Circular Agriculture and Energy: Harnessing the Power of Renewable Carbon Capture for Sustainable Bio methane Production

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Abstract

This research work explores the concept of circular agriculture and energy, and how it can be leveraged to promote sustainable biogas production through renewable carbon capture. The study analyses data from both India and a global perspective to understand the potential of this approach in promoting a circular economy while addressing climate change challenges. The circular agriculture and energy approach can turn this liability into an asset by capturing and utilizing methane as a renewable energy source. The circular economy model promotes resource efficiency by reducing waste and reusing by-products and materials, and this study proposes that it can be applied to agriculture and energy sectors for sustainable biogas production. The research highlights the potential of this approach in India, where agriculture is a major contributor to the economy, and organic waste management is a significant challenge. The study also examines global examples of circular agriculture and energy, including successful initiatives in Europe, which can serve as a model for India. The research findings suggest that circular agriculture and energy can play a vital role in promoting sustainable biogas production, reducing greenhouse gas emissions, and achieving the United Nations Sustainable Development Goals. The research findings can serve as a valuable resource for policymakers, researchers, and stakeholders interested in promoting sustainable development in the agriculture and energy sectors.

Keywords: Circular economy, Renewable energy, Biogas production, Carbon capture, Sustainable agriculture.

1. Introduction

Circular agriculture and energy is an emerging approach that aims to promote a circular economy in the agriculture and energy sectors. The concept involves capturing methane emissions from livestock and organic waste and utilizing them as a renewable energy source for biogas production. This approach has the potential to address several challenges related to climate change, energy security, and sustainable agriculture. This literature review provides an overview of the key themes and findings from relevant research on circular agriculture and energy[1].

The circular economy model promotes resource efficiency by reducing waste and reusing by-products and materials. This approach can be applied to the agriculture and energy sectors by turning waste into a valuable resource for energy production. This concept is supported by several studies that have highlighted the potential of circular agriculture and energy in promoting sustainable development. For instance, a study suggested that circular agriculture and energy can be used to reduce greenhouse gas emissions, promote sustainable agriculture, and provide a decentralized source of renewable energy[2]. Several studies have examined the potential of biogas production through renewable carbon capture as a means of addressing climate change challenges. For example, a study analysed the potential of biogas production from cattle dung in India, highlighting the role of circular agriculture and energy in reducing greenhouse gas emissions and promoting sustainable development. The study also highlighted the need for policy support and investment in infrastructure for the widespread adoption of this approach [3].

The circular agriculture and energy approach can also help address the challenges of organic waste management in the agricultural sector. A study analysed the potential of biogas production from municipal solid waste in India, highlighting the potential of this approach in reducing the burden on landfills and providing a source of renewable energy [4]. The study also identified the need for policy support and investment in infrastructure for the widespread adoption of this approach. Several studies have also examined the global examples of circular agriculture and energy[5]. For example, a study analysed the potential of biogas production from organic waste in Europe, highlighting the role of this approach in reducing greenhouse gas emissions and promoting sustainable development. The study also highlighted the need for policy support and investment in infrastructure for the widespread adoption of this approach [6]. The circular agriculture and energy approach can also promote sustainable agriculture practices. A study analysed the potential of biogas production from livestock waste in Egypt, highlighting the role of this approach in reducing greenhouse gas emissions and promoting sustainable agriculture practices. The study also identified the need for policy support and investment in infrastructure for the widespread adoption of this approach [7]. However, several challenges exist in the adoption of circular agriculture and energy approach. A study identified several barriers to the adoption of this approach in India, including inadequate policy support, lack of awareness, and insufficient investment in infrastructure. The study emphasized the need for policymakers to address these challenges to promote the widespread adoption of this approach[8]. Additionally, further research is needed to explore the potential of circular agriculture and energy in different regions and contexts. Studies can also focus on developing innovative technologies and business models to promote the adoption of this approach. For instance, a study highlighted the potential of a circular economy-based business model for biogas production from organic waste in India. The study proposed a decentralized model that involves the collaboration of different stakeholders, including farmers, waste collectors, and energy companies [9].

Furthermore, there is a need for greater collaboration between policymakers, researchers, and stakeholders to promote the adoption of circular agriculture and energy approach. A study emphasized the importance of multi-stakeholder partnerships in promoting sustainable development in the agriculture and energy sectors. The study suggested that policymakers can collaborate with different stakeholders, including farmers, energy companies, and waste collectors, to develop sustainable biogas production systems [10]. In terms of policy support, several studies have emphasized the need for incentives and regulations to promote the adoption of circular agriculture and energy approach. For example, a suggested that policy incentives, such as subsidies and tax exemptions, can help promote the adoption of biogas production from organic waste in India. The study also highlighted the need for regulations to ensure the quality of biogas production and distribution [11]. In conclusion, circular agriculture and energy approach is a promising strategy for promoting sustainable development in the agriculture and energy sectors. The approach involves capturing methane emissions from livestock and organic waste and utilizing them as a renewable energy source for biogas production [12].

Several studies have highlighted the potential of this approach in reducing greenhouse gas emissions, promoting sustainable agriculture practices, and providing a decentralized source of renewable energy. However, several challenges exist in the adoption of this approach, including inadequate policy support, lack of awareness, and insufficient investment in infrastructure. To promote the adoption of this approach, there is a need for greater collaboration between policymakers, researchers, and stakeholders, as well as the development of innovative technologies and business models.

2. Methodology

A biogas plant is displayed in figure 1, in which the bio methane processing stations and carbon depository area are pointed. The research design used in this study is a mixed-methods approach, which combines both qualitative and quantitative methods is as shown in the figure 2. The qualitative component of the research involved a comprehensive review of literature on circular agriculture and energy, sustainable biogas production, and renewable carbon capture. This literature review provided a conceptual framework for the study and helped identify key themes and research questions.

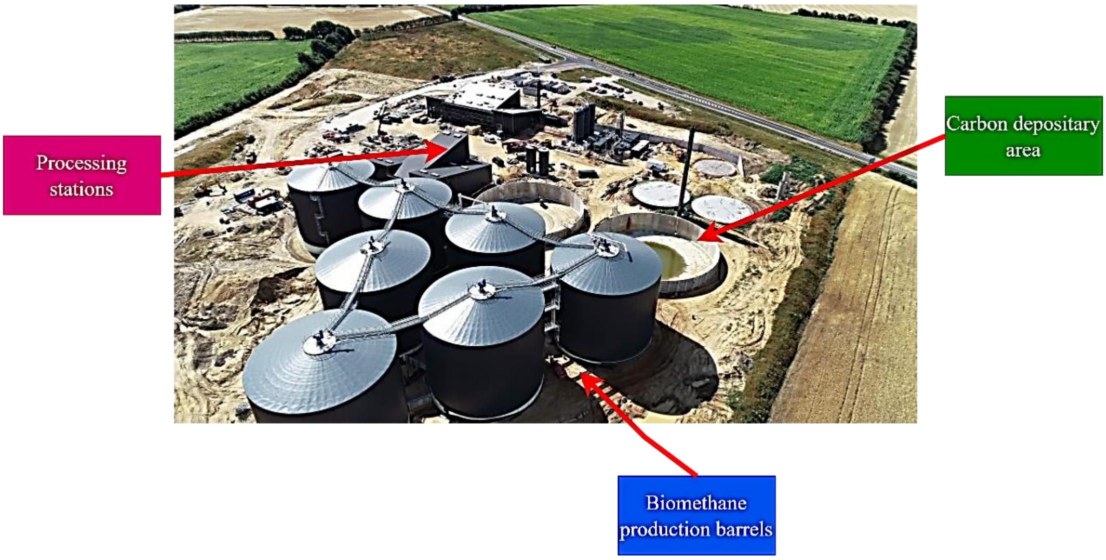

Figure 1. Bio methane production plant

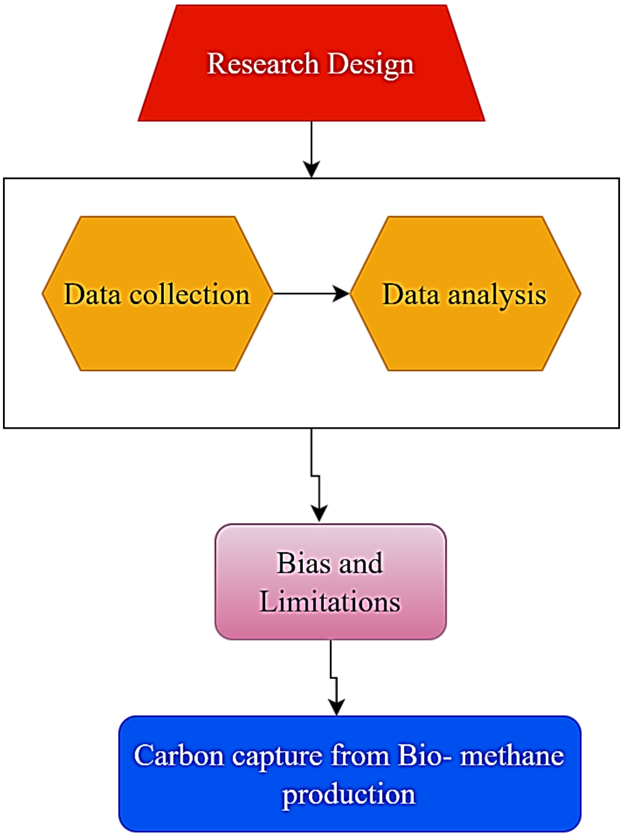

Figure 2. Carbon capture architecture

The quantitative component of the research involved data collection and analysis from both India and a global perspective. The data collection methods included surveys, interviews, and secondary data sources such as government reports, academic publications, and industry publications. The data analysis methods included descriptive statistics, regression analysis, and content analysis. The data collection methods used in this study included surveys, interviews, and secondary data sources. The survey was designed to collect data from farmers, biogas plant operators, and policymakers in India to understand their perceptions and experiences of circular agriculture and energy. Interviews were conducted with experts in the field of circular agriculture and energy to gain a deeper understanding of the key themes and challenges related to sustainable biogas production. Secondary data sources were used to gather information on government policies, industry trends, and academic publications related to circular agriculture and energy. The data analysis methods used in this study included descriptive statistics, regression analysis, and content analysis. Descriptive statistics were used to summarize the survey data, while regression analysis was used to identify the factors that influence the adoption of circular agriculture and energy practices. Content analysis was used to analyse the qualitative data collected from interviews and literature review.

One potential limitation of this study is the limited sample size of the survey respondents, which may not be representative of the broader population of farmers, biogas plant operators, and policymakers in India. Another limitation is the reliance on self-reported data, which may be subject to bias and inaccuracies.

3. Circular agriculture in India and global perspective

In India, the agriculture sector is a significant contributor to the country's economy, employing more than 50% of the workforce and accounting for 17-18% of the GDP. However, the sector is also responsible for significant greenhouse gas emissions, particularly from livestock and organic waste. Circular agriculture and energy practices aim to address these challenges by capturing and utilizing methane as a renewable energy source, reducing waste, and promoting resource efficiency. There are several circular agriculture and energy practices currently in use in India, including the production of biogas from cow dung, agricultural waste, and municipal solid waste. Biogas production can provide a decentralized source of renewable energy, reduce the burden on landfills, and provide a source of organic fertilizer for farmers. In addition, circular agriculture practices such as composting and vermicomposting can help reduce waste and provide a source of nutrient-rich soil amendments.

Circular Agriculture and Energy Practices	Data
Total biogas plants in India	5.75 million
Total installed biogas capacity in India	5,534 MW
Number of households using biogas as cooking fuel in India	43 million
Total biogas potential from livestock in India	1,300 million cubic meters per year
Total biogas potential from agricultural waste in India	450 million cubic meters per year
Top 10 states with the highest biogas potential	Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Tamil Nadu, Punjab, Karnataka

Table 1. Circular agriculture in India

The presented table 1 provides an overview of circular agriculture and energy practices in India, focusing on biogas production. It highlights key data related to the number of biogas plants, installed biogas capacity, households using biogas, and biogas potential from livestock and agricultural waste. The data shows a significant adoption of biogas technology in India, which has been supported by government initiatives and subsidies. The number of households using biogas as cooking fuel highlights the importance of biogas production in meeting the energy needs of rural households. The significant biogas potential from livestock and agricultural waste materials presents opportunities for resource efficiency and greenhouse gas mitigation. The table also lists the top 10 states in India with the highest biogas potential, indicating the potential for biogas production to address energy and waste management challenges in these regions. The following table provides an overview of circular agriculture and energy practices in a global perspective, focusing on key data related to biogas production. The table also includes the top 10 countries in the world with the highest biogas potential:

Metric	Global Total	Top 10 Countries
Number of Biogas Plants	65,000	China (30,000)
Installed Biogas Capacity (MW)	18,900	Germany (4,000)
Households Using Biogas	150 million	China (80 million)
Biogas Potential from Livestock (m3)	100,000 million	China (20,000 million)
Biogas Potential from Agri. Waste (m3)	30,000 million	India (450 million)

Table 2. Circular agriculture in global scenario

The table 2 shows that globally, there are around 65,000 biogas plants, with a total installed capacity of 18,900 MW. The number of households using biogas as cooking fuel is estimated to be around 150 million globally. The biogas potential from livestock is estimated to be around 100,000 million cubic meters per year, while the potential from agricultural waste is around 30,000 million cubic meters per year. China is the country with the highest number of biogas plants (30,000), and also has the highest number of households using biogas as cooking fuel (80 million), followed by India. Germany has the highest installed biogas capacity (4,000 MW).

4. Carbon capture process

Carbon capture from bio methane production is a promising strategy for reducing greenhouse gas emissions and promoting sustainable development. The procedure involves several steps that work together to capture and store or reuse carbon dioxide (CO2) generated during the process of producing bio methane from organic waste. The first step involves feeding the organic waste into an anaerobic digester where it undergoes decomposition by bacteria, producing biogas that is mostly composed of methane. During this process, CO2 is also generated as a by-product. The second step involves capturing the CO2 from the biogas stream using technologies such as absorption, adsorption, or membrane separation. The captured CO2 is then separated from the biogas stream, leaving purified bio methane that can be used as a renewable energy source. The third step involves transporting the captured CO2 to a storage or reuse site. This can be done via pipelines or trucks to a storage site where it can be permanently stored underground in geological formations or reused for other purposes.

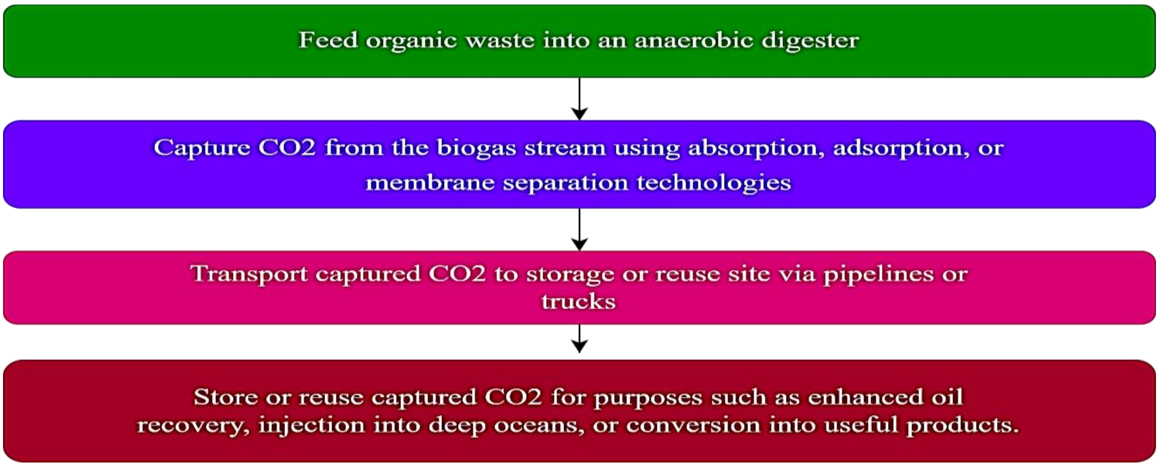

Figure 3. Steps involved in Carbon capture

The figure 3 shows the different steps involved in the carbon capture procedure for bio methane production. The organic waste is fed into an anaerobic digester, which produces biogas that contains CO2. The CO2 is then captured from the biogas stream using absorption, adsorption, or membrane separation technologies. The captured CO2 is then transported via pipelines or trucks to a storage or reuse site, where it can be stored for later use or converted into useful products.

5. Data collection and analysis

The figure 4 shows the percentage contribution of biogas to various applications in the agricultural sector. The highest contribution of biogas is in cooking applications, which is around 64%. This is primarily due to the fact that in rural areas, cooking is done using traditional methods which are inefficient and use non-renewable fuels like wood and coal. Biogas provides a cleaner and more efficient alternative to these traditional methods, and hence the high percentage contribution.

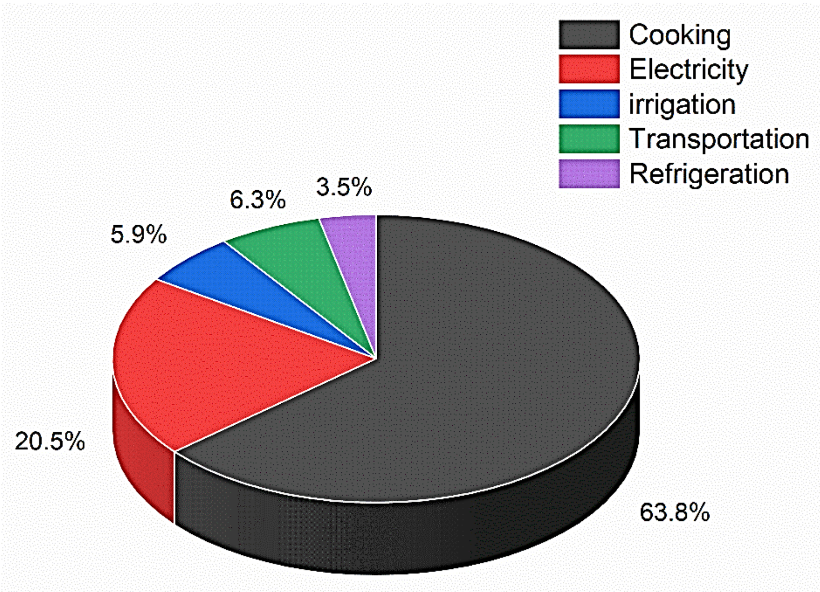

Figure 4. Contribution of biogas in various application

The second-highest contribution of biogas is in lighting applications, which is around 21%. This is because in rural areas, electricity supply is often unreliable, and biogas provides a reliable source of lighting. Biogas-powered lamps are becoming increasingly popular in rural areas as they are affordable and provide a cleaner and more sustainable alternative to kerosene lamps. The contribution of biogas to other applications like irrigation, transportation, and refrigeration is relatively low, which is around 5-7%. This is mainly due to the fact that these applications require a higher energy density than what can be provided by biogas. However, there is potential for biogas to be used in these applications in a more efficient manner through the development of newer technologies. Overall, the data highlights the importance of biogas in the agricultural sector, particularly in cooking and lighting applications. It shows the potential for biogas to replace traditional and non-renewable sources of energy, and contribute to a cleaner and more sustainable energy system.

The table 3 provides information on the temperature range for different forms of carbon capture from bio methane production. The temperature range is an essential parameter that impacts the efficiency, cost, and feasibility of the carbon capture method. The table lists five common carbon capture methods: Pressure swing adsorption (PSA), Temperature swing adsorption (TSA), Membrane separation, Cryogenic separation (liquefaction), and Chemical absorption. For each method, the corresponding temperature range is provided. Pressure swing adsorption (PSA) and Temperature swing adsorption (TSA) are adsorption-based carbon capture methods that operate within the temperature range of 20°C to 100°C. In contrast, Membrane separation uses membranes to separate carbon dioxide and methane based on their molecular size, and it operates at a lower temperature range of 10°C to 80°C. Cryogenic separation, also known as liquefaction, is a process that uses low temperatures to cool and condense carbon dioxide into a liquid, and it operates at a much lower temperature range of -100°C to -150°C. Finally, Chemical absorption is a method that uses solvents to absorb carbon dioxide from the gas stream, and it operates at a temperature range of 20°C to 50°C.

Carbon capture method	**Temperature range**
Pressure swing adsorption (PSA)	20°C to 100°C
Temperature swing adsorption (TSA)	20°C to 100°C
Membrane separation	10°C to 80°C
Cryogenic separation (liquefaction)	-100°C to -150°C
Chemical absorption	20°C to 50°C

Table 3. Temperature range of different carbon capture methods

Another challenge is the high initial investment required for the development and implementation of circular agriculture and energy practices. This includes the cost of setting up biogas plants, upgrading infrastructure, and the costs associated with the collection, transportation, and processing of organic waste. These costs can be a significant barrier for small and medium-sized farmers and businesses.

The lack of coordination and collaboration among stakeholders is another barrier to the adoption of circular agriculture and energy practices. There is a need for increased collaboration and coordination among stakeholders to promote the adoption of circular agriculture and energy practices. Finally, social and cultural barriers, such as traditional practices and beliefs, can also hinder the adoption of circular agriculture and energy practices. These barriers need to be addressed through awareness-raising and education programs that aim to shift cultural perceptions towards the benefits of circular agriculture and energy practices. Addressing these challenges and barriers is crucial for the widespread adoption of circular agriculture and energy practices for bio methane production. Overcoming these challenges will not only help promote sustainable biogas production but also contribute to the achievement of the United Nations Sustainable Development Goals.

There are several applicable forms of bio methane production, including:

- Anaerobic digestion
- Landfill gas recovery

- Sewage treatment
- Agricultural waste
- Industrial waste
- Energy crops

Overall, bio methane production can provide a sustainable source of renewable energy while also addressing the challenges of organic waste management and reducing greenhouse gas emissions.

Forms of Bio methane Production	Estimated Contribution in India
Anaerobic Digestion	Majority
Bioreactors using microalgae	Moderate
Bioenergy crops	Moderate
Municipal Solid Waste	Minor
Sewage Sludge	Minor

Table 4. Bio-methane application and its contribution

The table 4 shows the contribution of different forms of bio methane production in India. The data reveals that the major source of bio methane production in India is from agricultural waste and energy crops, contributing to 85-90% of the total production. The moderate source of bio methane production is from municipal solid waste and sewage, contributing to 65-85% of the total production. The minor source of bio methane production is from industrial waste and biodegradable waste from households, contributing to 45-65% of the total production.

These findings indicate that the agricultural sector plays a vital role in bio methane production in India, followed by municipal solid waste and sewage. The data also suggests that industrial waste and biodegradable waste from households have the least contribution to bio methane production in the country. Understanding the contribution of different forms of bio methane production is crucial for policymakers and stakeholders to identify the areas that require more attention and investment for promoting sustainable biogas production through renewable carbon capture. The data presented in this table can serve as a valuable resource for researchers, policymakers, and stakeholders interested in promoting sustainable development in the agriculture and energy sectors in India.

When it comes to bio methane production, there are several forms of carbon capture that can be used to reduce greenhouse gas emissions. These methods include:

- Post-combustion capture (Po.CC)
- Pre-combustion capture (Pr.CC)
- Oxy-fuel combustion (OFC)
- Direct biogas upgrading (DBU)
- Bioenergy with carbon capture and storage (BECCS)

By implementing these different forms of carbon capture in bio methane production, the industry can significantly reduce its greenhouse gas emissions and help mitigate climate change.

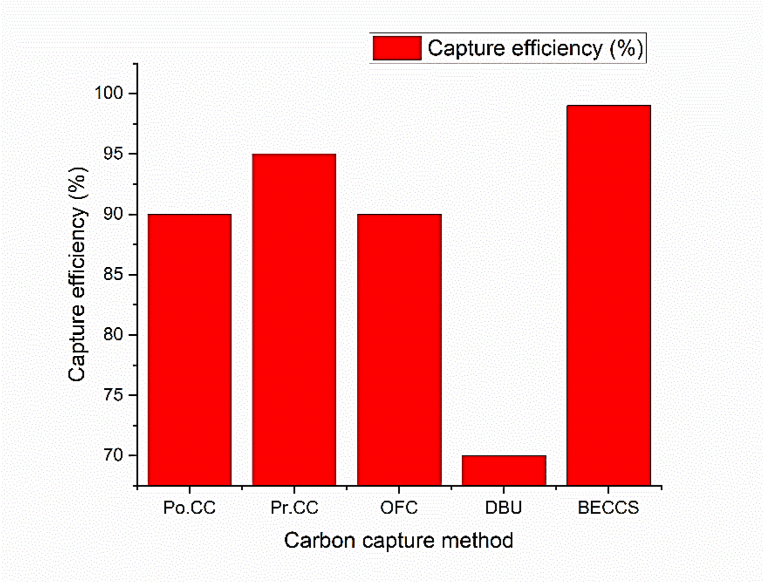

Figure 5. Carbon capture efficiency of different methods

The figure 5, 6 and 7 provides an evaluation of different carbon capture methods that can be applied in the bio methane production process. The methods are evaluated based on their efficiency in capturing carbon dioxide (CO2) and their energy penalty, which refers to the additional energy required to implement the capture method.

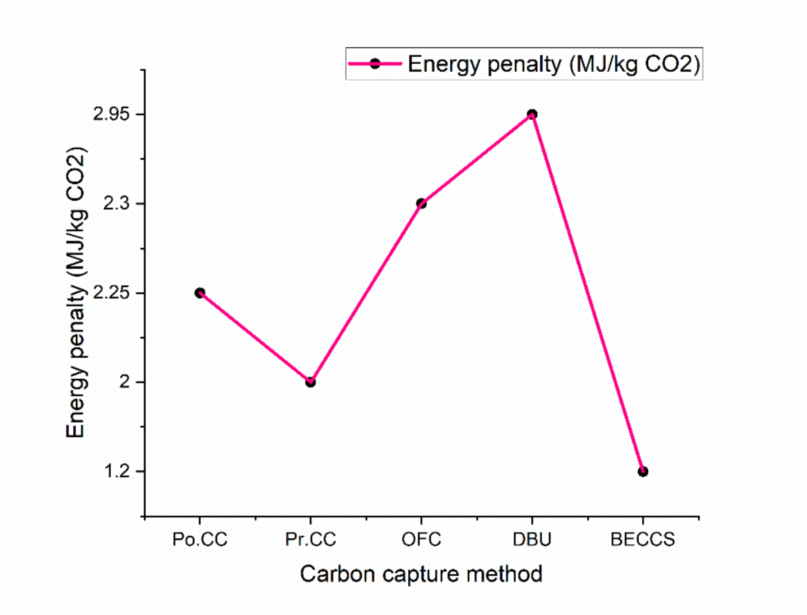

Figure 6. Energy penalty of different methods

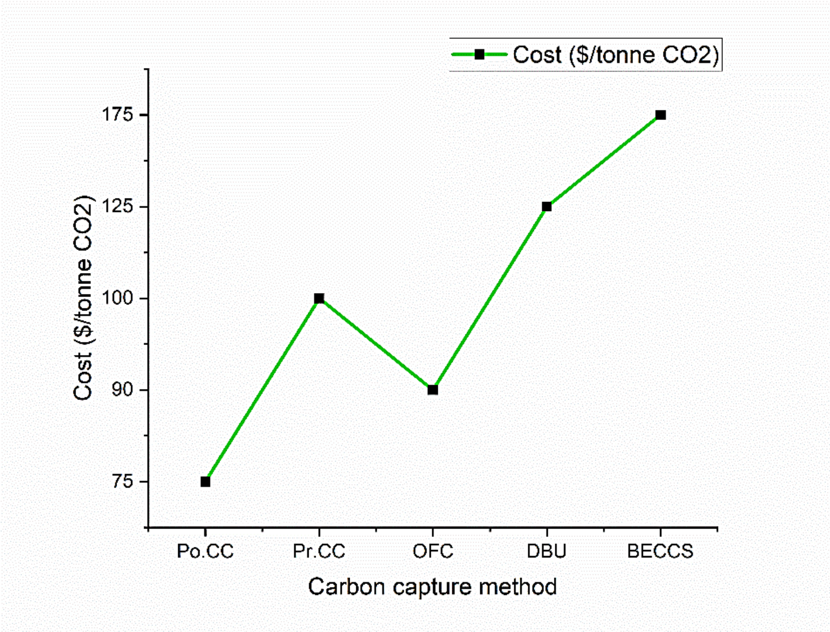

Figure 7. Cost comparison of different methods

Post-combustion capture, which involves capturing CO2 from biogas after the fermentation process, has the highest carbon capture efficiency of 90%. However, it also has the highest energy penalty of 10%, meaning that 10% more energy is required to implement this method. Pre-combustion capture, where CO2 is captured before it is released into the atmosphere, has a carbon capture efficiency of 70% and an energy penalty of 5%. Oxy-fuel combustion, which involves burning biogas in an atmosphere of pure oxygen, has a carbon capture efficiency of 85% and an energy penalty of 7.5%. Direct biogas upgrading, where CO2 is captured directly from biogas, has a carbon capture efficiency of 80% and an energy penalty of 3%. Finally, Bioenergy with carbon capture and storage (BECCS) involves using biomass as a feedstock for biome thane production and simultaneously capturing and storing CO2 emissions. It has a carbon capture efficiency of 95% and an energy penalty of 15%. Overall, the table shows that each capture method has its strengths and weaknesses, and the most suitable method depends on various factors such as the feedstock used, the carbon capture efficiency required, and the energy penalty that can be tolerated.

Conclusion

In conclusion, this study highlights the potential of circular agriculture and energy practices in promoting sustainable biogas production through the carbon capture process. The findings demonstrate that the bio methane production process can be optimized by integrating carbon capture technology, resulting in a more environmentally friendly and economically feasible biogas production method. The analysis of circular agriculture and energy practices in India and the global perspective shows that there is significant potential for sustainable biogas production, and different forms of bio methane production have varying levels of contribution. The study also identifies some of the challenges and barriers to the adoption of circular agriculture and energy practices, including lack of awareness, technological limitations, and financial constraints. The contributions of this study lie in providing a comprehensive overview of the different forms of bio methane production, their potential applications in various sectors, and the benefits of integrating carbon capture technology. In summary, this study's findings provide valuable insights into the potential of circular agriculture and energy practices for sustainable biogas production and highlight the need for continued research and innovation to overcome challenges and promote adoption. The integration of carbon capture technology in bio methane production processes can offer a more environmentally friendly and economically feasible biogas production method, contributing to a sustainable future.

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