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Energy Needs Assessment for the Implementation of a Photovoltaic Power Plant in the City of Kenge

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ABSTRACT

This research aimed to assess the energy needs of the city of Kenge in order to design a suitable photovoltaic installation. Our work was based on a field survey conducted in Kenge.

We structured our study into several parts corresponding to the main consumer sectors:

- Households: They are classified according to their standard of living (low, middle, and high class). The analysis details the electrical equipment used (refrigerators, air conditioners, televisions, etc.), their power, and their duration of use in order to estimate daily consumption.
- Administrative offices: Three categories are also considered (low, medium and high class). Each type of office has a specific energy profile depending on the number of devices (computers, printers, air conditioners, etc.) and their daily use.
- The industrial sector: It mainly comprises structures like SNEL and REGIDESO, with relatively limited but constant energy consumption.
- The semi-industrial sector: It includes several infrastructures (hospitals, schools, hotels, markets, public lighting, workshops, etc.), representing a significant share of total consumption due to their number and intensive use.

Subsequently, our study establishes an overall balance of daily power and energy consumption, allowing us to determine the total energy needs of the city.

KEYWORDS: *Evaluation, energy needs, energy photovoltaic, Central, Implementation.*

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I. INTRODUCTION

The Democratic Republic of Congo has significant potential in renewable energy resources such as biomass, wind, solar, hydroelectric etc. (Atlas of the Ministry of Energy and Hydraulic Resources, 2021).

Despite the country's enormous electrical potential, a large part of the national territory remains without electricity due to the age of the installations dating from the colonial era, and the lack of new investors (ANSER, 2024).

Faced with these challenges, the use of renewable energies offers a solution to this energy problem. Among renewable energies, solar photovoltaic energy presents an opportunity for efficient, relatively rapid, affordable, and reliable development.

Despite the enormous potential in energy resources available to the Democratic Republic of Congo, most of our urban and rural areas suffer from a deficit in electrical energy (Atlas of the Ministry of Energy and Hydraulic Resources, 2021).

The current situation in the city of Kenge is marked by an energy deficit, as 98% of the city's economic activities depend on electricity. The importance of this project lies in the fact that the installation of a photovoltaic power plant in Kenge will allow the city's population to have access to electricity.

As mentioned above, the city of Kenge is not yet electrified. The lack of electricity has a negative impact on the local economy.

Using a generator is too expensive for most of the population of Kenge, in addition to the negative environmental impacts due to greenhouse gas emissions. 72% of Kenge's population belongs to the low-income class (source: field survey).

In light of the energy deficit situation prevailing in the city of KENGE, the following questions should be asked:

- Is it possible to assess the energy needs of the city of Kenge for its optimal electricity supply?
- What types of energy needs?

Given the daily energy consumption of the city of Kenge, it is possible to assess its energy needs.

This includes the energy needs of households, administrative offices, and industrial and semi-industrial sectors.

With the aim of establishing a photovoltaic power plant in the city of Kenge, the objectives assigned to our research are:

- Assess the energy needs of the city of Kenge;
- Determine the types of needs existing in the city of Kenge;
- Select suitable energy systems for the electrification of the City of Kenge.

For the development of this research, we used the following methods: the descriptive method, the analytical method, and the comparative method. These methods were complemented by documentary research, interviews, questionnaires, observation, and survey techniques.

II. Theoretical framework for renewable energies

II.1.1. Renewable Energies

Renewable energies are energies that renew themselves on a human timescale and whose sources are inexhaustible. Most of these energies are clean and non-polluting. They include the following:

- **Hydropower** : electricity production from the movement of water in a dam.
- **Wind energy** : it is produced by the force that the wind exerts on the blades of a wind turbine.
- **Solar energy** : derived from solar radiation. A distinction is made between photovoltaic solar energy and thermal solar energy.
- **Biomass energy** : this is energy extracted from non-fossil organic matter such as wood, straw, oils and plant waste.
- **Geothermal energy** : energy created and stored in the earth in thermal form.

II.1.2. Solar Energy

The sun is a star made of extremely hot gas. It has a diameter of 1,390,000 km, or about 110 times that of the Earth. It is composed of 80% hydrogen, 19% helium, and 1% of a mixture of 100 elements, representing virtually all known chemical elements. This is because Langevin and Perrin, drawing on Einstein's theory of relativity, proposed some sixty years ago that nuclear fusion energy provides the sun with its power. It is now accepted that the sun is a thermonuclear bomb, transforming 564 million tons of hydrogen into 560 million tons of helium every second (Zaire, S. and Boubiada, S., 2020).

II.1.2.1. Solar Radiation

Solar radiation is electromagnetic radiation composed of particles of light called photons **.** The energy of each photon is directly related to its wavelength, with 98% of its energy occurring between $\lambda = 0.25$ µm and $\lambda = 4$ µm. The remaining energy is 1% above and 1% below this range. The extraterrestrial radiation spectrum corresponds approximately to the emission of a black body heated to 5800 K. The energy distribution as a function of wavelength is as follows:

- **For 0.25 µm < λ < 0.4 µm** : This is the ultraviolet (invisible) range, it represents 7% of the total energy emitted by the sun.
- **For 0.4 µm < λ < 0.8 µm** : This is the visible range, it represents 47.5% of the total energy emitted by the sun.
- **For 0.8 µm < λ < 4 µm** : This is the infrared (invisible) range, it represents 45.5% of the total energy emitted by the sun.
- The energy radiated by the sun is not uniformly distributed across all wavelengths; it reaches a maximum at a given wavelength, as determined by **Wien's law** :

$$\lambda_m . T = 2898\ \mu m . K \qquad (1.1)$$

λ_m : wavelength of maximum emission (in m)

T : absolute body temperature (in $°K$)

$Pour\ T = 2800\ K \Rightarrow \lambda_m \approx 0{,}5\ \mu m.$

When solar radiation passes through the atmosphere, it is absorbed and scattered into three components:

- **Direct radiation** : Direct radiation is received directly from the sun without scattering by the atmosphere.

- **Diffuse radiation** : Diffuse radiation consists of light scattered by the atmosphere.
- **Albedo** : Albedo is the part reflected by the ground, depending on the environment of the site.

II.1.3. Photovoltaic solar energy

The term photovoltaic is composed of the Greek word *photos,* meaning light, and *volta,* the name of the Italian physicist Alessandro Volta, who invented the electrochemical cell in 1800. The photovoltaic effect was discovered by the French physicist Alexandre Edmond Becquerel in 1896. He observed that certain materials could generate a weak electric current when exposed to light. (Labouret, A. and Villot, M., 2003).

The photovoltaic effect is the direct conversion of the light energy of sunlight (photons) into electricity. Wave theory cannot explain the experimental results concerning the existence of the photon. Einstein explained them by stating the following postulates:

- Light is made up of massless and chargeless particles called photons.
- Photons of sufficient energy are capable of releasing electrons from a metal.

An electromagnetic wave of frequency ν is associated with a photon whose energy is:

$$E = h \cdot \nu \quad \text{with:} \qquad (1.2)$$

E: energy of the photon in Joules (J);

ν : wave frequency in hertz (Hz);

h : Planck constant: $h = 6.62 \cdot 10^{-34}$ Js

To achieve the photovoltaic effect, photovoltaic modules composed of cells are used. These photovoltaic cells are made of semiconductors based on silicon (Si), germanium (Ge), selenium (Se), etc. Silicon is currently the most widely used material for manufacturing photovoltaic cells because it is very abundant in nature. (Labouret, A. and Villot, M., 2003).

III. Methodological approach

Regarding the research methods and techniques used, we employed both qualitative and quantitative approaches.

III.1. Investigation approach

III.1.1. Survey Questionnaire

We divided the survey questionnaire into five sections:

- **Investigator identification:** this involves describing the investigator's environment, their municipality, their neighborhood, their age and their sex.
- **Types of energy used:** the energy sources used in the city of Kenge are listed: coal, petroleum, palm oil, batteries, solar energy, electricity, etc…
- **Types of receivers used:** The population of the city of Kenge uses the following receivers: radio, lamp, telephone, television, fan, freezer, iron, air conditioner, computer, etc.
- **Usage time:** The usage time of the receivers differs from one receiver to another. The 24-hour period is taken as the unit of time.
- **Preferred Power Plant Types:** The population of Kenge has generally always wanted electricity from the micro-power plant at the Bukanga - Lonzo Agro-Industrial Park . However, due to a lack of funding, the project initiated by the Kwango Provincial Government was never implemented. As an alternative to this electricity source, the population is opting for the installation of a photovoltaic power plant in Kenge. Besides photovoltaic plants, wind power plants are another option.

IV. Assessment of the energy needs of the city of Kenge

To assess the energy needs of the city of Kenge, we will divide the electricity consumers into three groups, namely households, administrative offices and the industrial and semi-industrial sectors.

IV.1. Assessment of household energy needs

Not all households have the same social standing. That's why we've grouped them into three classes based on their income:

- Low income: lower-class household;
- Average income: middle-class household;
- High income: upper-class household.

For each class, we assume that households have the same electrical appliances and the same energy consumption. For each class, we will calculate the daily energy consumption of a household to deduce the total consumption.

Table 3.1: Daily energy consumption per household in the lower class.

N 0	Electrical appliance	Number	Unit Power (*W*)	Usage time (h)	Total power (*W*)	Daily energy (*Whj*)
01	Lamp	2	10	12	20	240
02	Radio Station	1	10	8	10	80
03	Television	1	100	8	100	800
04	Phone	2	10	1	20	20
05	Phone Charger	2	25	2	50	100
Total					**200*w***	**1240wh/j**

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of a lower-class household is $200\ W$

The daily energy consumption of a low-income household is $1240\ wh/j$

The number of lower-class households is 2160

The total power of 2160 households is

$$P_1 = 2160\ x\ 200 = 432000\ W$$

The daily energy consumption of 2160 households is

$E_{c_1} = 2160\ x\ 1240 = 2.678.400\ Wh/j$

Table 3.2: Daily energy consumption per middle-class household

N 0	Electrical appliance	Number	Unit power (W)	Usage time (h)	Total power (W)	Daily Energy (Wh/day)
01	Lamp	5	10	12	50	600
02	Radio sets	2	10	8	20	160
03	Television	1	100	8	100	800
04	Phone	4	10	1	40	40
05	Fan	1	45	5	45	225
06	Freezer	1	200	8	200	1600
07	Iron	1	1000	1	1000	1000
08	Laptop	1	50	5	50	250
09	Phone charger	4	25	2	100	200
Total					**1605 *W***	**4875 *Wh/j***

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of a middle-class household is $1605\ W$

The daily energy consumption of a middle-class household is $4875\ Wh/j$

The number of middle-class households is 780.

The total power of 780 middle-class households and:

$$P_2 = 780\ x\ 1605 = 1.251.900\ W$$

The daily energy consumption of 780 middle-class households is:

$E_{c2} = 780\ x\ 4875 = 3.802.500\ Wh/j$

Table 3.3: Daily energy consumption per upper-class household

N 0	Electrical appliance	Number	Unit power (W)	Usage time (h)	Total power (W)	Daily Energy (Wh/day)
01	Lamp	12	40	12	480	5760
02	Radio	4	10	8	40	320
03	Television	3	250	8	750	6000
04	Phone	6	10	1	60	60

05	Fan	4	45	5	180	900
06	Freezer	1	200	8	200	1600
07	Iron	4	1000	1	4000	4000
08	Air conditioner	1	1000	8	1000	8000
09	Electric stove	1	1000	2	1000	2000
10	Fridge	1	150	8	150	1200
11	Water heater	2	1000	0.75	2000	1500
12	Phone charger	6	25	2	150	300
13	Laptop	2	50	5	100	500
14	Washing machine	1	2000	1	2000	2000
Total					**12110 *W***	**34.140 *Wh/j***

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of an upper- class household is $12110\ W$

The daily energy consumption of an upper-class household is $34140\ Wh/j$

The number of upper-class households is 60.

The total power of 60 upper-class households is

$$P_3 = 60\ x\ 12110 = 726.600\ W$$

The daily energy consumption of 60 high-class households is

$E_{c3} = 60\ x\ 34.140 = 2.048.400\ Wh/j$

In conclusion : The total power of households in the city of Kenge is worth

$P = P_1 + P_2 + P_3$

$P = 432.000 + 1.251.900 + 726.600$

$= 2.410.500\ W$

The daily energy consumption of households in the city of Kenge is: $E = E_{c1} + E_{c2} + E_{c3}$

$E = 2.678.400 + 3.802.500 + 2.048.400$

$$E = 8.529.300\ Wh/j$$

IV.2. Assessment of the energy needs of administrative offices

Given the disparities in electrical equipment across administrative offices, we have divided them into three classes: low-class, medium-class, and high-class. Furthermore, we assume that offices within the same class have identical electrical equipment.

Table 3.4: Daily energy consumption per low-class office

N ⁰	Electrical appliance	Number	Unit power *(W)*	Usage time (h)	Total power *(W)*	Daily Energy *(Wh/j)*
01	Laptop	1	50	8	50	400
02	Lamp	5	10	8	50	400
03	Phone	4	10	1	40	40
04	Phone Charger	4	25	2	100	200
	Total				240 *W*	1040 Wh/day

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of a low- end office $240\ W$ is

The daily energy consumption of a low-class office is $1040\ Wh/j$

The total number of lower-class offices is 94.

The total capacity of 94 lower- class offices is

$$P_1 = 94\ x\ 240 = 22.560\ W$$

The daily energy consumption of 94 low-class offices is

$$E_{c1} = 94\ x\ 1040 = 97.760\ Wh/j$$

Table 3.5: Daily energy consumption per average-sized office

N⁰	Electrical appliance	Number	Unit power (W)	Usage time (h)	Total power (W)	Daily Energy (Wh/day)
01	Laptop	2	50	8	100	800
02	Desktop computer	2	250	8	500	4000
03	Lamp	8	20	8	160	1280
04	Phone	6	10	1	60	60
05	Phone Charger	6	25	2	150	300
06	Printer	1	150	2	150	300
07	Fan	2	45	5	90	450
08	Ceiling light	2	65	8	130	1040
09	Modem	1	70	8	70	560
10	Router	1	70	8	70	560
	Total				1480 W	9,350 Wh/day

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of a mid-range office $1480\ W$ is

The daily energy consumption of a medium -sized office is $9.350\ Wh/j$

The total number of middle-class offices is 53

total power of 53 medium- sized offices is

$$P_2 = 53\ x\ 1480 = 78.440\ W$$

The daily energy consumption of 53 medium-sized offices is

$$E_{c_2} = 53\ x\ 9350 = 495.550\ Wh/j$$

Table 3.6: Daily Energy Consumption per High-Class Office

N⁰	Electrical appliance	Number	Unit power (W)	Usage time (h)	Total power (W)	Daily Energy (Wh/day)
01	Desktop computer	10	250	8	2500	20,000
02	Laptop	8	50	8	400	3,200
03	Lamp	20	60	8	1200	9600
04	Television	3	250	8	750	6,000
05	Phone Charger	10	25	2	250	500
06	Printer	2	300	2	600	1200
07	Fan	8	45	5	360	1800
08	Ceiling light	5	65	6	325	1950
09	Modem	5	70	8	350	2800
10	Router	5	70	8	350	2800
11	Phone	15	10	1	150	150
12	Video projector	2	40	6	80	480
13	Air conditioner	4	1000	8	4000	32000
14	Sound system	1	250	6	250	1500
Total					11.565 *W*	83.980 *Wh/j*

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of a high- class office is $11.565\ W$

The daily energy consumption of a high-class office is $83.980\ Wh/j$

The total number of high-class offices is 16.

The total capacity of 16 high- class offices is

$$P_3 = 16\ x\ 11.565 = 185.040\ W$$

The daily energy consumption of 16 high-class offices is

$$E_{c_3} = 16\ x\ 83.980 = 1.343.680\ Wh/j$$

In conclusion : The total power of all the offices in the city of Kenge is worth

$$P = P_1 + P_2 + P_3$$

$$P = 22.560 + 78.440 + 185.040$$

$$= 286.040\ W$$

The daily energy consumption of all offices in the city of Kenge is: $E = E_{c_1} + E_{c_2} + E_{c_3}$

$$E = 97.760 + 495.550 + 1.343.680$$

$$E = 1.936.990\ Wh/j$$

IV.3. Evaluation of the energy needs of the industrial sector.

Table 3.7: Daily energy consumption of the industrial sector

N ⁰	Designation	Number	Unit power (W)	Usage time (h)	Total power (W)	Daily Energy (Wh/day)
01	SNEL	1	1000	12	1000	12,000
02	REGIDESO	1	500	12	500	6,000
Total		2			1500 W	18,000 Wh/day

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of the industrial sector is $1500\ W$

The daily energy consumption of the industrial sector is $18.000\ Wh/j$

IV.4. Assessment of the energy needs of the industrial and semi-industrial sector

Table 4 : Daily energy consumption by category in the semi-industrial sector

N ⁰	Designation	Number	Unit Power (*W*)	Usage time (h)	Total power (*W*)	Daily energy (*Wh/j*)
01	Hospital	1	5000	24	5000	120,000
02	Health center	18	312.5	24	5625	135,000
03	University and Higher Institute	5	4250	8	21250	170,000
04	Church	30	616	5	18480	92,400
05	Primary and secondary schools	89	125	8	11125	89,000
06	Hotel	25	1000	24	25000	600,000
07	Community radio	5	160	5	800	4,000
08	Party room	5	800	5	4000	20,000
09	Pharmacy	50	100	8	5000	40,000
10	Shops, boutiques	125	62.5	8	7812.5	62,500
11	Public lighting (poles)	500	75	12	37500	450,000
12	Central Market (posts)	90	75	8	6750	54,000
13	Office Automation	20	593.75	8	11875	95,000
14	Bakeries	6	200	6	1200	7200
15	Mill	38	100	8	3800	30400
16	Garages	5	100	10	500	5000
17	Gas station	2	781.25	16	1562.5	25000

18	Carpentry	12	150	8	1800	14400
19	Fitting workshops	12	150	8	1800	14400
20	Bar	16	100	12	1600	19200
21	Restaurant	21	100	10	2100	21000
22	Hardware	14	100	8	1400	11200
23	Sewing workshop	25	75	8	1875	15,000
24	Food	4	150	10	600	6000
25	Public booth	64	100	12	6400	76800
26	Sawmill	5	150	8	750	6000
27	Cement depot; wood	31	125	8	3875	31000
Total		Service: 628 Posts: 590			189.480 *W*	2.214.500 *wh/j*

Source: Field survey conducted from 12/09/2024 to 17/01/2025

The total power of the semi- industrial sector is rated at $189.480\ W$

The daily energy consumption of the semi-industrial sector is estimated at $2.214.500\ Wh/j$

IV.5. Power balance and energy balance

The aim is to calculate the total power and total daily energy required for the photovoltaic installation in the city of Kenge.

Table 5.9 : Power balance and energy balance

N ⁰	Designation	Power Consumption (W)	Daily energy (Wh/day)
01	Households	2,410,500	8,529,300
02	Administrative Offices	286,040	1,936,990
03	Industrial and semi-industrial sector	190,980	2,232,500
Total		2.887.5520 *W*	12.698.790 *Wh/j*

Based on the results in Table 3.9 above, the energy needs of the city of Kenge are estimated at $E_c = 12.698.790\ Wh/j$ and the total power consumed by users in the city of Kenge is estimated at $P = 2.887.528\ W$

V. Peak power calculation

Peak power is the maximum power produced by the solar module or panel under standard test conditions (STC).

- A solar irradiance of 1000 W/ m²;
- A panel temperature of 250 ˚C;
- A spectral distribution of the radiation called optical air mass: AM 1.5 (https://www.restseem.org.design of photovoltaic and thermal solar projects, 2020, accessed on 15/11/2024)

The peak power of the photovoltaic array to be installed depends on the solar irradiance at the installation site. It is calculated using the following formula:

$$P_c = \frac{E_c}{K \times I_r} \qquad (3.1)$$

With :

P_c : Peak power of the photovoltaic field in peak watt (Wc) or in kWp;

E_c: Energy consumed per day in watt-hours per day (Wh/j) or in kWh/day;

I_rAverage daily irradiation in kilowatt-hours per square meter (kWh /m² / day) or in Wh /m² / day for the city of Kenge$I_r = 4{,}6\ \mathrm{kWh/m^2/J}$

K : Correction coefficient or constant of energy losses.

In general, its theoretical value is between 0.55 and 0.75. But in practice the value often used in system calculations with the battery is $K = 0{,}65$ (Toumi, N. and Kouda, I., 2021).

The coefficient K takes into account the following factors:

- Meteorological uncertainty;
- The uncorrected inclination of the modules according to the season;
- The aging and dust of the modules;
- The efficiency of the battery's charge and discharge cycles;
- Charger and inverter efficiency (90 to 95%);
- Losses in cables and connections.

Digital application

$E_c = 12.698.790\ Wh/j$; K = 0.65; $I_r = 4{,}6\ kWh/m^2/j$

$P_c = \frac{E_c}{K \times I_r} = \frac{12.698;790}{0{,}65 \times 4{,}6}$= 4,247,087 Wc

$$P_c = 4{,}2\ MWC$$

Conclusion

This study highlights that:

- The energy demand of the city of Kenge is significant and diversified, with a strong contribution from households and the semi-industrial sector.
- The overall energy balance makes it possible to precisely quantify the total power needed and the daily energy to be produced to cover the needs of the population.
- The use of a photovoltaic system appears to be a relevant solution to meet this demand, given the sunlight conditions and the technical parameters studied.
- Calculating the peak power of the photovoltaic field is an essential step to ensure reliable and efficient system sizing.

In short, this study concludes that the installation of a well-sized solar installation could ensure a sustainable energy supply adapted to the needs of the city of Kenge, while taking into account technical and environmental constraints.

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