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Theoretical Analysis of Biogas Production from Septic Tanks: The Case of the City of Kinshasa

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ABSTRACT

As many think that respect for the environment, is not only a question intended for industrialists but has all the sectors of life, in particular sanitary also. In this regard, our article brings alternative management of human waste (excrement) to solve the problems that plague our dear beautiful capital, namely: 1) Lack of latrines that meet the standards; 2) Emptying of septic tanks directly into the gutters and; 3) Water pollution by sewage csompanies. In order to carry out the cartographic analysis of the study area, we used Shapefile data from the OpenStreetMap, Diva-Gis. These different data allowed us, analyzed, to categorize with the software ArArcGIS 0.8.1 to produce different zones according to the cases incurred in the city of Kinshasa. To do this, the analytical method uses the Buswell equation to determine the amount of gas contained in human excrement. Focusing on the analysis of the excrements produced by the population of age superior to 10 years, for 2023, we obtained: 138355.7283 m^3/day of CH_4 (885476.66 kWh/day or 885.476 MWh/day), which, energy can light: 138,355 lamps of 60 to 100 W for six hours or nearly 70,000 lamps of 60 to 100 W for 12 hours. Considering the last one which offers the lowest access rate, *i.e.* 3% of the district population to these latrines, we have: a) In Tshangu, we produce: 1618.762 m^3/day (10360.07 kWh/day or 10.36 MWh/day) which can light nearly 1600 lamps from 60 to 100 W for six hours or nearly 800 lamps from 60 to 100 W for twelve hours. b) Mont-Amba, we produce 1402.927 m^3/day (8978.73 kWh/day or 8.97 MWh/day) which can light nearly 1400 lamps from 60 to 100 W for six hours or nearly 700 lamps from 60 to 100 W for twelve hours; c) In Lukunga, we produce: 946.35 m^3/day (6056.66 kWh/day or 6.056 MWh/day) which can light nearly 900 lamps from 60 to 100 W for six hours or nearly 450 lamps from 60 to 100 W for twelve hours. d) Funa, we

produce: 182.629 m^3/day (1168.83 kWh/day or 1.17 MWh/day) which can light almost 180 lamps from 60 to 100 W for six hours or almost 90 lamps from 60 to 100 W for twelve hours.

1. INTRODUCTION

For the past few decades, global warming has been a major concern and is at the center of major debates on environmental issues [1]. Among the solutions considered to reduce its harmful impact on the planet earth, it is worth mentioning the respect for the environment through the application of the three Rs (Reduce, Reuse, and Recycle). As many think respect for the environment, is not only a question destined for industrialists but for all sectors of life notably the sanitary one too. For, it plays an important role in the destruction of the environment as shown in **Figure 1**.

In 2020, nearly 6 billion people had cell phones while 2 billion people still do not have a toilet or latrine. Of these, 673 million defecate in the open, for example in gutters, behind bushes, or in water bodies [2]. This situation creates huge stocks of waste and leads to the appearance of numerous microbes responsible for quite serious diseases. This is especially true in Africa.

Indeed, the transmission of diseases such as cholera, dysentery, hepatitis A, typhoid, polio, and diarrhea occurs as a result of poor sanitation (WHO, June 15, 2019) [3]. The latter alone is responsible for about 8% of all deaths in Africa. Yet these deaths are preventable. Improving water supply, sanitation, and hygiene would, according to WHO, prevent the deaths of 297,000 children under the age of 5 each year.

Faced with this situation, the provincial city of Kinshasa, the largest city in the DRC, is no exception. More than half of the population lives in peri-urban areas with a lack of adequate sanitary facilities.

And the majority of those who have hygienic installations have a problem of regular maintenance. Because, a regular maintenance guarantees the good functioning of a septic tank, something which is very little respected in the city province of Kinshasa and everywhere in the country.

As a workaround, some individuals take advantage of the rain to empty their septic tanks into the gutters or rivers near their place of residence and even some buildings and public toilets located in the commune of Gombe empty directly into the Congo River. Some call on the local drainage company, which uses the procedure shown in **Figure 2**.

Indeed, the latrines, although neglected, could be a source of valorizable energy, they naturally produce two gases (CO_2 and CH_4), from which the methane (CH_4), otherwise called biogas, can be removed by a simple process and within the reach of all the purses.

As a reminder, 1.33 to 1.87 m^3 of biogas is equivalent to 1 L of gasoline. In this study, this energy would be used primarily for cooking and lighting [4].

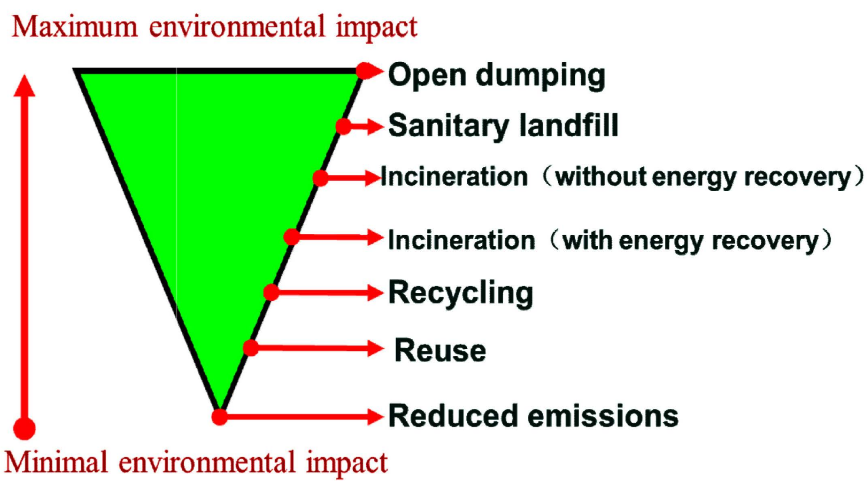

Figure 1. Degree of environmental impact.

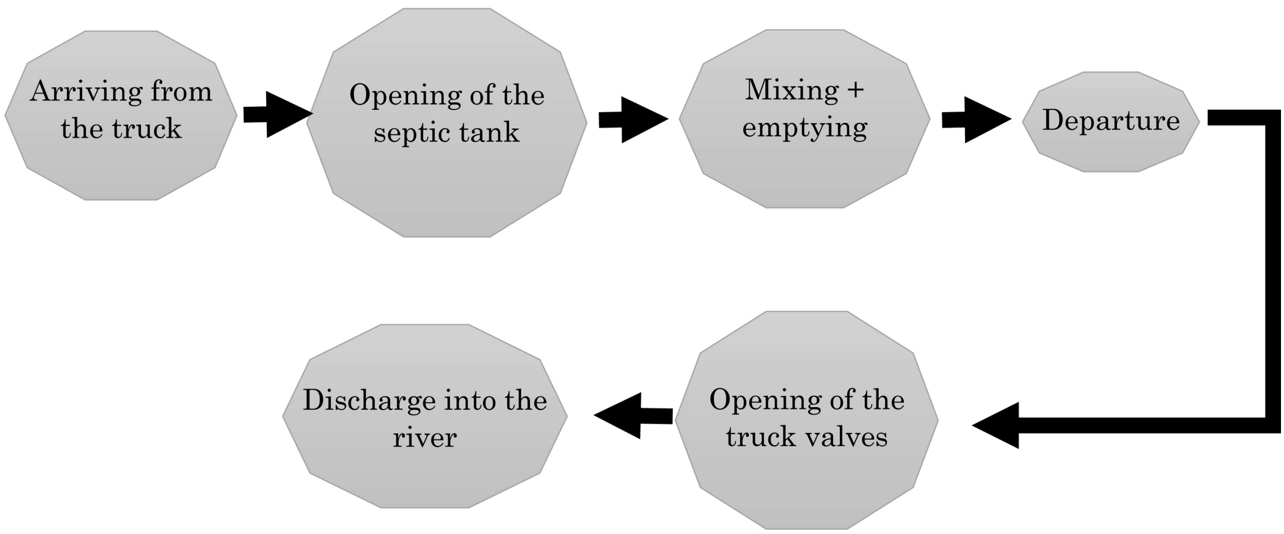

Figure 2. Emptying procedure in Kinshasa.

For this purpose, 1 m^3 of biogas is equivalent to:

- Light a 60 - 100 Watt bulb for 6 hours.
- Cook 3 dishes for a family of 5 - 6 people.
- 0.7 kg of oïl.

It can generate 1.25 kWh of electricity.

In this regard, our article provides an alternative management of human waste (excrement) to solve the problems that plague our dear beautiful capital, namely:

- Lack of latrines that meet the standards;
- Emptying of septic tanks directly into the gutters and;
- Water pollution by sewage companies.

2. PRESENTATION OF THE CITY

As shown **Figure 3**, the city of Kinshasa (/kin.ʃa.sa/; Lingala: Kisásá), known as Léopoldville (Dutch: Leopoldstad) from 1881 to 1966, is the capital and largest city of the Democratic Republic of Congo (DRC) and covers an area of 9965 km^2. With an estimated population of 15,628,085 in its metropolitan area in 2022, it is the third largest metropolitan area in Africa after Cairo and Lagos, and is the largest French-speaking metropolitan area in the world, having surpassed Paris in the 2010s, and is one of the most populous metropolitan areas in the world.

Located on the southern bank of the Congo River, at the Malebo Pool, it faces the capital of the Republic of Congo, Brazzaville (**Figure 4**). The city limits are very large, and more than 90% of its area is rural or forested (especially in the commune of Maluku); the urbanized parts are located in the west of the territory. Kinshasa has the administrative status of a city and is one of the country's 26 provinces. The city is composed of [5]:

- 24 municipalities;
- 370 quarters;
- 49,950 avenues and
- 1,240,220 parcels.

2.1. Urbanization of the City

The urban population of the Democratic Republic of Congo is growing rapidly. Estimated at 42 percent in 2015, the proportion of the population living in urban areas in the Democratic Republic of Congo

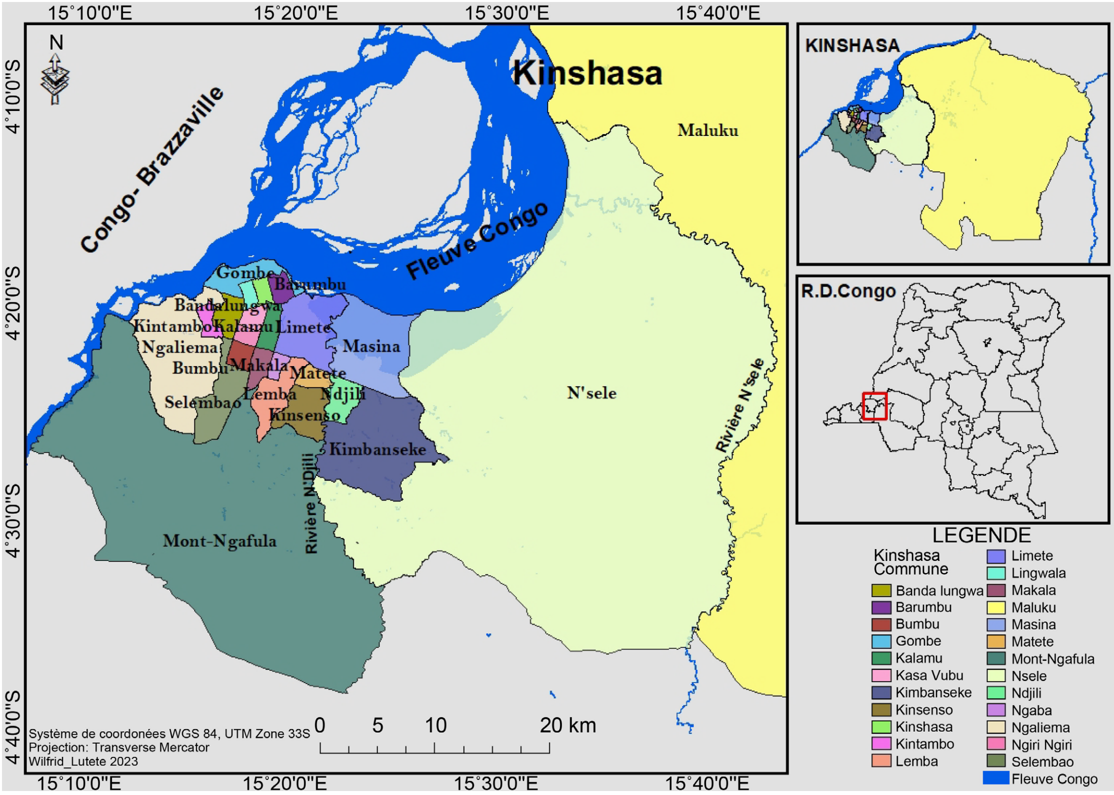

Figure 3. The city of Kinshasa (Source Wilfrid_Lutete 2023).

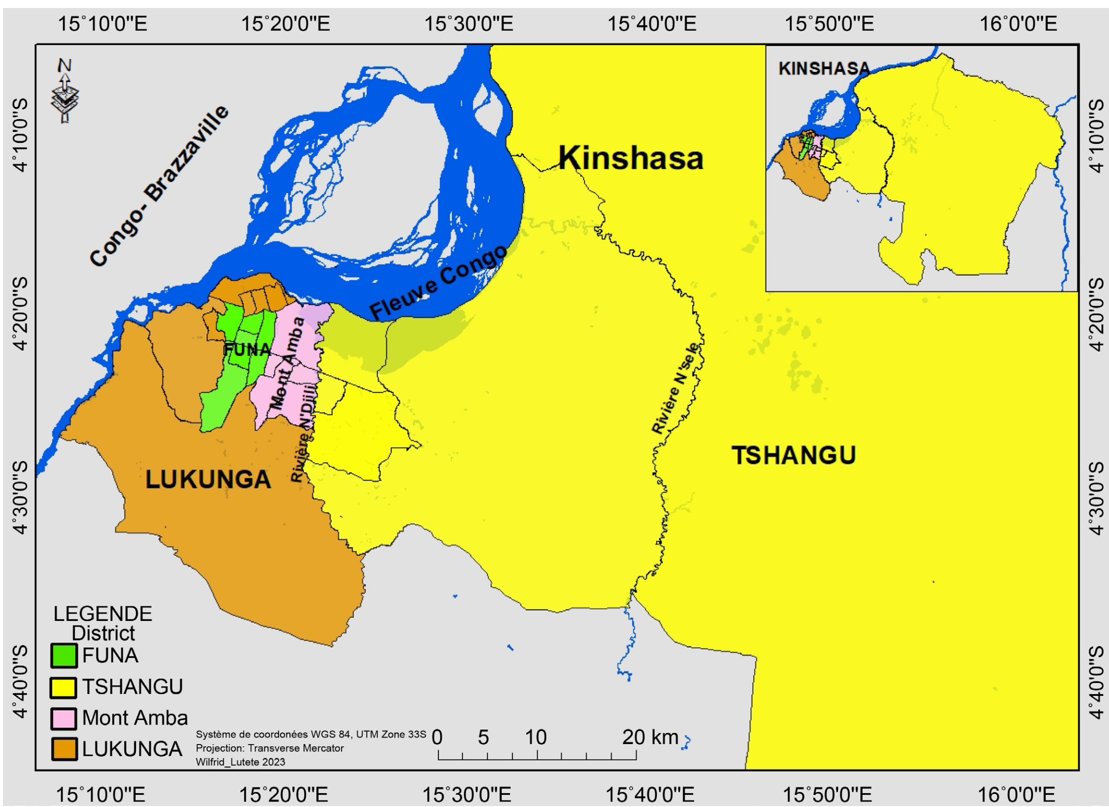

Figure 4. The special distribution of the different districts of the city of Kinshasa.

is the third largest in sub-Saharan Africa, after South Africa and Nigeria [6].

Much of this population growth is attributable to factors in the source localities (*i.e.*, conflict and inadequate rural services) rather than to incentives in the cities (including better work and living opportunities). With an estimated population of 12 million in 2016, Kinshasa represents the densest and fastest growing urban system in Central Africa. At its current rate of growth, the city will be home to nearly 24 million people within ten years and will be the most populous city in Africa, ahead of Cairo and Lagos. This prospect constitutes an opportunity, but also a risk that the living conditions of the people in Kinshasa will become even more precarious and that the city will become the largest slum in Africa (**Figure 5**) if urbanization is not properly managed and the trend of exclusive urbanization and marginalization is not reversed [7].

Rapid population growth brings with it many challenges. It increases the demand for:

- Social services and infrastructure.
- Education, health and basic services.
- To make cities livable.

At the same time, significant investments are needed to ensure that capital, infrastructure and businesses are productive. The city is made up of several large squares through which many people pass and which need to be improved (sanitary facilities, stops, garbage garbage cans, etc.).

2.2. Population

Between 1984 and 2010, the city's annual population growth rate averaged 5.1%, compared to 4.1%

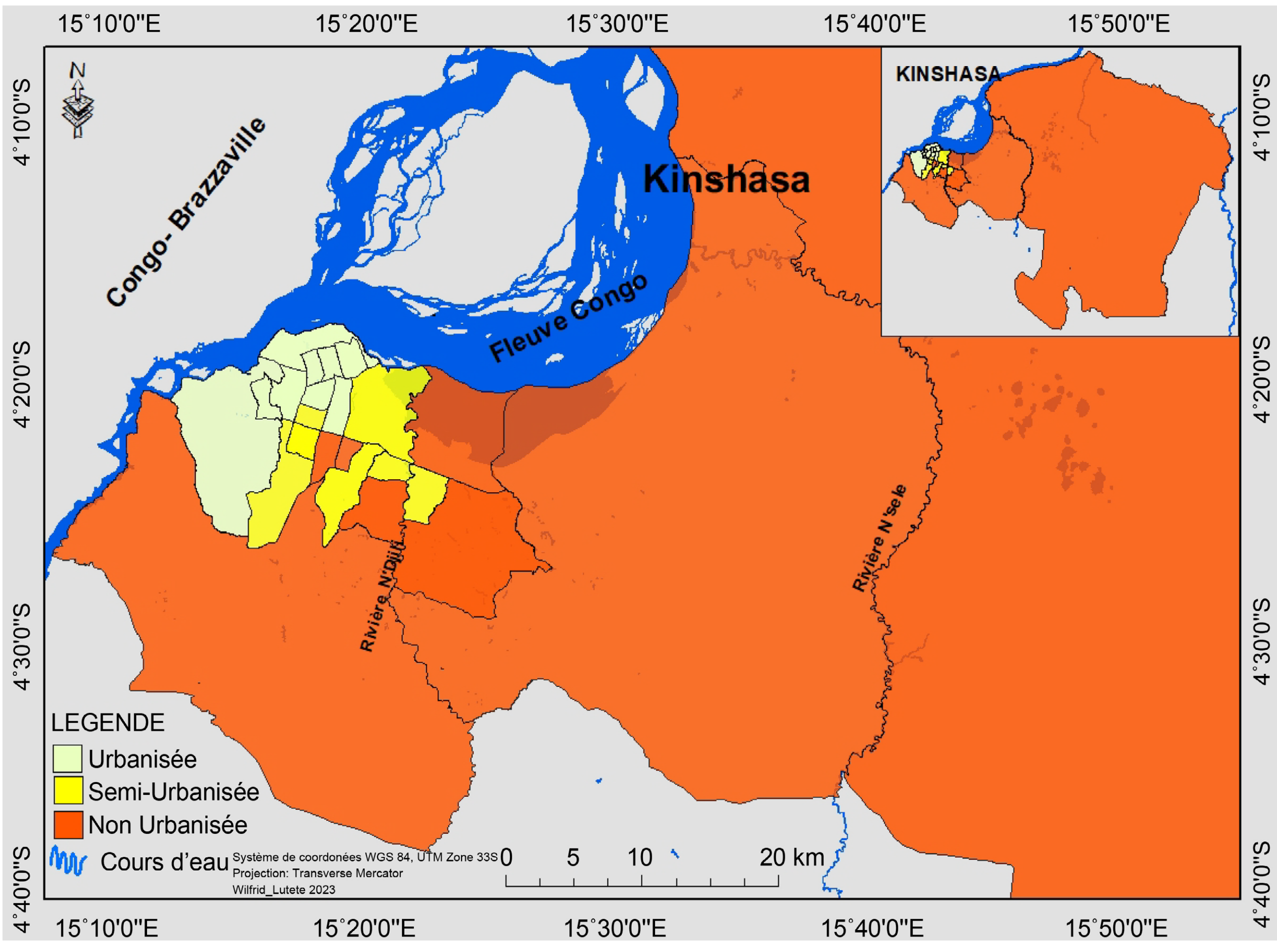

Figure 5. Map of the city showing major slums.

nationally [5]. Given this population density, the city of Kinshasa will become the largest megacity in Africa by 2030. Table 1 represents the population evolution for the period from 2010 to 2035.

3. BIOGAS FROM LATRINES

Table 2 and Table 3 show us how Biogas is a solution to fight deforestation. The production of this gas is done by fermenting in a tank (called digester) buried. Human and animal wastes, excrements and slurry of pigs or cattle for example are used as raw materials. This process of biological degradation, called methanization and due to the biological fermentation of fermentable organic matter in an anaerobic environment, *i.e.*, without oxygen, is the same as that which occurs in certain circumstances in swampy areas, sludge from sewage plants or in uncontrolled landfills. This simple and natural process allows for better treatment of animal excrements and dejecta and for their valorization through the use of the gas produced for lighting and cooking.

Table 1. Evolution of the population of Kinshasa [8].

Year	Population	Growth Rate	Growth
2035	26,681,824	3.91%	1,002,968
2034	25,678,856	3.96%	978,604
2033	24,700,252	4.02%	954,162
2032	23,746,090	4.07%	928,042
2031	22,818,048	4.12%	903,706
2030	21,914,342	4.18%	878,496
2029	21,035,846	4.23%	853,878
2028	20,181,968	4.28%	827,544
2027	19,354,424	4.32%	801,604
2026	18,552,820	4.36%	774,346
2025	17,778,474	4.38%	746,152
2024	17,032,322	4.39%	716,788
2023	16,315,534	4.40%	687,449
2022	15,628,085	4.39%	657,625
2021	14,970,460	4.38%	628,021
2020	14,342,439	4.36%	599,161
2019	13,743,278	4.34%	572,022
2018	13,171,256	4.33%	546,912
2017	12,624,344	4.33%	524,202
2016	12,100,142	4.33%	502,436
2015	11,597,706	4.33%	481,573
2014	11,116,133	4.33%	461,577
2013	10,654,556	4.33%	442,410
2012	10,212,146	4.33%	424,040
2011	9,788,106	4.33%	406,433
2010	9,381,673	4.33%	389,556

Table 2. Contents of human excrement [9].

Component	Unit (per wet mass)	Amount
Dry mass (at excretion)	g/kg	216
Total nitrogen (TN)	g/kg	11
Total phosphorus (TP)	g/kg	4
Potassium	g/kg	8
Moisture content	%	78
Dry matter content (at excretion)	%	22
pH	-	7 - 9

Table 3. Amount of biogas produced [4].

Source	Waste amount/day/kg	% Water	Dry matter	Biogas m^3/kg dry waste
Cow	20 - 30 (28)	80	20	0.023 - 0.040
Dairy cow	20 - 30 (28)	80	20	0.023 - 0.040
Buffalo	30 - 40 (35)	83	20	0.023 - 0.040
Roaster/Hen	0.15 - 0.20 (0.18)	72	28	0.065 - 0.116
Pig	3.00 - 4.00 (3.40)	67	9	0.04 - 0.059
Human	0.10 - 0.40 (0.15)	77	23	0.02 - 0.028

In Africa in general and in DRC in particular, most rural and mountain areas are isolated and have no other source of energy than wood. The latter, widely used for cooking, contributes to deforestation.

3.1. Benefits of Biogas

This technology offers several advantages [10] namely:

- Free fuel used (for cooking and lighting) and especially less polluting.
- Use of the residues as natural fertilizer and finally.
- Improvement of the hygiene of houses and waterways.
- The investment cost is low despite the need for skilled help, especially in construction.
- This is a boon for poor and poorly urbanized regions.
- The construction can also be done with local materials and with little land, the tank being built underground in most cases.
- Improving the living conditions of urban, peri-urban and rural populations, and more particularly the living conditions of women by reducing the time they spend collecting wood (for peri-urban and rural areas). While eliminating respiratory diseases caused by the prolonged inhalation of harmful fumes from the burning of wood, coal or in some regions dried cow dung.
- Sensitization of the populations to alternative energies in order to remedy the serious problem of deforestation caused, among other things, by the use of wood for cooking, whose uncontrolled use can lead to the desertification of many regions of the world.
- Finally, the construction of biogas tanks meets the criteria of sustainable development, as the tech-

nique of methanization consists of producing clean energy from organic matter such as manure and its use is accompanied by a transfer of technology to the beneficiary communities, the training of personnel, both for the construction of the system and for its maintenance, and the creation of management committees.

3.2. The Process

The process consists of concentrating and treating animal excrement and waste in an anaerobic tank or digester where, in the absence of oxygen (anaerobic), micro-organisms multiply and derive the energy necessary for their development from organic substances which they decompose into gas with a high proportion of methane and with a high caloric and energy potential.

The biogas tank is buried and directly connected to a family (or public) latrine built on its roof. For insulation reasons (digestion by anaerobic bacteria is optimal at 37˚ and constant temperature).

The performance of the system is improved by:

- Direct connection of the latrine to the digester.
- Association of a small animal yard (mainly pigs).
- On the roof of the tank (improvement of the sanitary situation and provision of additional insulation for better gas production.

4. METHODOLOGY

In order to carry out the cartographic analysis of the study area, we used Shapefile data from the OpenStreetMap, Diva-Gis. These different data allowed us, analyzed, to categorize with the software ArcGis 10.8.1 to produce different zone according to the cases incurred in the city of Kinshasa.

To carry out this study we use the analytical method using the BUSWELL equation. This equation was developed by BUSWELL and MULLER in 1952 [11]. It allows to predict the quantity and the theoretical composition of biogas produced during the anaerobic biodegradation of a substrate whose elementary composition is known.

Formula:

$$\mathrm{C}_a\mathrm{H}_b\mathrm{O}_c+\left(a-\frac{b}{4}-\frac{c}{2}\right)\mathrm{H_2O}\Rightarrow\left(\frac{a}{2}-\frac{b}{8}+\frac{c}{4}\right)\mathrm{CO_2}+\left(\frac{a}{2}+\frac{b}{8}-\frac{c}{4}\right)\mathrm{CH_4} \tag{1}$$

The Equation (1) was completed by BOYLE in 1976 by integrating sulfur and nitrogen, becoming:

$$\begin{aligned}&\mathrm{C}_a\mathrm{H}_b\mathrm{O}_c\mathrm{N}_d\mathrm{S}_e+\left(a-\frac{b}{4}-\frac{c}{2}+\frac{3d}{4}+\frac{e}{2}\right)\mathrm{H_2}\\&\Rightarrow\left(\frac{a}{2}-\frac{b}{8}+\frac{c}{4}+\frac{3d}{8}+\frac{e}{4}\right)\mathrm{CO_2}+\left(\frac{a}{2}+\frac{b}{8}-\frac{c}{4}-\frac{3d}{8}-\frac{e}{4}\right)\mathrm{CH_4}+d\mathrm{NH_3}+e\mathrm{H_2S}\end{aligned} \tag{2}$$

We use this expression for the production of biogas. However, this method is not the only one.

The expression used in practice is the following:

$$\begin{aligned}&\mathrm{C_{450}H_{2050}O_{950}N_{12}S_1}+(450-512.5-475+9+0.5)\mathrm{H_2O}\\&\Rightarrow(225-256.25+237.5+4.5+0.25)\mathrm{CO_2}\\&\quad+(225+256.25-237.5-4.5-0.25)\mathrm{CH_4}+12\mathrm{NH_3}+\mathrm{H_2S}\end{aligned} \tag{3}$$

This gives:

$$\mathrm{C_{450}H_{2050}O_{950}N_{12}S_1}+(-528.5)\mathrm{H_2O}\Rightarrow 211\mathrm{CO_2}+239\mathrm{CH_4}+12\mathrm{NH_3}+\mathrm{H_2S} \tag{4}$$

Assumptions

In order to make our calculations possible, certain assumptions are essential, namely:

1) We will consider that 20% of the population under >10 years of age

2) Each household is composed of at least 6 people

3) In order to determine the quantity of gas contained in the fecal matter we will make the calculation for 10,000 people

4) Either the biodegradable carbon content is 60% or

5) We will analyze the following biogas production scenarios:

- 30% of the population (Pop) in the district access public toilets for high need.
- 20% of the district's population accesses public toilets for high need.
- 10% of the district's population accesses public toilets on a high need basis.
- 3% of the district's population accesses public toilets for high need.

6) The distribution of the population of Kinshasa by district is as follows

- Tshangu: 39%;
- Mount Amba: 33%;
- Lukunga: 22.8% and
- Funa: 4.4.

5. RESULTS AND INTERPRETATION

5.1. Biogas Calculation

From Equation (4), we determine the following:

$$\text{Min of } C_{450}H_{2050}O_{950}N_{12}S_{1} = 22850 \text{ g/mol} \tag{5}$$

$$\text{Min of } C_{450} = 12 \times 450 = 5400 \text{ g/mol} \tag{6}$$

$$\begin{aligned} \%\text{carbone} &= \frac{5400}{22850} = 24\% \\ \%CH_4 &= \frac{239}{450} = 53\% \\ \%CO_2 &= \frac{211}{239+211} = \frac{211}{450} = 47\% \end{aligned} \tag{7}$$

Consider 10,000 people (assumption c) and that each produces approximately 250 g of fecal matter per day. [12]

$$\Rightarrow 10000 \times 250 = 2500 \text{ kg/day}$$

On the other hand, from 100 to 400 g of fecal matter is contained 30 to 60 g of dry matter [13].

Therefore, in the 2500 kg/day of faeces obtained above we will have 750 kg of dry matter, when producing biogas 50% of the organic matter can be degraded to total solids (TS) or 60% to volatile solids (VS) [4].

Now let's use Equation (4) to determine the amount of biogas that can be produced from the dry matter of human excrement for the following composition:

- Carbon (24%) of 750 kg of dry matter obtained above

$$\Rightarrow 750 \times 0.24 = 180 \text{ kg carbone}$$

Using the assumption d to determine the amount of carbon that will be converted to biogas, we will have: 180 × 0.6 = 108 kg.

From Equations (4) and (7), we have: 53% CH_4 in the biogas, so the weight of methane carbon (CH-C) will be: 108 × 0.53 = 57.24 kgcarbone.

The weight of the methane will be: $57.24 \times \frac{16}{12} = 76.32 \text{ kg } CH_4$

$$57.24 \text{ kg} = 57240 \text{ g de } CH_4$$

$$\Rightarrow \frac{57240}{16} \text{ moles de gaz} = 3577.5 \text{ moles de } CH_4$$

Or,

$$1 \text{ mole de gaz a NTP} = 22.4 \text{ l}$$

$$3577.5 \times 22.4 \times \frac{16}{12} = 106847.9 \text{ l de } CH_4$$

Hence, the estimate of methane produced by 2500 kg/day of feces is 106.848 m^3 CH_4 respectively.

The calorific value of biogas is variable depending on the quantity of methane contained, *i.e.* 22 - 26 MJ/m^3 (5.6 - 7.2 kWh/m^3) [14].

In order to determine the calorific value of the gas contained in the fecal matter calculated above, we consider the standard calorific value of biogas which is 22 MJ/m^3.

We will have: 106.848 × 22 = 2350.656 MJ/m^3 soit 15044.1984 kWh/m^3/jour.

Now, let's use the results obtained above on the population of the city of Kinshasa.

5.2. Estimation of the Biogas Production of the Population of Kinshasa

Table 4 gives an estimate of the quantity of biogas that we can produce in Kinshasa under normal conditions, which means that we exploit the totality of the human excrements of the city.

5.3. Production by Public Toilet

Table 5 shows the population of the city of Kinshasa by district according to hypotheses a and f.

We will start with the most populated district and end with the least. We will then have:

- Tshangu;
- Mount Amba;
- Lukunga and
- Funa.

To do this, all the hypotheses were taken into account for the Tshangu district alone, because it is the most populated. For the rest of the districts, only the last hypothesis (*i.e.*, 3% access) was taken into account.

1) Tshangu

Biogas production from public toilets in this district under the high-need access assumptions is shown in Tables 6-9.

2) Mount Amba

The biogas production from public toilets in this district is shown in Table 10.

3) Lukunga

Biogas production from public toilets in this district is shown in Table 11.

4) Funa

Biogas production from public toilets in this district is shown in Table 12.

5.4. Interpretation of Results

With 1,240,220 parcels and a population of 15,628,085 in 2022, this results in an average of 13 people per parcel and under assumption b, an average of two families per parcel. And according to assumption a, each of these plots will have 10 people over the age of 10 and would produce 1.06 m^3/day. This could power nearly 10 compact fluorescent lamps of 10 W or less for 5 hours. This would help the high and or students in their studies.

If we analyze the demographic growth of the city of Kinshasa as presented in Table 5, this causes a great problem and is the source of several diseases. If we look only at the year 2023, the population will be approximately 16 million. Energetically, it constitutes a great potential. Focusing on the analysis of the excrements produced by the population of age superior to 10 years, for 2023, we obtained:

Table 4. Overall biogas production in Kinshasa.

Year	Population	Target population	Biogas production m^3/day	MJ/m^3	kWh/day	MWh/day
2035	26,681,824	21,345,459	226261.8675	4977761.1	1,448,076	1448.08
2034	25,678,856	20,543,085	217756.6989	4790647.4	1393642.9	1393.64
2033	24,700,252	19,760,202	209458.137	4,608,079	1340532.1	1340.53
2032	23,746,090	18,996,872	201366.8432	4430070.6	1288747.8	1288.75
2031	22,818,048	18,254,438	193497.047	4,256,935	1238381.1	1238.38
2030	21,914,342	17,531,474	185833.6202	4088339.6	1189335.2	1189.34
2029	21,035,846	16,828,677	178383.9741	3924447.4	1141657.4	1141.66
2028	20,181,968	16,145,574	171143.0886	3,765,148	1095315.8	1095.32
2027	19,354,424	15,483,539	164125.5155	3610761.3	1050403.3	1050.40
2026	18,552,820	14,842,256	157327.9136	3461214.1	1006898.6	1006.90
2025	17,778,474	14,222,779	150761.4595	3316752.1	964873.34	964.87
2024	17,032,322	13,625,858	144434.0906	3,177,550	924378.18	924.38
2023	16,315,534	13,052,427	138355.7283	3,043,826	885476.66	885.48
2022	15,628,085	12,502,468	132526.1608	2915575.5	848167.43	848.17
2021	14,970,460	11,976,368	126949.5008	2,792,889	812476.81	812.48
2020	14,342,439	11,473,951	121623.8827	2675725.4	778392.85	778.39
2019	13,743,278	10,994,622	116542.9974	2563945.9	745875.18	745.88
2018	13,171,256	10,537,005	111692.2509	2457229.5	714830.41	714.83
2017	12,624,344	10,099,475	107054.4371	2355197.6	685148.4	685.15
2016	12,100,142	9,680,114	102609.2042	2257402.5	656698.91	656.70
2015	11,597,706	9,278,165	98348.54688	2,163,668	629430.7	629.43
2014	11,116,133	8,892,906	94264.80784	2073825.8	603294.77	603.29
2013	10,654,556	8,523,645	90350.63488	1,987,714	578244.06	578.24
2012	10,212,146	8,169,717	86598.99808	1,905,178	554233.59	554.23
2011	9,788,106	7,830,485	83003.13888	1826069.1	531220.09	531.22
2010	9,381,673	7,505,338	79556.58704	1750244.9	509162.16	509.16

Table 5. Population of Kinshasa by district.

Year	Population	Target population	Tshangu	Lukunga	Mount Amba	Funa
2035	26,681,824	21345459.2	8,324,729	4,866,765	7214765.21	939200.2
2034	25,678,856	20543084.8	8,011,803	4,683,823	6943562.662	903895.7
2033	24,700,252	19760201.6	7,706,479	4,505,326	6678948.141	869448.9
2032	23,746,090	18996872	7,408,780	4,331,287	6420942.736	835862.4
2031	22,818,048	18254438.4	7,119,231	4,162,012	6170000.179	803195.3
2030	21,914,342	17531473.6	6,837,275	3,997,176	5925638.077	771384.8
2029	21,035,846	16828676.8	6,563,184	3,836,938	5688092.758	740461.8
2028	20,181,968	16145574.4	6,296,774	3,681,191	5457204.147	710405.3
2027	19,354,424	15483539.2	6,038,580	3,530,247	5233436.25	681275.7
2026	18,552,820	14842256	5,788,480	3,384,034	5016682.528	653059.3
2025	17,778,474	14222779.2	5,546,884	3,242,794	4807299.37	625802.3
2024	17,032,322	13625857.6	5,314,084	3,106,696	4605539.869	599537.7
2023	16,315,534	13052427.2	5,090,447	2,975,953	4411720.394	574306.8
2022	15,628,085	12502468	4,875,963	2,850,563	4225834.184	550108.6
2021	14,970,460	11976368	4,670,784	2,730,612	4048012.384	526960.2
2020	14,342,439	11473951.2	4,474,841	2,616,061	3878195.506	504853.9
2019	13,743,278	10994622.4	4,287,903	2,506,774	3716182.371	483763.4
2018	13,171,256	10537004.8	4,109,432	2,402,437	3561507.622	463628.2
2017	12,624,344	10099475.2	3,938,795	2,302,680	3413622.618	444376.9
2016	12,100,142	9680113.6	3,775,244	2,207,066	3271878.397	425925
2015	11,597,706	9278164.8	3,618,484	2,115,422	3136019.702	408239.3
2014	11,116,133	8892906.4	3,468,233	2,027,583	3005802.363	391287.9
2013	10,654,556	8523644.8	3,324,221	1,943,391	2880991.942	375040.4
2012	10,212,146	8169716.8	3,186,190	1,862,695	2761364.278	359467.5
2011	9,788,106	7830484.8	3,053,889	1,785,351	2646703.862	344541.3
2010	9,381,673	7505338.4	2,927,082	1,711,217	2536804.379	330234.9

Table 6. **Energy production using assumption 1 (*i.e.*, 30% access).**

Year	Population	30%/Pop	biogas m^3/day	kWh/day
2035	8324729.088	2497418.726	26472.64	169424.8864
2034	8011803.072	2403540.922	25477.53	163056.2161
2033	7706478.624	2311943.587	24506.60	156842.253
2032	7408780.08	2222634.024	23559.92	150783.4922
2031	7119230.976	2135769.293	22639.15	144890.5888
2030	6837274.704	2051182.411	21742.53	139152.2148
2029	6563183.952	1968955.186	20870.92	133573.9198
2028	6296774.016	1889032.205	20023.74	128151.9448
2027	6038580.288	1811574.086	19202.69	122897.186
2026	5788479.84	1736543.952	18407.37	117807.1417
2025	5546883.888	1664065.166	17639.09	112890.1809
2024	5314084.464	1594225.339	16898.79	108152.247
2023	5090446.608	1527133.982	16187.62	103600.7694

Table 7. **Energy production using assumption (*i.e.*, 20% access).**

Year	Population	If 20%/Pop	biogas m^3/day	kWh/day
2035	8324729.088	1664945.818	17648.42567	112949.9243
2034	8011803.072	1602360.614	16985.02251	108704.1441
2033	7706478.624	1541295.725	16337.73468	104561.502
2032	7408780.08	1481756.016	15706.61377	100522.3281
2031	7119230.976	1423846.195	15092.76967	96593.72588
2030	6837274.704	1367454.941	14495.02237	92768.14318
2029	6563183.952	1312636.79	13913.94998	89049.27986
2028	6296774.016	1259354.803	13349.16091	85434.62985
2027	6038580.288	1207716.058	12801.79021	81931.45735
2026	5788479.84	1157695.968	12271.57726	78538.09447
2025	5546883.888	1109376.778	11759.39384	75260.12059
2024	5314084.464	1062816.893	11265.85906	72101.49801
2023	5090446.608	1018089.322	10791.74681	69067.17958

Table 8. **Energy production using assumption 3 (*i.e.*, 10% access).**

Year	Population	If 10%/Pop	biogas m³/day	kWh/day
2035	8324729.088	832472.9088	8824.212833	56474.96213
2034	8011803.072	801180.3072	8492.511256	54352.07204
2033	7706478.624	770647.8624	8168.867341	52280.75099
2032	7408780.08	740878.008	7853.306885	50261.16406
2031	7119230.976	711923.0976	7546.384835	48296.86294
2030	6837274.704	683727.4704	7247.511186	46384.07159
2029	6563183.952	656318.3952	6956.974989	44524.63993
2028	6296774.016	629677.4016	6674.580457	42717.31492
2027	6038580.288	603858.0288	6400.895105	40965.72867
2026	5788479.84	578847.984	6135.78863	39269.04723
2025	5546883.888	554688.3888	5879.696921	37630.0603
2024	5314084.464	531408.4464	5632.929532	36050.749
2023	5090446.608	509044.6608	5395.873404	34533.58979

Table 9. **Energy production using assumption 4 (*i.e.*, 3% access).**

Year	Population	If 3%/Pop	biogas m³/day	kWh/day
2035	8324729.088	249741.8726	2647.26385	16942.48864
2034	8011803.072	240354.0922	2547.753377	16305.62161
2033	7706478.624	231194.3587	2450.660202	15684.2253
2032	7408780.08	222263.4024	2355.992065	15078.34922
2031	7119230.976	213576.9293	2263.91545	14489.05888
2030	6837274.704	205118.2411	2174.253356	13915.22148
2029	6563183.952	196895.5186	2087.092497	13357.39198
2028	6296774.016	188903.2205	2002.374137	12815.19448
2027	6038580.288	181157.4086	1920.268532	12289.7186
2026	5788479.84	173654.3952	1840.736589	11780.71417
2025	5546883.888	166406.5166	1763.909076	11289.01809
2024	5314084.464	159422.5339	1689.87886	10815.2247
2023	5090446.608	152713.3982	1618.762021	10360.07694

Table 10. Energy production using case 4 (*i.e.* 3% access).

Year	Population	If 3%/Pop	biogas m^3/day	kWh/day
2035	7214765.21	216442.9563	2294.295337	14683.49015
2034	6943562.662	208306.8799	2208.052927	14131.53873
2033	6678948.141	200368.4442	2123.905509	13592.99526
2032	6420942.736	192628.2821	2041.85979	13067.90266
2031	6170000.179	185100.0054	1962.060057	12557.18436
2030	5925638.077	177769.1423	1884.352908	12059.85861
2029	5688092.758	170642.7828	1808.813497	11576.40638
2028	5457204.147	163716.1244	1735.390919	11106.50188
2027	5233436.25	157003.0875	1664.232727	10651.08946
2026	5016682.528	150500.4758	1595.305044	10209.95228
2025	4807299.37	144218.9811	1528.7212	9783.815677
2024	4605539.869	138166.1961	1464.561678	9373.194741
2023	4411720.394	132351.6118	1402.927085	8978.733345

Table 11. Energy production using assumption 4 (*i.e.*, 3% access).

Year	Population	If 3%/Pop	biogas m^3/day	kWh/day
2035	4866764.698	146002.9409	1547.631174	9904.839513
2034	4683823.334	140514.7	1489.45582	9532.51725
2033	4505325.965	135159.7789	1432.693657	9169.239404
2032	4331286.816	129938.6045	1377.349207	8815.034928
2031	4162011.955	124860.3587	1323.519802	8470.526731
2030	3997175.981	119915.2794	1271.101962	8135.052556
2029	3836938.31	115108.1493	1220.146383	7808.936849
2028	3681190.963	110435.7289	1170.618726	7491.959848
2027	3530246.938	105907.4081	1122.618526	7184.758567
2026	3384034.368	101521.031	1076.122929	6887.186746
2025	3242793.658	97283.80973	1031.208383	6599.733652
2024	3106695.533	93200.86598	987.9291794	6322.746748
2023	2975953.402	89278.60205	946.3531817	6056.660363

Table 12. Energy production using assumption 4 (*i.e.*, 3% access).

Year	Population	4 (if 3%)	biogas m^3/day	kWh/day
2035	939200.2048	28176.00614	298.6656651	1911.460257
2034	903895.7312	27116.87194	287.4388425	1839.608592
2033	869448.8704	26083.46611	276.4847408	1769.502341
2032	835862.368	25075.87104	265.804233	1701.147091
2031	803195.2896	24095.85869	255.4161021	1634.663053
2030	771384.8384	23141.54515	245.3003786	1569.922423
2029	740461.7792	22213.85338	235.4668458	1506.987813
2028	710405.2736	21312.15821	225.908877	1445.816813
2027	681275.7248	20438.27174	216.6456805	1386.532355
2026	653059.264	19591.77792	207.672846	1329.106214
2025	625802.2848	18774.06854	199.0051266	1273.63281
2024	599537.7344	17986.13203	190.6529995	1220.179197
2023	574306.7968	17229.2039	182.6295614	1168.829193

138355.7283 m^3/day of CH_4 (Table 4) and that corresponds to 885476.66 kWh/day or 885.476 MWh/day. Now, according to the information contained in the introduction (Table 2), with this quantity of gas we can power 138,355 lamps of 60 to 100 W for six hours or nearly 70,000 lamps of 60 to 100 W for 12 hours.

At present, the problem is how to collect this energy? Hence, the possibility of producing it by using public toilets in large squares in each district.

By doing the study for the Tshangu district for the four access hypotheses, we have:

- For Hypothesis 1: For 30% of the population to have access to public latrines by the year 2023, gives:
  - 16187.62 m^3/day (103600.7 kWh/day or 103.6 MWh/day) which can light nearly 16,000 lamps from 60 to 100 W for six hours or nearly 8000 lamps from 60 to 100 W for twelve hours.
- For Hypothesis 2: For 20% of the population to have access to public latrines by the year 2023, gives:
  - 10791.74 m^3/day (60967.17 kWh/day or 60.9 MWh/day) which can light nearly 10,000 lamps of 60 to 100 W for six hours or nearly 5000 lamps of 60 to 100 W for twelve hours.
- For Hypothesis 3: For 10% of the population to have access to public latrines by the year 2023, gives:
  - 5395.87 m^3/day (34533.17 kWh/day or 34.5 MWh/day) which can light nearly 5000 lamps from 60 to 100 W for six hours or nearly 2500 lamps from 60 to 100 W for twelve hours.
- For Hypothesis 4: For 3% of the population to have access to public latrines by the year 2023, gives:
  - 1618.762 m^3/day (10360.07 kWh/day or 10.36 MWh/day) which can light nearly 1600 lamps from 60 to 100 W for six hours or nearly 800 lamps from 60 to 100 W for twelve hours.

For the district of Mont-Amba, Lukunga and Funa, considering only hypothesis 4 (*i.e.* 3% of the population uses public latrines for great need) and for the year 2023 alone, we have the following situation.

- **Mont-Amba**, we produce: 1402.927 m^3/day (8978.73 kWh/day or 8.97 MWh/day) which can light nearly 1400 lamps from 60 to 100 W for six hours or nearly 700 lamps from 60 to 100 W for twelve hours;
- **In Lukunga**, we produce: 946.35 m^3/day (6056.66 kWh/day or 6.056 MWh/day) which can light nearly 900 lamps from 60 to 100 W for six hours or nearly 450 lamps from 60 to 100 W for twelve

hours;

- **Funa**, we produce: 182.629 m^3/day (1168.83 kWh/day or 1.17 MWh/day) which can light almost 180 lamps from 60 to 100 W for six hours or almost 90 lamps from 60 to 100 W for twelve hours.

6. CONCLUSIONS

To conclude, we say that the increase in the population of the city of Kinshasa in particular, and that of DR Congo, in general, can be translated into an excellent opportunity for development in the field of energy with environmental respect. From this fact, the rule of three Rs (Reduce, Reuse, and Recycle) offers an unparalleled opportunity.

Hence, the objective of this article by valorizing the human excrements of the city of Kinshasa by transforming it into energy. In order to better manage this waste, we have just demonstrated how much it will be beneficial for our dear city.

Indeed, 1 m^3 of biogas can light a 60 - 100-Watt bulb for 6 hours or cook 3 dishes for a family of 6 people. For our case, this biogas by human excrements through a process of biological degradation called methanization and due to the biological fermentation of fermentable organic matter in an anaerobic environment, that is to say deprived of oxygen.

To do this, the analytical method, using the Buswell equation for the determination of the amount of biogas contained in human excrement.

Focusing on the analysis of the excrements produced by the population of age superior to 10 years, for 2023, we obtained: 138355.7283 m^3/day of CH_4 (885476.66 kWh/day or 885.476 MWh/day), which, energy can light: 138,355 lamps of 60 to 100 W for six hours or nearly 70,000 lamps of 60 to 100 W for 12 hours.

However, the recovery of this energy directly is difficult, that is why we proposed to produce it in public latrines implanted in each big place of each district and to arrive to make the calculations certain assumptions. Considering the last one which offers the lowest access rate, that is 3% of the district population to these latrines, we have:

- **In Tshangu,** we produce: 1618.762 m^3/day (10360.07 kWh/day or 10.36 MWh/day) which can light nearly 1600 lamps from 60 to 100 W for six hours or nearly 800 lamps from 60 to 100 W for twelve hours;
- **Mont-Amba**, we produce: 1402.927 m^3/day (8978.73 kWh/day or 8.97 MWh/day) which can light nearly 1400 lamps from 60 to 100 W for six hours or nearly 700 lamps from 60 to 100 W for twelve hours;
- **In Lukunga**, we produce: 946.35 m^3/day (6056.66 kWh/day or 6.056 MWh/day) which can light nearly 900 lamps from 60 to 100 W for six hours or nearly 450 lamps from 60 to 100 W for twelve hours;
- **Funa**, we produce: 182.629 m^3/day (1168.83 kWh/day or 1.17 MWh/day) which can light almost 180 lamps from 60 to 100 W for six hours or almost 90 lamps from 60 to 100 W for twelve hours.

Moreover, this can be extended to large places such as markets, universities etc. and the government through its Ministry of Urbanism and Habitat, could build a law around this solution by directing future constructions to valorize the waste from septic tanks.

This solution could be implemented throughout the republic. And in rural areas, it would encourage the population to raise animals such as pigs and to use their excrements and this will significantly reduce deforestation.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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