [60], which studies the possibilities of capturing methane as a source of energy from livestock manure. While [24,62] looks at the particular case of China to study the potential, challenges, current situation, perspectives, and future trends of biogas energy. On the other hand [58,59] discusses the different anaerobic digestion technologies and configurations that are used in the treatment of livestock waste.

Even a further close look at these articles in terms of their subject distribution has been shown in Fig. 4 with the help of a pie chart. From Fig. 4, it can be illustrated that the distribution of the papers as per their related subject areas has been divided into four subject categories. It can be seen that economics as a subject has the most documents (n = 38), followed by environmental science (n = 27), business management (n = 17), and social science (n = 16). It helps us identify the interdisciplinary nature of the research literature in the existing area, along with their collaborations.

The geographical distribution of the all the reviewed articles has been graphically mentioned in Fig. 5. The articles were geotagged based on the primary author's affiliation location, to study the global reach of the research area. The pattern in terms of the regional concentration of the articles is helpful to know the areas of hotspots where the research is taking place. It can be seen that China is the only country which has maximum number of articles related to this research domain (n = 37), followed by United states (n = 10), Denmark (n = 8), Germany (n = 6), and Japan (n = 5). The figure depicts the top ten countries in terms of their document's publications.

The above Fig. 6 shows the list of most commonly used keywords in the research articles. It can be seen that there has been a prevalence of words like "anaerobic digestion", "methane", "fertilizers", "livestock", "manure", "agriculture", "animals", "biofuel", "biomass", "fermentation", "anaerobiosis", "phosphorus", "anaerobic growth", "ammonia", and "carbon dioxide".

5. Discussion

This study aims to describe the environmental, social, and economic benefits of biogas plants [83], reduce environmental pollution [17], and promote the development of economically sustainable models [112]. Over the past decade, there has been significant deployment worldwide to promote a sustainable and resilient energy system, and recent studies document that anaerobic digestion can make a significant contribution to achieving the ambitious renewable energy targets in the European Union [113]. Over the years, spatial density and socio-economic changes have had major repercussions in terms of emissions in the agricultural sector, with the production of cattle and pigs and the use of chemical fertilisers and pesticides, which, if not properly managed, can generate irreversible damage to global warming and groundwater [114]. Recently, biomass plants have been on all political agendas due to their ability to produce renewable energy, reduce emissions [99], and develop new agribusiness models [115]. They are used not only to

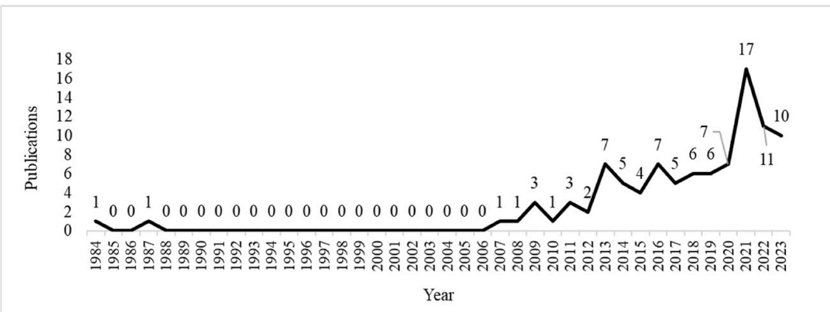

Fig. 2. Publication trend.

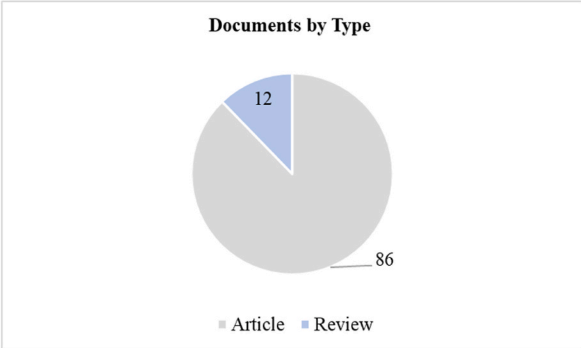

Fig. 3. Documents classification in terms of research articles and review studies.

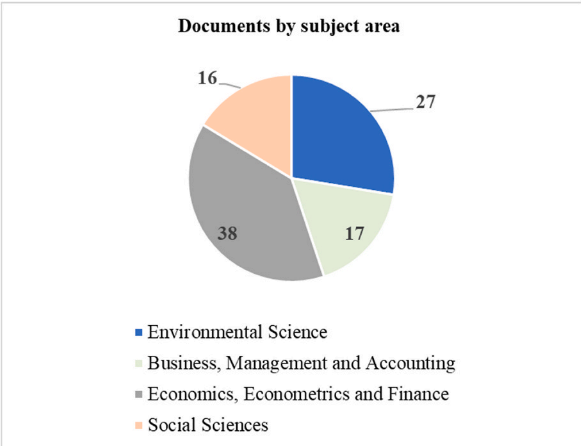

Fig. 4. Classification of the Documents as per the subject areas.

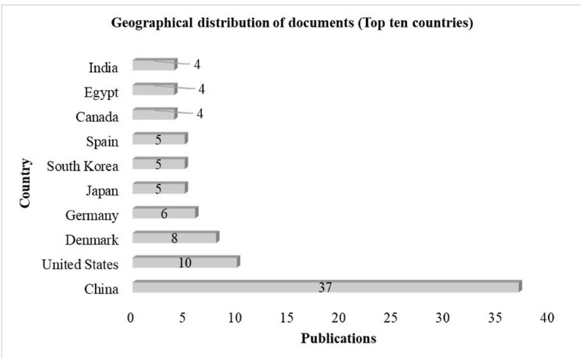

Fig. 5. Top countries in terms of Publications.

stimulate the economy in rural areas but also to spread a culture oriented towards the circular economy. Recent studies document the potential of biomass plants [116] and how the proper relocation of plants has an important potential for decarbonisation as well as playing a major role in rural areas with new regional energy sources [84]. Scientific literature confirms that biogas plants have a positive effect on the reduction of greenhouse gas (GHG) emissions and the reduction of energy poverty. In fact, it has been estimated that the daily use of biogas energy in Quang Tri province allows farms to reduce 16.01 tonnes of CO2 and GHG [68], with important repercussions also from an agronomic point of view [90].

Further studies document that an integrated agricultural system can reduce emissions and have positive effects on both productivity [85] and farmer profitability, with manure effluents being used for fertigation [86] and biofertilizers playing a central role in the

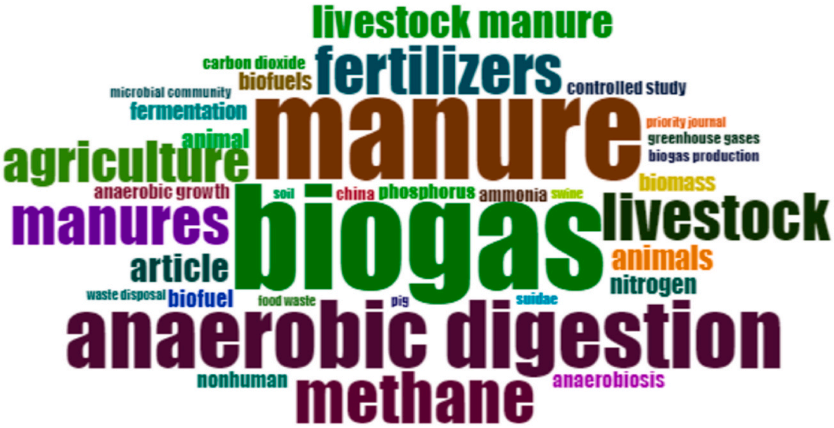

Fig. 6. Keywords word cloud analysis.

future of the agricultural sector [117]. In India, it has been estimated that farmers' profitability can increase using vermicomposting and organic composting [85] by promoting the sale of environmentally friendly organic products. An interesting study [69] conducted in Indonesia (Yogyakarta) documents that the conversion of manure through biogas technology could reduce the livestock sector's carbon dioxide emissions by 80 % and ensure self-sufficiency in the agricultural field with the nitrogen produced by organic fertilisers [66]. Being rich in nutrients, it promotes the growth and development of crops, increasing their productivity and avoiding the use of chemicals. This eco-revolution preserves ecological balances, improves soil and water fertility, and conserves biodiversity. Moreover, a further interesting aspect could be the creation of an Eco-Industrial Park (EIP), with biogas providing carbon dioxide and thermal heat inside the greenhouses [118]. Intensive livestock farming has inevitably increased the profitability of agricultural economies [76], yet biogas allows for offsetting fuel costs [98] and greater access to electricity. It is crucial to improve waste management [92] to increase environmental efficiency, lower pollution costs, and reduce negative externalities, ensuring a balance between exploitation and preservation.

In northeast China, intensive livestock farming is one of the main pillars of the economy [119], and studies in the literature confirm that biogas production, especially in rural areas, has contributed to the reduction of environmental externalities. However, especially small and medium-sized farms need state support [92] to enable storage and transport. Furthermore, especially on small farms, the installation of digesters and the application of biogas can be very beneficial [114], to develop a mixed system [120] of crop livestock and to generate more economic value while reducing externalities [119]. China produces half of the world's pork [119], with very high environmental costs, and policy instruments and investments are needed to minimise emissions to the atmosphere. In fact, in addition to the classic problems of eutrophication, the incorrect management of livestock effluents could generate problems of antimicrobial resistance [121], with consequences for the health of the population. Further studies aim to identify the benefits for the various stakeholders through a cost-benefit analysis [72]. Despite its potential, the diffusion rate of biogas is quite slow [74]. It has been estimated that education and financial access can accelerate the diffusion process [74], with local policies playing an important role at various stages. However, policymakers need to implement effective policy instruments [101] to improve manure management.

In Switzerland, the manure produced by cattle could produce 430 million cubic metres of biogas [67]. However, looking at the spatial distribution of plants in Switzerland, to date only 6 % of the manure produced is disposed of through an anaerobic digester [67]. It is important not only that plants are relocated but also that the various farms cooperate with each other; in fact, farms that joined a cooperative were significantly more likely to use biogas plants [122]. In this direction, a proper relocation of plants is necessary, which could have important environmental and economic repercussions. It is also estimated that annual emissions of 159 kt CO2 could be avoided. Also in Ontario, feed-in tariff (FIT) programmes have been adopted that provide incentives for biogas production [123], and in Iran [124], the potential of biogas is considerable for the proper allocation of emissions. In Turkey, through a survey [125], it was determined that the best solution would be to unify all small and medium-sized farms under one cooperative [125], which would reduce pollution and produce biogas and fertiliser with a potential of around 23,483,275 cubic metres. In Thailand, electricity production is currently 90 percent from fossil fuels [126]. However, it manages to produce around 1 billion cubic metres of biogas per year, and current utilisation is only 90 % of its potential.

In the Leningrad Region, estimates of biogas yield have been made using computational methods [71], and according to calculations, it will produce 500 million cubic metres of biogas. The construction of energy communities, and in particular agricultural communities, could totally cover the energy inputs of farms [71] as well as play a key role in optimising energy schemes and achieving sustainable development goals [89]. Agriculture and livestock farming are the main sources of income for rural economies [85], and the conversion of agricultural products can have an important potential for increasing farmers' income and promoting the circular economy [112]. Relevant studies [102] document that the installation of new biogas plants is economically feasible only in the presence of flexible incentive schemes. Many studies [81] confirm that the diffusion of biogas is hampered by the low investment capacity of rural households. Instead, economic feasibility and resource acquisition are strongly influenced by the geographical location of the plants. The construction of a hybrid model, including a solar/biogas/battery/diesel system, could reduce approximately

778 metric tonnes [127] of carbon emissions and meet the energy needs of farms. In the literature, many studies aim at analysing, through the technique of product life cycle assessment (LCA), the impacts of livestock manure [128] to observe how manure management systems can improve the environmental profile of the reference production and how the presence of structural constraints can prevent the diffusion and profitability of the systems [87]. This systematic literature review examined the relationship between animal biomass and biogas power plants and sought to provide a clear answer to the research hypothesis. This project offers a comprehensive assessment and analysis of externalities and benefits in economic, social, and environmental terms, as has been extensively discussed within the analysis process. Biogas has a number of multifunctional benefits involving economic sustainability, the promotion of sustainable agricultural practices, and the reduction of energy poverty. The systematic review confirms the crucial role of biogas plants, not only in combating energy poverty but also in promoting economically sustainable models through localised energy production. However, one of the main obstacles is related to the initial investment, and from this perspective, the analysis offers some important policy recommendations regarding increased public subsidies, appropriate policies for the promotion of small and medium-sized plants, and geographically targeted investments. The potential economic and social benefits of biogas should encourage the spread of public subsidies with the goal of incentivizing the installation and maintenance of biogas plants. In addition, an assessment and analysis of different regional contexts could be a key element in encouraging geographically targeted investments and ensuring an equitable distribution of benefits. The analysis suggests that the success of such plants is not only and exclusively related to the amount of biomass available but also to geographic and socio-economic factors. For this reason, an adaptation of policies to the local context could make it possible to maximise impacts and minimise costs. Based on the review of the selected articles, it has been found that biogas production from livestock manure has far-reaching consequences. It helps in mitigating the problem of climate change and finally assists in attaining sustainable development. It helps in methane gas capture, which is produced during organic waste decomposition (such as livestock manure), and utilises it as biogas through anaerobic digestion. If methane gas is let go easily, then its potential to contribute to global warming is more severe when compared to carbon dioxide. Finally, biogas production reduces the need for fossil fuels as it can be used to generate energy that doesn't emit greenhouse gases.

In addition, biogas production contributes to waste management by providing solutions to treat organic waste matter. It contributes to renewable energy access (SDG 7), which is clean and affordable. Countries can benefit from advanced technological and innovative solutions that will help make digester plants a great success (SDG 9). Even urban dwellers can keep their environment healthier and more sustainable by reducing their carbon footprint and providing solutions for sustainable waste management (SDG 11). The reliance on synthetic fertilisers can be reduced through biogas production from livestock manure. This helps in promoting the quality of soil health along with biodiversity conservation (SDG 15). It further encourages circular economy practices as waste is minimised with efficient resource utilisation (SDG 12). The employment opportunity contributes to the local community's participation through decent work in the form of maintaining, constructing, and operating these biogas plants (SDG 8). It is quite evident that biogas production has immense potential to contribute towards sustainable development by answering issues related to waste management, sustainable agriculture practices, energy access, and economic growth. It offers green transition pathways towards a low-carbon future.

6. Conclusions

In conclusion, the systematic review of the literature confirms that biogas plants are an important tool to promote the energy transition and to guarantee the reduction of emissions into the atmosphere; furthermore, a strategic relocation in rural areas could fuel the benefits from a socio-economic perspective, promoting employment and the spread of green jobs; however, due to the substantial initial investments, the lack of dedicated incentives could hinder its diffusion, with repercussions and consequences also in economic and social terms. The political sphere also plays an important role; a mix of adequate political measures and the offer of financial incentives for companies that invest in and operate in the production of biogas could inevitably accelerate their diffusion across the territory. In this regard, various measures could be adopted, such as subsidised loans, tax credits, and economic subsidies. Furthermore, at a regulatory level, the introduction of a top-down manoeuvre could force the adoption of such systems and guarantee subsidised financing for the development of such innovations. A further interesting aspect that emerges from the analysis is linked to awareness-raising. Communication, dissemination, and dissemination campaigns on the importance of this technology could have a positive effect on the degree of acceptance and avoid the "NIMBY" Not In My Backyard phenomenon. We believe that this study contributes twofold to the existing scientific literature. First of all, to date, there are no updated scientific studies aimed at investigating and analysing the production of biogas for the disposal of livestock manure from intensive farming. Secondly, this study provides a clear and complete vision of the current scenario, of the strengths and weaknesses of biogas plants, as well as clarifying the negative externalities generated by incorrect disposal of livestock waste. Future research work should aim to explore various innovative technological solutions to overcome current barriers so as to further improve the efficiency of the entire process, taking into account geographical and orographic characteristics.

7. Limitations and future research

The study has taken articles from the Scopus database. The research work from other databases, such as Web of Science and Google Scholar, has not been considered part of the inclusion criteria for the present article. Also, many works have been omitted, such as those that are part of the grey literature, white papers, editorials, and conference proceedings. There can be some studies that may be omitted due to this sample bias and thus affect the study findings. The analysis also offers interesting ideas for the implementation of new research. Firstly, it might be interesting to further analyse a series of socio-economic variables to observe how they influence the adoption and success of biogas. Furthermore, long-term geographical analysis could allow for an in-depth assessment of social, economic, and environmental aspects over time.

Data availability

Data not used in this article.

CRediT authorship contribution statement

Mohsen Brahmi: Writing – review & editing, Supervision. **Bruna Bruno:** Supervision, Writing – review & editing. **Karambir Singh Dhayal:** Methodology, Data curation, Writing – review & editing. **Luca Esposito:** Methodology, Data curation, Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Anna Parziale:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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