

CO₂ emissions in rice paddies in Kollo, Tillaberi region, Niger

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Abstract

This study makes an important scientific contribution to the understanding of CO₂ emissions from irrigated rice farming systems in Kollo, a context that remains poorly documented in West Africa. The results obtained provide a baseline for future research incorporating other greenhouse gases, such as methane and nitrous oxide, and for the development of more sustainable rice farming practices that reconcile agricultural productivity with climate change mitigation.

Keywords: CO₂; Emission; Rice; Paddies; Kollo

1. Introduction

The global energy crisis and increasing environmental degradation compel us to rethink modes of energy production and consumption. While fossil fuels still dominate energy systems, their negative impacts in terms of greenhouse gas emission, air pollution, and climate change are wide documented. In this perspective, renewable energies provide a sustainable alternative. Among them, biogas, derived from the anaerobic digestion of organic matter, is gradually emerging as both an energy and environmental solution, since it not only produces energy but also valorizes water often considered problematic (Alvarez et al. 2025). Indeed, biogas production relies on a system called a biodigester, a device that transforms agriculture, municipal, or industrial waster into a methane rich gaseous mixture and a residue that can be used as natural fertilize (López et al., 2025).

Thus, the biodigester plays a central role in this dynamic by organizing the transformation of organic matter through a biological process in four stages : hydrolysis, acetogenesis, and finally methanogenesis (Zuo, He, and Tan 2025). Each of these steps is carried out by a specific microbial community working in synergy. The result is the production of a gas composed of 50 to 70% methane and 30 to 50% carbon dioxide, sometimes accompanied by traces of hydrogen sulfide and ammonia, which can be directly used as an energy source for cooking, heating, or even electricity production (Busilaoco et al. 2025). At the same time, the biodigester also produces a digestate rich in nitrogen, phosphorus, and potassium, which constitutes a natural fertilizer capable of replacing chemical fertilizers and improving agricultural productivity within a circular economy logic (Wallace 2024).

Moreover, the socio-economic importance of biodigesters is particularly evident in developing countries. In many rural communities, these systems meet domestic energy needs, reduce pressure on forests through substitution for firewood, and improve quality of life by reducing exposure to toxic smoke from traditional wood burning (Dzokom and Dezeu 2025). In addition, local biogas production decreases dependence on imported fossil fuels and strengthens energy

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autonomy. Socially, biodigesters also contribute to the creation of green jobs related to their manufacture, installation, and maintenance, while reducing household energy costs. Finally, from an environmental perspective, they help reduce methane emissions from the uncontrolled decomposition of organic waste while contributing to carbon neutrality (Luna et al. 2025). Thus, these systems appear as a holistic solution integrating energy, agriculture, public health, and sustainability.

However, despite their many advantages, biodigesters still face technical and environmental challenges that limit their large-scale adoption. First, the efficiency of energy yield depends on several parameters such as temperature, pH, dry matter concentration, and the nature of the substrate used. Poor management of these factors leads to a decrease in methane production and process instability (Achinas and Euverink 2019). Second, the maintenance of installations requires technical skills that rural communities do not always possess, which can cause breakdowns and shorten the lifespan of systems. In addition, social acceptability sometimes remains an obstacle, since the use of animal or human waste still raises cultural resistance (Dzokom and Dezeu 2025). Finally, the performances of biodigesters vary greatly depending on their design: fixed-dome models, tubular digesters, or floating drum types do not offer the same yields or durability under local conditions (Alvarez et al. 2025).

Faced with these limitations, scientific research is working on technological innovations to improve biodigester design, reduce costs, and increase efficiency. Several studies show that the use of co-substrates, combining for example animal manure with agricultural residues or algae, helps increase process stability and methane yield (López *et al.*, 2025; Busilaoco et al. 2025).

Ultimately, biogas production through biodigester systems perfectly illustrates how a relatively simple technology can simultaneously address energy, environmental, economic, and social issues. By transforming waste into resources, biodigesters embody one of the fundamental principles of sustainable development: closing material and energy cycles. Although challenges remain, technological innovations, substrate diversification, and the integration of biodigesters into decentralized energy systems open the way to wider diffusion. In this sense, their role in the global energy transition is expected to grow, and their adoption represents a unique opportunity to reconcile social equity, energy efficiency, and environmental protection.

2. Methodology

The adopted methodology was based on the valorization of recyclable materials available at the Nuclear Physics Laboratory of Abdou Moumouni University in Niamey. The main objective was to design and set up a low-cost experimental biodigester, relying primarily on recovered and locally available materials adapted for practical use for the rural community.

2.1. Selection and collection of materials

Source of materials: The laboratory provided various recyclable items (drums, pipes, fittings, plastic containers, etc.), which were carefully selected for their ability to withstand the mechanical and chemical constraints of the methanation process.

2.2. Selection criteria:

- Tightness and impermeability of containers.
- Resistance to corrosion.
- Local availability and ease of replacement.
- Reduced environmental impact through reuse.



Figure 1 Confection of the recycle materials

2.3. Demonstration plot

A test plot was chosen for installation.

Pits were dug in which the drums serving as the main reactors were buried.

This burial system ensured:

- Better stability of the structure,
- Regulation of the internal temperature (thanks to natural soil insulation),
- Reduced risk of leakage or tipping.



Figure 2 Dispositive of the biodigester

2.4. Biodigester Setup

The biodigester is established by first installing recovered drums in pits to act as the main reactors where anaerobic digestion takes place. An input system is then added, allowing a slurry made of organic waste and water to be introduced into the drums. This setup ensures that the biomass is properly fed into the system under conditions favorable for microbial breakdown of organic matter.

To handle the products of digestion, an output system is constructed to collect the digestate, a nutrient-rich residue that can be used as organic fertilizer for crops. At the same time, airtight pipes are connected to the drums to capture the biogas released during the process. The collected gas can then be stored or directed for practical uses such as cooking or lighting, turning organic waste into both renewable energy and sustainable fertilizer.



Figure 3 Materials composite the biodigester

2.5. Study area

The experimentation was conducted at the Nuclear Physics Laboratory of Abdou Moumouni University in Niamey.

3. Results

3.1. Dynamic of the biodigester for biogas production

Table 1 Evolution of the biodigester

	Test	α	H (m)	ΔCO_2 (ppmv/s)	P (mbar)	T ($^{\circ}\text{K}$)	FCO_2 ($\mu\text{ mol m}^{-2}\text{ s}^{-1}$)
Test before organic matter	Bio_test_0	12.03	0.447	0.31	8868.24	315.62	4.64
1 Week after organic matter	Bio_test_1	12.03	0.447	0.04	983.76	320.71	0.7
	Bio_test_2	12.03	0.447	0.36	986.93	326.09	6.01
	Bio_test_3	12.03	0.447	0.36	987.64	313.47	6.21
	Bio_test_4	12.03	0.447	0.33	984.03	319.2	5.48
	Bio_test_5	12.03	0.447	0.37	990.01	314.16	6.28
3 Week after organic matter	Bio_test_6	12.03	0.447	0.02	986.13	313.2	0.35
	Bio_test_7	12.03	0.447	0.32	995.37	311.44	5.56
	Bio_test_8	12.03	0.447	0.35	985.36	313.57	5.94
	Bio_test_9	12.03	0.447	0.33	987.58	315.4	5.55
	Bio_test_10	12.03	0.447	0.58	991.21	312.8	9.92
	Bio_test_11	12.03	0.447	0.61	987.61	314.7	10.32

The results show that before the addition of organic matter, biodigester CO_2 flux (FCO_2) was moderate at $4.64\ \mu\text{mol m}^{-2}\text{ s}^{-1}$, representing the baseline level of biodigester respiration. One week after amendment, respiration responses were heterogeneous: while one test recorded a sharp decline to $0.70\ \mu\text{mol m}^{-2}\text{ s}^{-1}$, most others showed increases ranging between 5.48 and $6.28\ \mu\text{mol m}^{-2}\text{ s}^{-1}$. This indicates that microorganisms began decomposing the added material, but with uneven intensity, likely due to differences in the distribution and accessibility of organic substrates across micro-sites.

After three weeks, the biodigester respiration displayed even greater variability, ranging from 0.35 to more than $10\ \mu\text{mol m}^{-2}\text{ s}^{-1}$. Some replicates maintained moderate levels (around $5.5\ \mu\text{mol m}^{-2}\text{ s}^{-1}$), while others showed very high fluxes, almost double the baseline, reflecting intensified microbial activity. This pattern suggests that the decomposition of organic matter continued over time, with delayed peaks in some part of the biodigester, possibly linked to the breakdown of more recalcitrant fractions. Overall, organic matter addition stimulated the biodigester CO_2 efflux, though the response was highly variable and strongly dependent on time and micro-environmental conditions.

3.2. Concentration of CO_2 on the biodigester

The figure shows the variation of CO_2 flux (FCO_2 , in $\mu\text{mol m}^{-2}\text{ s}^{-1}$) across different biological tests. Overall, the data fluctuate considerably, with alternating peaks and drops, suggesting heterogeneous CO_2 exchange dynamics. The flux starts moderately high at bio_test_0 (around 4.5), drops sharply to near zero at bio_test_1, then rises to a stable plateau around 6 for bio_test_2 to bio_test_5. A notable dip occurs at bio_test_6, where the flux nearly falls to zero again, followed by a recovery and stabilization around $5-6$ from bio_test_7 to bio_test_9. The most pronounced increase is observed at bio_test_10 and bio_test_11, where flux values surge to their maximum, reaching nearly $10-10.5$. This trend indicates that while CO_2 flux remains relatively stable in the middle series of tests, there are sharp fluctuations at specific points, and the system exhibits a strong increasing trend toward the final measurements.

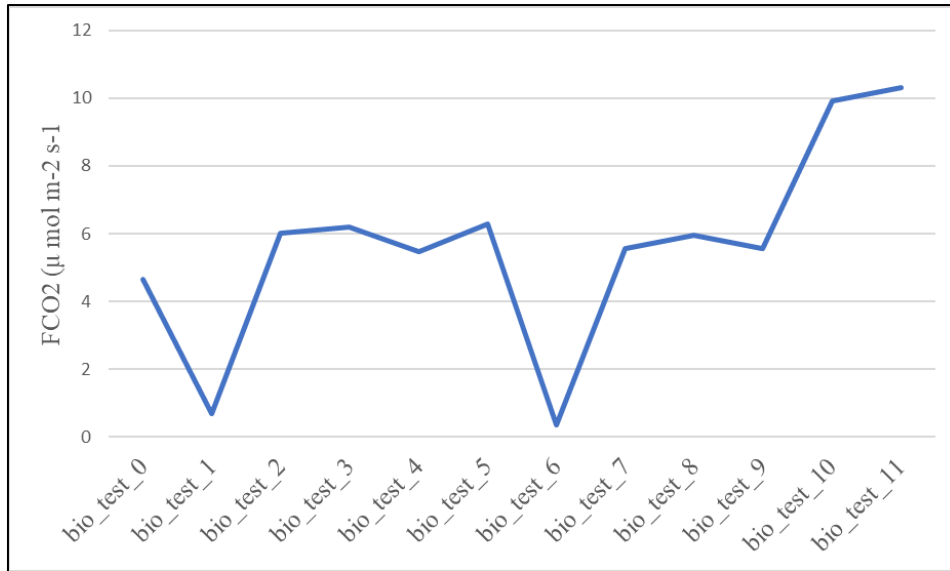


Figure 4 Flux of CO₂ By test

3.3. Concentration of the temperature

3.3.1. Outside temperature

The filtered outside air temperature showed a progressive increase from approximately 39.5 °C to over 42 °C, followed by a stabilization phase with minor fluctuations. This thermal pattern is characteristic of daytime atmospheric warming and suggests enhanced atmospheric mixing during peak temperatures. Consequently, CO₂ concentrations outside the chamber are expected to remain relatively stable and primarily reflect background atmospheric conditions, supporting their use as a reference for chamber-based CO₂ measurements.

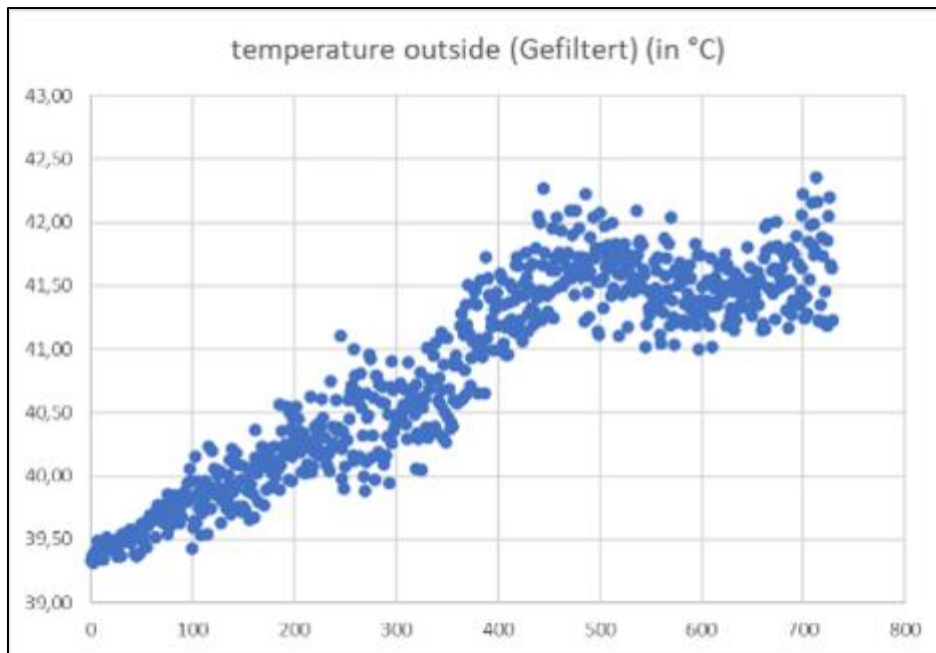


Figure 5 Outside temperature

4. Conclusion

This study, conducted in rice paddies in Kollo, aimed to assess carbon dioxide (CO₂) concentration and emissions under different experimental setups, including the presence or absence of rice plants, floodwater, and the use of open and closed chambers. The comparative approach allowed for a clearer distinction between the respective contributions of soil and plants to CO₂ fluxes in Sahelian rice paddies. The results show that CO₂ emissions vary significantly depending on the experimental conditions. Plots with rice plants and closed chambers exhibit the highest CO₂ concentrations and fluxes, reflecting the combined effect of autotrophic plant respiration and heterotrophic soil respiration. Conversely, open setups, with or without water, recorded lower concentrations due to direct exchange with the atmosphere and CO₂ dispersion. Bare soil plots under closed chambers highlight the major role of soil microbial activity in CO₂ emissions, independent of plant presence. The influence of floodwater also appears crucial. While the presence of water tends to limit CO₂ diffusion from the soil to the atmosphere, it does not eliminate total emissions, particularly due to rice plant respiration and biochemical processes active in the rhizosphere. These results confirm observations reported in the literature, according to which rice farming systems exhibit complex carbon flux dynamics, highly dependent on water and biological conditions. Methodologically, the combined use of closed and open chambers proved relevant for CO₂ emission analysis. Closed chambers allowed for a precise estimation of fluxes, while open chambers provided a reference closer to natural conditions. This methodological complementarity strengthens the reliability of the results and underscores the importance of choosing the appropriate measurement device in greenhouse gas studies. Ultimately, this study makes a significant scientific contribution to understanding CO₂ emissions from irrigated rice farming systems in Kollo, a context that remains poorly documented in West Africa. The results obtained provide a baseline for future research incorporating other greenhouse gases, such as methane and nitrous oxide, and for the development of more sustainable rice farming practices that reconcile agricultural productivity with climate change mitigation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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Annexes



