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Physical experimentation of the productivity of biogas in the laboratory from putrescible waste

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Abstract

The methanization of organic waste for the production of biogas responds to several fundamental issues in rural areas of Chad. From an economic point of view, this solution offers a viable alternative to firewood, the excessive exploitation of which contributes to deforestation. By substituting biogas for wood, rural households not only reduce their energy costs, but they also become part of a dynamic of energy self-sufficiency. The valorization of residues in the form of biofertilizers constitutes another positive economic impact. These natural fertilizers enrich agricultural soils, thus improving yields while reducing dependence on chemical fertilizers that are often expensive and harmful to the environment. For our study, we collected samples of different food waste from local markets, sewage sludge from treatment plants for agricultural, human, animal, poultry and food waste from surrounding farms. The objective of this study is to determine the optimal parameters for the production of biogas from organic matter, with a view to efficient use for cooking and biofertilizer in rural Chad.

We were able to optimize the digestion conditions according to temperature, pH and retention time (RT) to maximize biogas production and ensure efficient conversion of organic matter. Then we used the digestates produced to improve soil fertility.

Keywords: Methanization; Organic waste; Optimal parameters; Temperature; pH; Retention

1. Introduction

Biogas production is therefore suitable for the specificities of rural areas in Chad, where households have limited financial resources and where the need for clean energy and soil fertility is pressing. In addition, this technology promotes the creation of local jobs, particularly in waste collection, the construction and maintenance of methanization units, and the distribution of derived products, thus helping to revitalize local economies. Biogas has multiple advantages over other types of energy [5].

Its availability, ease of storage, distribution through existing natural gas infrastructure, and direct use for domestic cooking and as a transport fuel. Biogas production can therefore help solve the energy problem[6]. It can be done using various techniques such as aerobic and anaerobic digestion.

Anaerobic digestion is one of the biological treatments for organic waste. It is receiving increasing attention due to its significant waste recovery [7]. The DA of organic waste offers possibilities for energy and nutrient recovery. Thus, it reduces the impact of waste on the environment, while producing sustainable and renewable energy, contributing to the reduction of greenhouse gas emissions [8].

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To this end, factors such as the physical and chemical characteristics of food waste affect the performance of anaerobic digestion. These are the pH, the total and volatile solid matter, the chemical and biological oxygen demand, etc.

In Chad, waste, landfills consist of more than 60% household waste. The substrate is therefore rich in organic matter. This high organic matter content promotes a high potential for methane and carbon dioxide emissions [9].

This therefore constitutes a real danger for the environment. To date, to our knowledge, the studies carried out on these landfills so far have been limited to the environmental impact and its potential for greenhouse gas emissions [10]. These studies have proven the existence of harmful effects related to this discharge on the environment such as the impact of leachate on the quality of groundwater and surface water.

In developing countries, rural households exclusively use firewood and urban households use firewood and/or charcoal, sometimes both, for cooking [11]. This massive use of biomass contributes to the rapid decline in the country's forest resources, promoting deforestation which brings global warming.

Furthermore, the production of biogas from organic matter of different origins: human waste, waste, cereal residues, plant matter, animal droppings, by-products of the agri-food industry, sludge from sewage treatment plants, household waste, etc., using anaerobic fermentation systems (processes) in appropriate digesters (bio-methanization) will allow better waste management, environmental preservation and development as well as diversification of energy resources (alternative energies) [12]. It is in this vision that we wanted to carry out a test of biogas production from goat waste, cereal bran, pig droppings, human waste and others.

To produce biogas there are 4 phases of degradation: Figure 1 shows us the biological degradation process in order to obtain quality biogas

1.1. Hydrolysis

Hydrolysis is the first crucial step in the anaerobic digestion process for biogas production. Hydrolysis also involves the degradation of these macromolecules into monomers such as glucose, fatty acids and nitrogenous bases. It is carried out by means of exoenzymes secreted by fermentative microorganisms [13].

1.2. Acidogenesis

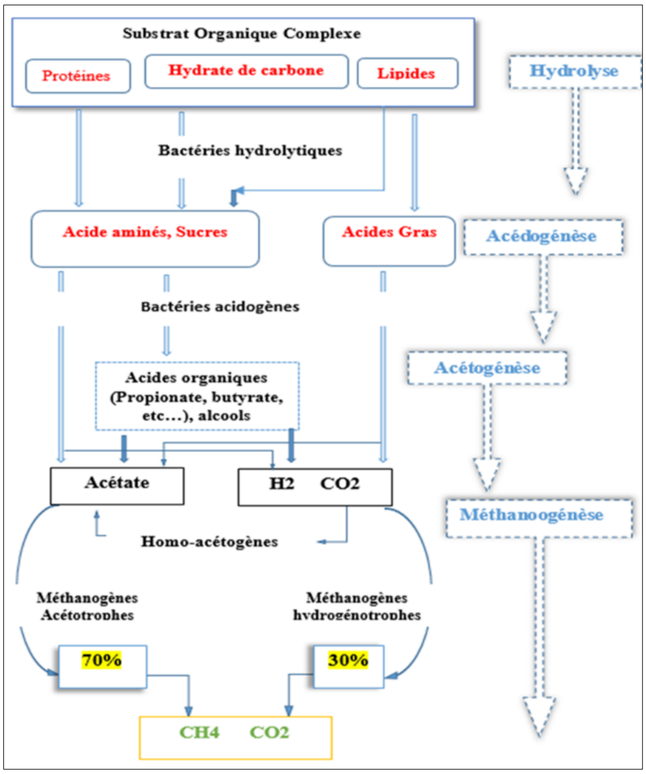

Figure 1 Complex biological process: 4 phases of degradation

This phase is crucial to maximize the yield and quality of the biogas, and also has implications for the use of the digestate as a biofertilizer. It is generally rapid due to the high rate of croes involved. Other co-products are also generated such as carbon dioxide and hydrogen, as well as ammoniacal nitrogen (in the form of NH_4^+ or NH_3) in the case of protein hydrolysis. [14]

1.3. Acetogenesis

This phase plays a crucial role in the conversion of organic acids produced during acidogenesis into acetate, hydrogen and carbon dioxide, which are the main substrates for methanogenic bacteria responsible for methane production. The quality and yield of biogas, as well as the value of the digestate as a biofertilizer, strongly depend on this step.[15] During this step, the acids resulting from acidogenesis require electron acceptors, a role that hydrogen fulfills [16,17]

$$\text{Propionate } CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + 3H_2 + CO_2$$

$$\text{Butyrate } CH_3CH_2CH_2COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2$$

$$\text{Palmitate } CH_3\,(CH_2)14COOH + 14H_2O \rightarrow 8CH_3COOH + 14H_2$$

These reactions are thermodynamically unfavorable and can only occur at very low hydrogen partial pressure and very low product concentration [18].

1.3.1. Methanogenesis

Methanogenesis is the final phase of the anaerobic digestion process, where organic acids and other compounds from the previous steps are converted into methane (CH_4) and carbon dioxide (CO_2) by methanogenic bacteria. [19] In general, the methanation reaction is summarized by:

$$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$$

The stoichiometric relationship of the methanation reaction varies depending on where methanogenesis occurs. Hydrogenotrophic or hydrogenophilic methanogens use the reduction of carbon dioxide or formic acid by hydrogen as an energy source, according to the following equation:

$$CO_2 + 4\,H_2 \rightarrow 2\,H_2O + CH_4$$

1.4. Main parameters

1.4.1. Temperature

Anaerobic digestion can be carried out under three temperature ranges:

- from 15 to 25°C: psychrophilic fermentation;
- from 25 to 45°C: mesophilic fermentation;
- from 55 to 65°C: the fermentation is called thermophilic.

Mesophilic digesters are the most used (at «38°C) in temperate zones.

1.4.2. pH (hydrogen potential)

pH is a very interesting indicator in the stabilization and proper functioning of anaerobic digestion. [20-29].

- Optimal Range: The optimal pH for methanogenesis is generally between 6.8 and 7.4. Variations in pH can inhibit the activity of methanogenic bacteria and reduce the efficiency of methane (CH_4) production.
- Impact: A stable and slightly alkaline pH is crucial to maintain methanogenic activity and avoid process disturbances [20].

2. Materials and Methods

We used the following materials and waste for the experimental realization of biogas production namely:

2.1. Rice bran

- Goat waste;
- Red millet bran residues
- Millet bran residues (beriberi)
- Human waste
- Pig waste
- Pigeon droppings
- Empty 750ml bottles of tangui spring;
- Sticky balloons;
- Gloves;
- A blouse
- A nose mask
- A butane gas canister;
- A pot;
- An electronic thermometer;
- A cup (measuring instrument);
- A bucket (instrument for mixing).
- Ten 750ml plastic bottles
- Sufficient inflatable balloons (ambouba)
- A knife
- An electronic thermometer
- A pair of gloves,
- A shovel,
- A nose mask.

2.2. Method of waste recovery and construction of digesters

For this phase, we collected different wastes to allow us to carry out these experiments on the production of biogas intended for cooking and biofertilizer. For this reason, wastes such as rice bran, red millet, beriberi millet were collected at the Djougoulié market in farcha. For goat waste, pig waste, pigeon waste, we collected them directly in their enclosure as well as human waste.

2.3. Experimental Methodology of Organic Waste Collections for Biogas Production

2.3.1. Experiments

Construction of Experimental Digesters

We considered it important to use the 750 ml capacity bottles as a digester and the inflating balloons as a biogas storage tank. [29].

We carry out ten different types of experiments by this procedure, consequently we have eight digesters. Of the eight digesters, two digesters must each contain a waste without mixture and of different nature. The five digesters must each contain two types of waste, one of which would be goat waste.

The eighth digester must contain the mixture of all the waste. Thus, we placed the waste in the following manner:

- Goat waste (alone);
- Bereri waste (bran) (alone);
- Rice bran (alone);
- Red millet bran (alone);
- Goat waste + beriberi bran + red millet bran + rice bran
- Wet human waste (alone)
- Pig waste (alone)
- Pigeon droppings (alone)
- Goat waste + pigeon droppings
- Pigeon waste + pigeon droppings

2.3.2. Experimental condition

We present to you the image of the different wastes collected before mixing.

Figure 2 Different types of waste collected for experimentation

For better fermentation, we first reduce the large particles to powder in order to obtain a homogeneous body. Once the mixture becomes homogeneous, we introduce the mixture into the digester (water bottle) at half equal.

We heat water to a minimum temperature of 45 ° C, measured using an electronic thermometer; we then add this hot water to the mixture while stirring to obtain homogenization in the container

Figure 3 Images of eight bottles filled with waste for the experiment

3. Results and Discussion

3.1. Results of the first week's experiments

The first week of the implementation of our experiment went well. Most of the different wastes were able to produce biogas. Figure 4 compared to Figure 3 demonstrate the positive extent of compliance with the conditions implemented to reproduce the biogas production processes on a laboratory scale.

Figure 4 Biogas productions after one week

3.1.1. Experiment report

Digester observations

- Pig excrement digester only: - Observation: No gas production after one day of agitation. The tank is empty.
- Pig excrement digester + goat waste: - Observation: Considerable biogas yield and presence of biofertilizer in the tank.
- Goat waste digester only: - Observation: Constant gas volume, without biofertilizer.
- Pigeon excrement digester + human urine: - Observation: Constant biogas volume in the tank.
- Rice bran digester only: - Observation: Constant gas volume in the tank.
- Human waste digester only: - Observation: No change. Constant biogas volume, without biofertilizer.

Figure 5 below gives us an overview of the productivity in terms of volume on the different types of waste

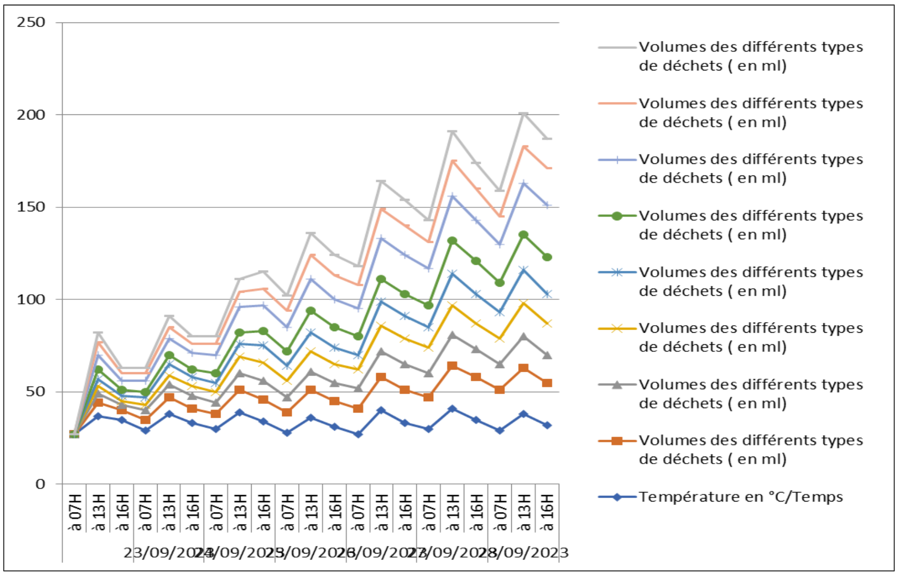

Figure 5 Productivity in terms of volume on different types of waste

3.2. Biogas volume estimates

Due to the lack of precise instruments to measure the volume of biogas produced daily, we used balloons of the same size in all digesters to visually estimate volume variations. This method, although estimative, allowed us to detect clear differences between digesters operating at ambient temperature and those operating at mesophilic temperature.

The balloons of mesophilic digesters showed a faster and more significant expansion, confirming an increased biogas production compared to digesters at ambient temperature. This result suggests that, despite the limitations of direct measurements, the adopted approach allowed

The analysis of the results obtained during this study of methanization by co-digestion of organic waste in N'Djamena highlights several key aspects relating to the parameters influencing biogas production. Among these, the ambient temperature, the nature of the substrates used, and the specific experimental conditions play determining roles in the efficiency and speed of biogas production[21].

3.3. Influence of temperature

Temperature measurements taken throughout the experiment show that this parameter is crucial in biogas production. Two types of thermal conditions were tested: ambient temperature and mesophilic temperature (generally between 30 and 40°C). The results show that biogas production is significantly faster and more efficient in digesters operating at mesophilic temperature compared to those left at ambient temperature [18-22].

Indeed, at ambient temperature, the microorganisms responsible for anaerobic digestion develop more slowly, which results in a lower biogas production during the first seven days. Daily fluctuations in the outside temperature also affect the stability of the digestion process, which can lead to temporary interruptions in production. Conversely, in digesters at mesophilic temperature, the process is more stable and regular, which allowed to obtain a higher biogas production over the same period. These results corroborate previous studies showing that anaerobic digestion is more efficient at moderate temperatures, close to those of the human body, where methanogenic microorganisms are most active [18-29] to establish reliable trends concerning the efficiency of biogas production as a function of thermal conditions.

3.4. Analysis of production speed

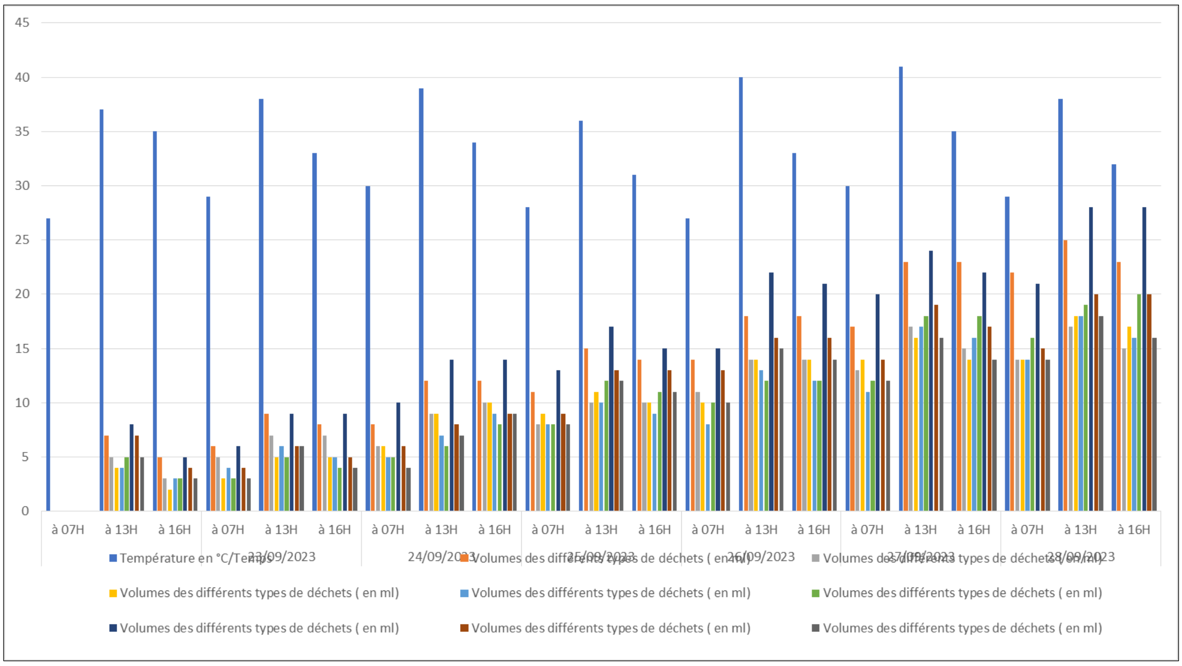

Figure 6 Responses of measurements of volumes produced from waste as a function of a given temperature from the first week of experimentation

The biogas production curves obtained from the collected data show a marked difference in the production rate depending on the temperature.

We can notice on the responses of the experiment given in Figure 6, Figure 7 and Figure 8 below that as the temperature changes during the day and during the week, there is an increase in the volume of the tank used for the recovery of biogas.

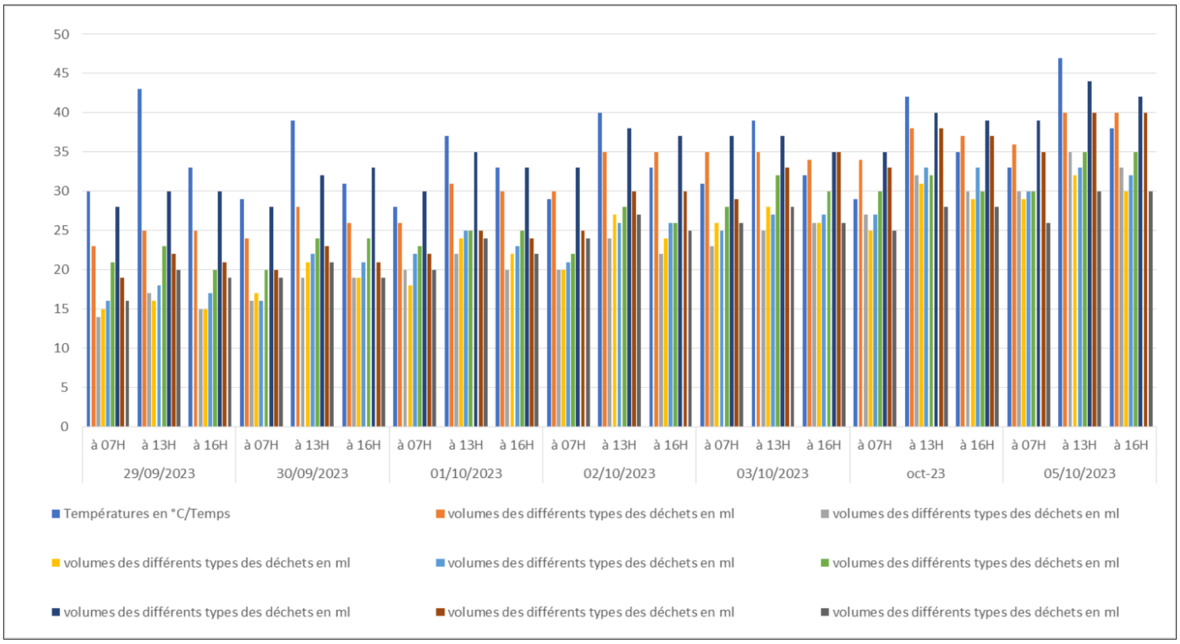

Figure 7 Responses of measurements of volumes produced from waste as a function of a given temperature from the second week of experimentation

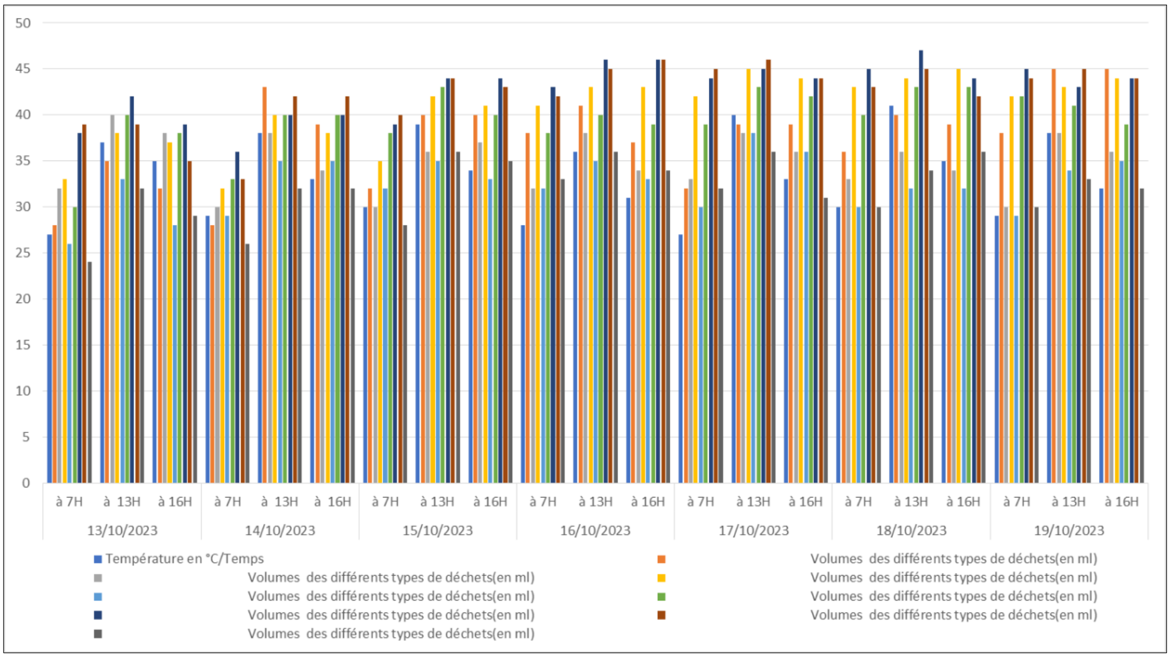

Figure 8 Responses of measurements of volumes produced from waste as a function of a given temperature from the last week of experimentation

At room temperature, the production rate increases slowly during the first days and then gradually stagnates, which may be due to the depletion of nutrients in the substrates or to the inhibition of microorganisms by the drop in night temperature. Conversely, at mesophilic temperature, the production rate remains relatively high throughout the observation period, with a tendency to accelerate during the first days. This indicates that methanogenic microorganisms multiply and function optimally under controlled thermal conditions, thus enhancing the productivity of the digester [20-29].

3.5. Experimental result based on the last week

Observation on anaerobic digesters gives us the following results:

Figure 9 Biogas production at the end of the experiment

Observation of rice bran digesters; goat waste with human urine; beriberi bran; red millet bran and the digester of pigeon excrement compounds with goat waste.

For pig waste with goat waste, we notice an increase in the volume of gas in the balloon with a significant amount of biofertilizer.

For mono digestion digesters of pig waste; goat waste and human waste, we note a decrease in the volume of gas in the balloon with biofertilizer with the exception of pig waste.

After any agitation, we note that the fluid (gas) rises more in all the balloons but with the exception of the digester containing goat waste with human urine always remains empty

4. Conclusion

Rural development in Chad remains a major challenge in the face of environmental, energy and socio-economic issues. In this context, the production of biogas for cooking, as well as biofertilizers from the methanization of organic waste, represents an innovative and sustainable solution. Indeed, this process presents itself as a multifaceted response to the pressing needs of rural communities, while being part of a perspective of transition towards a green economy. This research aims to analyze the implications of this technology, while measuring its social, economic and environmental impacts in the short and long term.

In addition, methanization offers a sustainable solution to the management of organic waste, often discarded without prior treatment in rural communities. By transforming this waste into energy and agricultural resources, biogas contributes to the reduction of environmental nuisances, such as soil and water pollution, while limiting the proliferation of diseases linked to poor sanitary conditions.

In addition, improving cooking conditions using biogas reduces exposure to toxic fumes generated by burning wood, thereby improving household health. This advance has beneficial effects, particularly in reducing respiratory diseases, which are a major concern in rural areas.

At the community level, the implementation of methanization systems promotes better management of organic waste, thereby strengthening public hygiene and quality of life. The implementation of such projects also encourages community participation and awareness of environmental issues, creating a collective dynamic around sustainable development.

In short, the production of biogas and biofertilizers in rural Chad represents much more than a simple technological solution: it embodies an integrated and sustainable vision of development. At the crossroads of economic, social and environmental issues, this approach offers tangible benefits for local communities while participating in the global energy transition. For these initiatives to reach their full potential, they must be supported by ambitious policies, solid partnerships and active mobilization of populations. In this way, Chad can assert itself as a key player in building a greener, more equitable and more prosperous future for all.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

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