THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE

Specialty: Electrical Engineering and Renewable Energies

The BIT's mini solar PV power plant Energy efficiency analysis

Thesis' ID: ……….

Presented and publicly defended by

Gertrude Stéphanie BAZONGO

Supervised by: Arnaud VALEA
Permanent Teacher at BIT

President: Dr Ali DOUMOUNIA
Lecturer in Physics at Ecole Normale Supérieure

Member: Mr Seidou MALE
Electromechanical Design Engineer

Academic year: 2023 – 2024

Table of contents

List of Acronyms and Abbreviations

AC: Alternating Current

AFAT: agriculture, forestry and other land uses

ADEME : Agence de l’Environnement et de la Maîtrise de l’Energie

BIT: Burkina Institute of Technology

BAES and BAEA: Blocs Autonomes d’Eclairage de Sécurité et d’Ambiance (self-contained emergency and ambient lighting units)

Cop21: 21TH Conference of the Parties

CNRS: French National Center for Scientific Research

DC: Direct Current

GHG: Green House Gases

IEA: International Energy Agency

KWh: Kilowatt-hour

LCA: Life Cycle Analysis

MPPT: Maximum Power Point Tracking

MRV: Measuring, Reporting and Verification

NOCT: Normal Operating Cell Temperature

PV: Photovoltaic

RES : Renewable Energy Sources

RIA : Robinets d’Incendie Armés

STC: Standard Test Conditions

SONABEL: Burkina Faso National Electricity Company

Ks, Ku: Simultaneity coefficient, utilization coefficient

g CO2 eq/kWh: gram of CO2 equivalent per kilowatt-hour

ρ: rho, $\rho Cu = 0.017\ \Omega\ mm^2/m$

List of tables

List of figures

General introduction

In a world facing unprecedented environmental and energy challenges, the transition to renewable energy sources has become an urgent necessity. Fossil fuels, although they have underpinned global economic development for decades, are associated with greenhouse gas emissions that contribute significantly to global warming. In the face of this reality, renewable energies, and solar power in particular, offer sustainable environmentally friendly solutions.

Burkina Faso, like many developing countries, is particularly vulnerable to fluctuations in fossil fuel prices and the impacts of climate change, and access to reliable and affordable electricity remains a major challenge, especially in rural and remote areas. Against this backdrop, mini photovoltaic power plants are a promising solution for meeting local energy needs in a decentralized, sustainable way. By exploiting the region's high sunshine potential, these systems make it possible to produce energy locally, thus reducing dependence on traditional electricity grids and reducing electricity transmission costs. Burkina Institute of Technology (BIT), aware of energy and environmental issues, has set up a mini photovoltaic power plant as part of its sustainable development and renewable energy promotion initiatives. However, during periods of high heat, the power delivered by this plant is insufficient, leading to frequent power outages, particularly in the evenings and mornings.

Energy efficiency, at the heart of this study, is defined as the ability to use less energy for the same level of service or production. This means optimizing the use of energy resources to minimize losses and improve the overall system performance. Applied to a mini photovoltaic power plant, energy efficiency involves identifying and reducing losses at different levels of the system, including panels, inverters, and cables. In addition to the technical analysis, an important environmental dimension of the study is the assessment of the plant's carbon footprint, which consists in calculating the total carbon footprint of the photovoltaic installation, taking into account its entire life cycle: from the manufacture of the solar panels to their operation, including transport and maintenance. This analysis shows that, although the production and installation of photovoltaic panels is polluting on the one hand, it considerably reduces the impact of fossil fuels.

This document, based on **Energy efficiency study and optimization of the BIT mini solar PV power plant,** aims to analyze the installations and the operation of the plant to detect anomalies and sources of loss and propose an effective optimization plan; but also, to show the positive and growing ecological impact of such an installation. This study is divided into three main parts: the first part presents the study site, describing the institutional framework of Burkina Institute of Technology and the technical characteristics of the mini photovoltaic power plant. The second part analyzes the plant's energy efficiency, by diagnosing the installations, identifying losses and the impact of weather conditions on the yield of the plates. The third part proposes strategies for optimizing the operation and environmental analysis through the carbon footprint of the plant and the state of CO_2 emissions in Burkina Faso. By combining technical and environmental analyzes, this thesis aims to contribute to a better understanding and improvement of the performance of photovoltaic systems.

CHAPTER I: PRESENTATION OF THE STUDY SITE

CHAPTER II: ENERGY EFFICIENCY ANALYSIS

I. Study methodology

I.1. Study plan

I.1.1. Aim of the study

Power outages, which frequently occur during periods of extreme heat, disrupt not only academic activities but also the overall energy efficiency of the institute. This context led us to undertake an in-depth study to identify areas of energy loss within the mini solar photovoltaic power plant. The energy audit conducted within the BIT has the following main objectives:

1. **Identify Sources of Energy Losses:** Analyze the different components of the photovoltaic system, in particular the solar panels, inverters, and batteries, to determine the main sources of energy losses.
2. **Analyzing the Impact of Environmental Conditions:** Study the effect of temperature, solar irradiance, shading, and dirt on the performance of photovoltaic panels, comparing warm and winter periods.
3. **Propose Optimization Solutions:** Based on the results obtained, formulate technical and strategic recommendations to improve the energy efficiency of the system, reduce losses, and ensure a more stable power supply, even during periods of high heat.

I.1.2. Analytical method

The study is based on a combined approach of on-site observations, analysis of collected data (solar radiation, temperature, etc.), and modeling of the photovoltaic system performance. Losses will be assessed according to several criteria, including irradiance, temperature, shading, dirt, and panel degradation. A comparison between the system performance in warm and winter periods will be carried out to identify the most favorable period for energy production. This study aims to provide concrete solutions to improve the resilience of the BIT photovoltaic system to environmental challenges and thus contribute to the stability of the institute's energy supply.

I.1.3. Applicable standards

The study is carried out in accordance with European international standards in this area and with the regulations in Burkina Faso. These references are:

- ✓ Standard C12-201 and its addenda dealing with fire protection in establishments open to the public;

- ✓ Standard C15-100 dealing with the execution and maintenance of low-voltage electrical installations
- ✓ Standard C15-102 relating to the rules for protection against lightning and lightning rods
- ✓ Standard C15-531 on protection against atmospheric overvoltage by lightning arrester;
- ✓ Standard NF S 60-303 of September 20, 1987 on fire protection plans and instructions.
- ✓ The decree of December 22, 1981: general provisions for fire safety in buildings open to the public;
- ✓ The instructions of the manufacturers of the equipment to be installed;

I.2. Installation diagnostic

I.2.1. The power sources

The bit electrical system does not have a secondary power source. In fact, the mini solar power plant is the main and only source of energy available to the institute, which explains the handicap in the institute's activities when there is no energy available. The plant with a total of 324 solar modules technically produces 84.341 kW per day, or an energy of 700.032 kWh for an insolation of 8.3 hours per day [11] .

I.2.2. Electrical receivers

Electrical receivers are a set of devices that convert the electrical energy they receive into another form of energy (mechanical, motors, chemical, thermal, etc.). The operating time of the equipment is random, that is to say, it depends on the behavior of the users. We decided to take an average of eight (10) hours of work during the day (8 a.m. to 12 p.m. and 2 p.m. to 6 p.m.) in order to estimate the energy consumption. All BIT equipment is mainly subdivided into 4 types:

- **Lighting:** with 120 and 60 cm LEDs (228), desk grid lamps (52), spotlights (11) and projector lamps (06) which consume 22; 10; 54.5; 20 and 100 W respectively. However, we noted a set of negative points, namely: poor maintenance (hanging strips), the absence and non-functioning of lamps in certain places; mainly in classrooms.

Figure 1: Illustration of defective lamps

- **Air conditioning:** this is a rather restricted circuit with a very slow maintenance frequency, composed of only four (04) air conditioners, 01 of which operates permanently (24/7) in the technical room to ensure an optimal operating temperature for the batteries, the charging inverters and computer lease.
- **Ventilation:** composed of twenty-seven (27) Panasonic brand air mixers, (03) humidifiers and (11) pedestal fans, they contribute to thermal comfort in lecture halls and administration. However, despite an acceptable general operating condition, the mixers (lecturers) encounter problems such as: lack of maintenance; abnormal squeaking and noise emission, causing noise pollution and waddling when started.
- **Office equipment:** this is the main consumer of energy, consisting of the administration's office supplies (printer, photocopier, projectors, etc.) and the IT equipment of staff and students (around 326 PCs), all for a consumption of around 240,320 Wh.
- **Other devices:** there are among other things household appliances, audio and video equipment for courses (Cisco equipment, audio mixer), inverters and regulators as well as routers, all for the most part relatively new and in good condition.

I.2.3. Overvoltage protection

The machine room is located on the first floor of the central building, commonly known as " *the tower"*. The 3-storey building should, in accordance with current standards, be equipped with a lightning conductor to protect against atmospheric overvoltage, as well as lightning arresters in the installation's switchboards; this is not the case.

I.2.4. Fire safety system

- **Rapid detection and reporting**

In the fire protection system two (02) factors must be taken into account:

- The technical factor which consists of ensuring the good quality of electrical installations (which are the cause of 50% of all fires) and their conformity with the current standards (Standard C12-201, and the decree of December 22, 1981).
- The human factor: at BIT this is not really taken into account because there is no awareness through posters; no safety register, no safety committee and no staff training on fire safety policy.

With regard to detection and reporting, we noted contradictory information: in fact, in front of each room in the institute, an evacuation plan for the room is displayed, specifying the location of fire detectors, fire alarm triggers, portable extinguishers, etc. However, this is not the case; only two rooms each have a fire detector (Cisco room and amphi100A), the other 10 rooms have no detection system. There is no addressable fire control unit[1] that can indicate precisely where a fire has started. Under these conditions, the occurrence of a fire at night, or when the premises are closed, could have serious consequences.

Figure 2: Fire detector (Amphi100A)

- **Rapid evacuation and extinguishing means**

For evacuation purpose, the institute's buildings are not equipped with self-contained emergency and ambient lighting units (BAES and BAEA), which are evacuation light sources intended to illuminate and show the location of exits, very practical in the event of darkness.

[1]An addressable fire alarm system uses sophisticated technology to pinpoint a fire's exact location. Every device is connected and communicates continuously with each other and a central monitoring station. They use digital signals to transfer vital information such as system health, device type, location, smoke density, etc. [14]

On the other hand, in front of each entrance there is an evacuation plan on an unalterable support which aims to facilitate emergency interventions such as those by the fire brigade.

As a means of extinguishing, only fire extinguishers are available, so regular checking is not effective. On average, 01 fire extinguisher is allocated to each class. The institute has neither fire hydrant (RIA) nor dry standpipes, even though such equipment is recommended for its category. The building’s fire safety deficiencies are significant, and some of the missing equipment should be integrated, in accordance with the intervention plans defined in standard NF S 60-303 of September 20, 1987 relating to fire protection plans and instructions [13] .

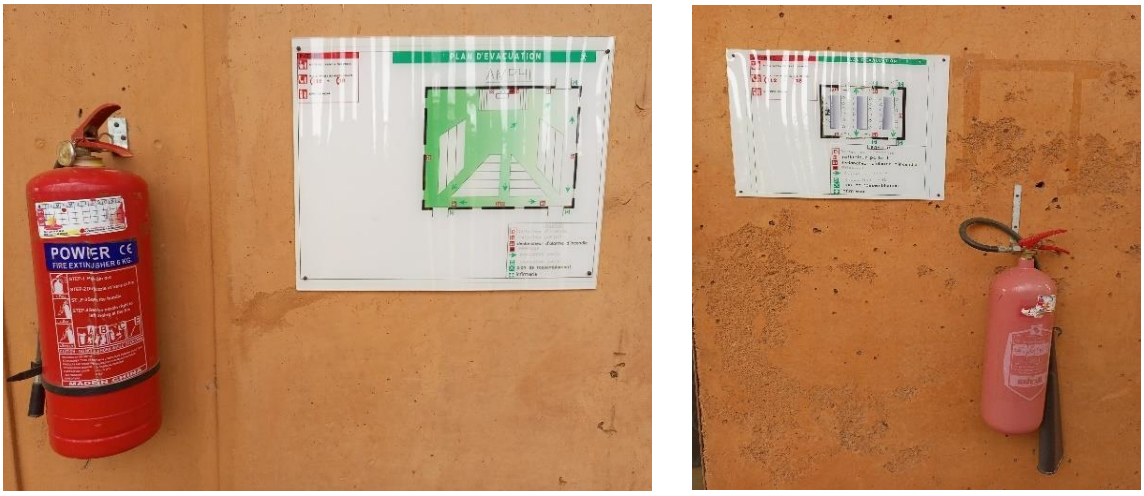


Figure 3: Evacuation plan and nearby fire extinguisher

II. Identification of losses

II.1.Losses at the panel level

II.1.1. Losses due to irradiance

Photovoltaic panels are designed to operate optimally at a reference irradiance of 1,000 W/m² STC. Any decrease in irradiance compared to this value results in a reduction in energy production. Losses can be calculated as a function of the reduction in average irradiance compared to this reference value. STCs are standardized "laboratory" conditions that do not perfectly represent reality. For example, irradiation is rarely 1000W/m². The sun can be veiled, and it is most of the time offset from the orthogonal axis of the panels. The temperature of the cells at 25° is just as utopian. When a solar panel is in the sun, it heats up quickly, and the temperature is higher. For this reason, to estimate the losses we will use the NOCT (Normal Operating Cell Temperature) conditions which are closer to normal use: irradiation of $800W/m^2$ and temperature of 45∓°C and outside temperature of 20°C.

BIT has an All-in-One Weather Station that provides real-time meteorological data such as irradiation, temperature, etc. For the warm and also the sunniest season, based on this data we note every day on average a peak of 835.682772 W/m² at 12 noon which is above the test standard so no losses. And for the winter season, which less sunny we note 682.657273 W/m². (*See data tables in Appendix n°3)*. We will calculate the losses only for this period [14] .

Power delivered by a panel under NOCT

$$Power\ NOCT = (irradiation * area) * efficiency \tag{1}$$

P= [800 W/m^2 *(1665*999 mm^2)] * 15.63% → P = 235.5642 W

Temperature coefficient:

$$KtPtotal = KtP * (NOCTpanneau - NOCToutside) \tag{2}$$

K_tP = (0.43%/°C) * (45° – 20°) → K_tP = 10.75%

Irradiance losses

$$losses = Power\ NOCT * KtPtotal \tag{3}$$

Losses (W) = 235.5642 W * 10.75% → Irradiance losses = 25.323 W or 8204.701 W for the photovoltaic field.

II.1.2. Losses due to temperature

The drop in solar panel performances is influenced by the panel temperature coefficient (approximately -0.4%/°C for most panels [15]). For WINAICO WST-260P6 modules, the typical efficiency loss is approximately -0.43% per degree Celsius above 25°C. High ambient temperatures during warm periods can lead to an efficiency reduction of up to 10% or more compared to STC (Standard Test Conditions). The choice of NOCT conditions is fully justified. According to the temperature measurements of the weather station, the average temperatures for the warm and winter period are 34.9948475°C and 29.1184593°C respectively. These are well below the NOCT value (45°C) which means that there are no losses.

II.1.3. Shading losses

Partial or total shading on some panels can lead to a significant drop in production. According to observations of the photovoltaic field, partial shading is noted on 24 panels from 2 p.m., which will considerably reduce their production. The degree of loss will depend on the density of the shading and the type of shading protection system in place (bypass diodes for example). Let us assume a 50% reduction in production for these shaded panels:

$$\text{Losses due to shading (\%)} = \frac{shaded\ modules}{total\ modules} * loss\ efficiency \qquad (4)$$

$$\text{Losses due to shading (\%)} = \frac{12}{324} * 50\% = 1.85\% = \ 1.56\ \text{kW}$$

II.1.4. Losses due to dirt and dust

Dirt, dust, and other debris on the panels reduce the amount of light that reaches the photovoltaic cells. During the winter season, rains reduce these losses. However, in dry periods, dust can significantly reduce production. A common method to estimate these losses is to measure production before and after cleaning the panels. Let's assume a 5% loss in dry periods due to dirt, and 2% in wet periods due to the effect of rain.

II.1.5. Degradation losses

Photovoltaic panels gradually lose performance over time, with a typical annual degradation of around 0.5% to 1%. The mini plant has been in operation since 2018, which makes it about 6 years old. Assuming the typical annual degradation is 0.5%, we will have a cumulative degradation rate of around 3% [16] .

Cumulative degradation = 0.5 * 6 = 3% → or degradation = 2.53kW

II.2.Losses at inverter level

II.2.1. Power inverter

Inverters are essential components in a photovoltaic power plant, as they convert the direct current (DC) produced by the solar panels into alternating current (AC) usable by the electrical grid. Inverter losses can be significant and are usually due to conversion inefficiencies. Conversion efficiency is typically around 98% to 99% at full load for this type of 60kW inverter. Conversion efficiency losses are mainly due to the difference between the DC power input to the inverter and the AC power output from the inverter. Inverter efficiency varies with the load, but for simplicity we'll use the nominal efficiency.

- **Loss calculation**

If the nominal efficiency is 98.5%, the losses will be:

$$Losses\ (\%) = 100\% - efficiency(\%) \qquad (5)$$

Losses (%) = 100% − 98.5% = 1.5%

Let's assume that each inverter handles a power close to its nominal capacity of 60 kW, then:
DC input power ≈ 60 kW

AC output power = 60 kW × 98.5% ≈ 59.1 kW

– Power losses for each inverter:

$$Power\ losses = DC\ input\ power - AC\ output\ power \quad (6)$$

Power losses = 60 kW − 59.1 kW = 0.9 kW

So, each inverter loses about **0.9 kW** when converting from DC to AC.

– Cumulative losses for the three inverters:

For the three inverters, the cumulative losses will be:

Total losses = 3 × 0.9 kW = 2.7 kW

- **Impact on overall plant efficiency**

Total inverter losses directly affect system efficiency. Assuming that the plant operates at full capacity for several hours per day, annual energy losses can be calculated. The Trio-TM-60.0 inverters, with a typical efficiency of 98.5%, cause losses of **2.7 kW** which will be taken into account for an accurate assessment of the photovoltaic power plant's efficiency.

II.2.2. Charging inverter

Charge inverters, such as the SUNNY ISLAND 6.0H, play a crucial role in hybrid or stand-alone PV systems, managing the charging and discharging of the batteries while converting the DC energy from the batteries to AC to power loads. To evaluate the losses in these inverters, here's how we'll proceed, taking into account their configuration: six (6) inverters (of 6kW) arranged in two rows with 3 inverters each (2 slaves and 1 master). Conversion efficiency losses for load inverters can be calculated in a similar way to PV inverters, but taking into account their specific role in battery management:

- **Yield loss**: Assuming an average yield of 95%, this means that for every 100 kW of energy supplied at the input (DC), around 95 kW will be available at the output (AC), with 5 kW lost as heat.

$$Losses = (1 - efficiency) * P_{AC} \quad (7)$$

Losses = (1 − 0.95) × 6 kW = 0.3 kW

For the 6 inverters we will have:

Losses per hour = 0.3W × 6 = 1800W = 1.8kW

- **Impact of Layout (Master/Slave)**:
  - Role: In each row, a master inverter controls two slave inverters. Although the masters have an additional management task, the conversion losses remain similar between masters and slaves
  - Additional Control related losses: There may be a slight increase in consumption for the master inverter due to its control function, but this is generally negligible compared to the overall losses.
- **Other Sources of Losses:**
  - **Self-consumption:** Even in standby mode or at low load, the inverter consumes energy (typically between 10W and 30W).
  - **Thermal losses:** Losses in the form of heat can also affect inverter components in the long term, although this does not directly contribute to energy losses, but rather to wear and tear.

II.3.Cable losses

Wiring losses are a common source of inefficiency in photovoltaic systems. These losses are mainly due to cable resistance and connections. When electric current flows through a cable, part of the energy is dissipated as heat, resulting in power losses. In our case, over a distance of around 300 m, the copper cabling with a cross-section >36 mm² connects the photovoltaic field to the equipment room.

✓ **Cable resistance:** Cable resistance is determined by the following formula:

$$R = \rho * \frac{L}{S} \tag{8}$$

R = 0.017 × (300/36) → R = 0.14 Ω

- R is the resistance of the cable (in ohms, Ω).
- ρ (rho) is the resistivity of the cable material (in Ω mm²/m).
  - For copper, $\rho_{Cu} \approx 0.017\ \Omega \cdot mm^2/m$
- L is the length of the cable (in meters) and S is the cross-section of the cable (in mm²)

✓ **Calculation of power losses in the cable**

The resistance of the cable, defined above, will cause a drop in potential between the start of the cable and the end of the cable: $U = V_A - V_B = R \times I$. Thus, if the cable is a perfect conductor, then R = 0 and U = 0 i.e.: $V_A = V_B$. But as R > 0 for a real cable, we have $V_A > V_B$, which corresponds to a voltage drop. This leads to energy dissipation by Joule effect (the cable will heat up). The technical and economic optimization of a photovoltaic installation therefore involves reducing these voltage drops as much as possible. In general, regulatory texts recommend a maximum voltage drops of 3%, ideally 1% [17] . Power losses in a cable are given by Joule's law:

$$Pperte = I^2 * R \tag{9}$$

- I is the current flowing through the cable (in amperes, A).
- R is the resistance of the cable (in ohms, Ω).

Not having the exact data of all the characteristics of the plant in real time, we will estimate the intensity based on the apparent power of the installation:

$$S = UI\sqrt{3} \quad \leftrightarrow \quad I = {}^{S}\!/_{U\sqrt{3}} \tag{10}$$

$I = 46653.286 / (400\sqrt{3}) \leftrightarrow$ $\underline{I = 67.33\ A}$

$P_{loss} = 67.33^2 \times 0.15\ \Omega \leftrightarrow$ $\underline{P_{loss} = 642.22\ W}$

- ✓ **Impact on overall efficiency:** Losses of 642.22 W can affect the plant’s overall efficiency. To reduce these losses, resizing is necessary.

III. Analysis of the impact of weather conditions

III.1. The weather station at BIT

On February 2, 2023, an All-in-one weather station, codenamed TA00794 and with an ATMOS 41 sensor (S001857), was installed on the BIT site. It is installed two (02) meters above ground at the exact position of 12.217818 and -2.377763. The ATMOS 41 weather station combines 12 weather sensors in a single compact device to monitoring atmospheric conditions, it works perfectly with the ZL6[2] for simple, plug-and-play data recording as well as cloud storage and management. It has been designed for continuous deployment in harsh

[2]ZL6 is an advanced and more robust logger, which introduces cloud-based data delivery, Bluetooth® configuration, over-the-air firmware updates and embedded metadata. It can be configured via Bluetooth and stores over 80,000 recordings

climates, such as Africa, which means it has no moving parts that can fail. Installation and maintenance have been simplified to the maximum. Just reliability you can rely on. Unlike any other weather station, specialized real gold pins measure every drop of rain. The resolution of 0.017 mm means that it can accurately measure small rainfalls and even heavy dews that other rain gauges fail do detect [18] . For our study we will focus on two measurements: solar irradiance and average temperature which are provided every hour by the station.

Figure 4: ATMOS 41 weather station and ZL6 data logger

III.2. Effects of sunshine

The sun is a nuclear fusion reactor that has been operating for 5 billion years. Through a process of transforming hydrogen into helium, it emits enormous amounts of energy into space (63,500 kW/m²). This radiation escapes in all directions and travels through space at the speed of light (299,792,458 m/s). After traveling a distance of around 150 million km, solar irradiation reaches outside of the Earth's atmosphere with a power of about 1,367 W/m². This is called the solar constant. Solar energy is at the origin of the water cycle, wind and photosynthesis, itself at the origin of fossil fuels. All life on Earth depends on this energy source. Fortunately for humanity, according to astronomers, the sun is not expected to go out for another 5 billion years. The solar radiation received on a surface therefore varies over time depending on the position of the Sun and cloud cover. Maximum solar power on the Earth's surface is about 1,000 W/m² for a surface perpendicular to the sun's rays. [19] . Based on the data provided by the weather station, we have established a set of irradiation and temperature curves for two main seasons: the warm season and the winter season. Let's analyze and interpret these curves:

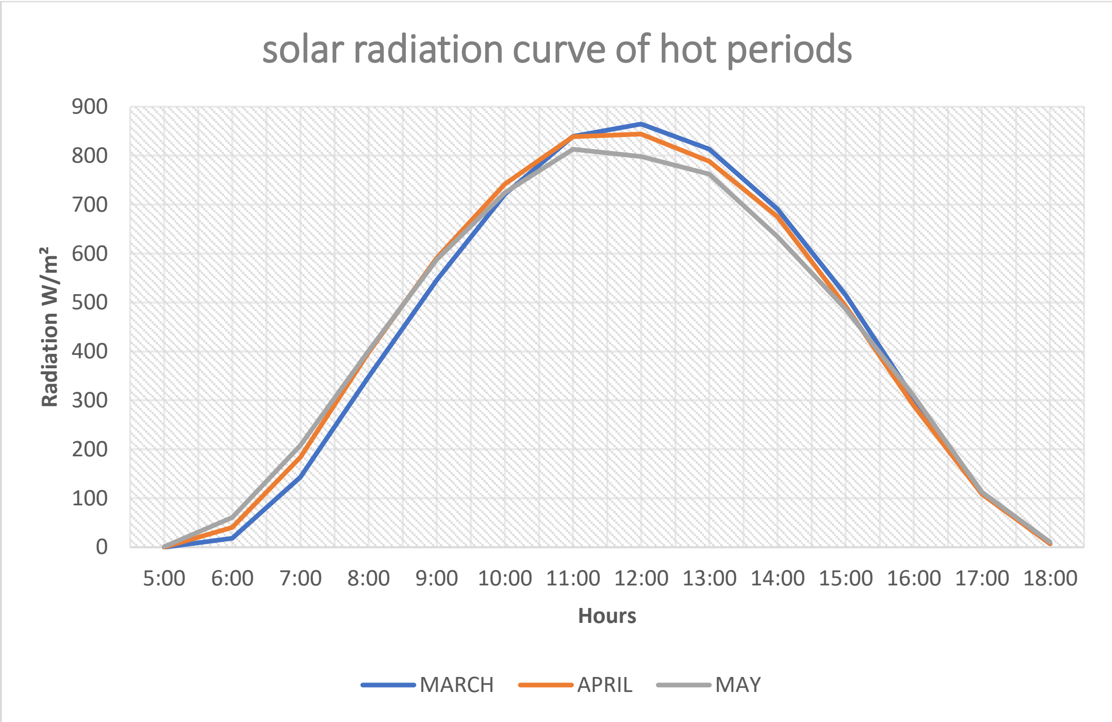


Figure 5 : Solar irradiation curve for warm periods (2024)

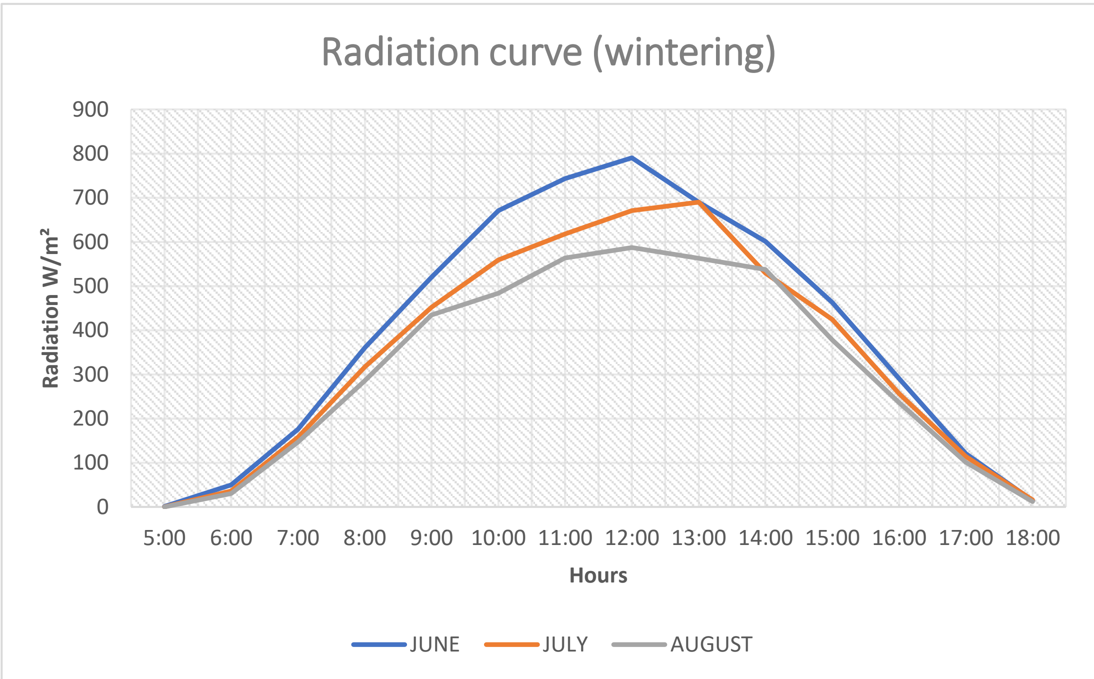


Figure 6 : Solar irradiance curve for Winter (2024)

March, April, May: The curves follow a similar profile, indicating that the sunshine conditions are relatively constant. Radiation levels of over 900 W/m² are sometimes recorded.

This high level of irradiance is favorable for solar energy production, as it corresponds to the period during which photovoltaic panels can operate at full capacity. May records a slightly lower production probably due to the transition to the rainy season.

June, July, August: The months of June and July have successive radiations, with a peak at 12:00 reaching 790.282222 and 689.916667 W/m² at 13:00. June is the month with the highest energy production. The month of August has the lowest radiation (562.916667 W/m²) probably due to the increase in cloud cover.

III.3. Effect of temperature

Module performance is strongly influenced by temperature variations, which can affect the overall system efficiency. The curves below represent the daily variations in average temperature during the operating hours of the panels: between 5am and 6pm. The hottest hours of the day, generally between 12pm and 3pm, are those where the impact of high temperatures is most significant with temperatures of around 30°C. Let's interpret and analyze these data:

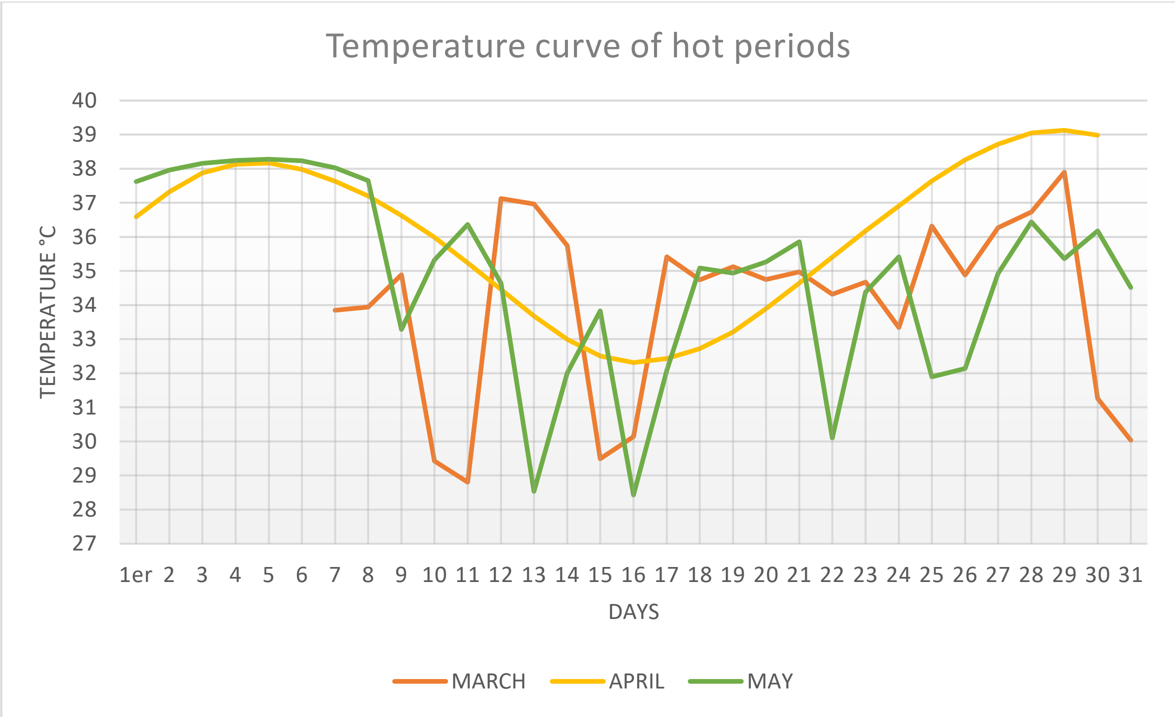


Figure 7 : Average warm- weather temperature curve (2024)

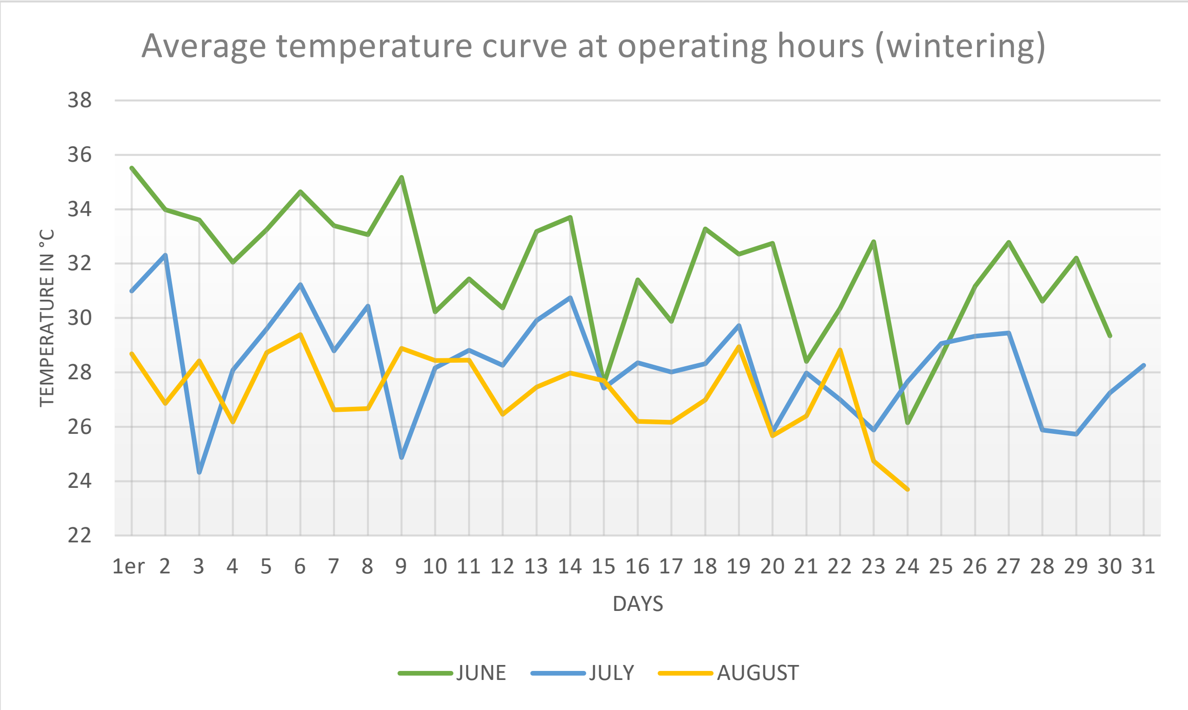


Figure 8 : Average winter temperature curve (2024)

March, April, May: The average temperatures are 34.04°C, 36.06°C and 34.9°C respectively. There are significant fluctuations with high temperature peaks, particularly in April, where temperatures reach 42°C *(see daily meteorological data in the appendix n°5).* These high temperatures reduce the efficiency of solar panels due to overheating.

June, July and August: Average temperatures are 31.8°C, 28.3°C and 27.3°C respectively. This period seems to be the most favorable for solar energy production, despite a slightly lower irradiance, due to the lower and more stable temperatures, allowing a more optimal performance of the panels according to STC.

III.4. Favorable period for energy production

Table 1: Comparison of weather-related losses according to NOCT

Losses	Warm period (%)	Winter period (%)
Related to Irradiance	0	9.73
Thermal	0	0
Dirt and debris	5	2
Total	5	11.73

The warm period is more favorable with overall losses of 5%, against 11.73% for the winter period according to NOCT, which Unlike the STC offers a wider extension in relation to thermal and irradiance losses. Under STC condition the losses would be very high of the order of 16.43% and 31.73% for irradiance; 6.44% and 1.77% for thermal losses all this due to the standard values of 1000W/m² and 25°C which are far from reality. In each of the hypotheses the warm period remains the most favorable for energy production.

IV. Audit report

IV.1. Power balance

The power assessment is an essential step in any electrical installation. It takes into account all the powers of the installed devices and their use for a detailed assessment of consumption. It enables correct sizing (choosing the right equipment), optimizing consumption by offering alternatives to energy-consuming equipment and selecting the right electricity contract with the local distributor (SONABEL) if necessary; all which guarantees the smooth running of the installation.

In carrying out this power assessment, we have summarized the data in the table below *(full assessment can be found in Appendix n°6).* For the sake of accuracy, we have applied to this balance a Simultaneity Coefficient (Ks) which indicates the percentage of devices operating at the same time and an Utilization Coefficient (Ku) to indicate that some electrical receivers do not operate at their nominal powers. These coefficients are respectively 0.8 and 0.75 in accordance with standards NFC 63-410 and NFC 15-100. [22]

$$PT = \Sigma P\ i\ ;\ QT = \Sigma Q\ i\ ;\ S' = \sqrt{\boldsymbol{Pt}^2 + \boldsymbol{Qt}^2}\ ;\ S = S' * Ku * Ks \qquad (11)$$

Table 2: Power balance

Level	**Cos phi**	**Tan phi**	**Power in W**	**Energy Wh**	**Reactive power Q (VA)**	**If**	**S**
Lighting	0.55	1,5184812	8272	90604	12560,8764	70296.8	44989,954
Office automation	0.9	0.4843221	30040	293000	14549,03603		
Air conditioning	0.8	0.75	3965.36	69753,5714	2974.017857		
Ventilation	0.8	0.75	3065	29590	2298.75		
Household appliances	0.8	0.75	3325	16020	2493.75		
audio/video equipment	0.9	0.4843221	9340	100400	4328,441092		
Other	0.8	0.75	227	4986	170.25		
Total			58234.4	604353,571	39375,12138		

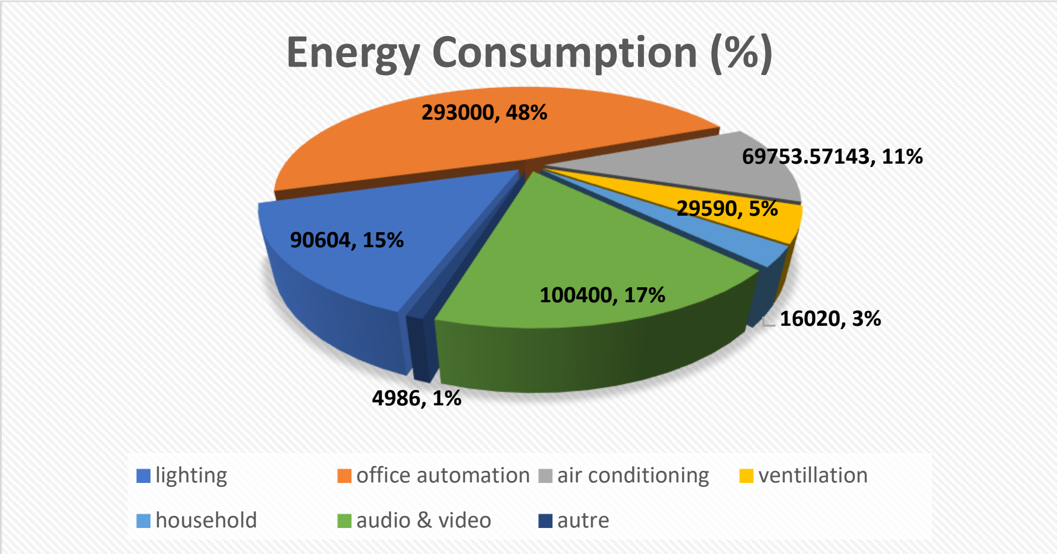


Figure 9 : Energy consumption diagram

This diagram provides an overview of energy consumption and highlights the main energy-consuming items: office automation (48%) and audio/video equipment (17%) for courses. These two items alone account for 65% of total consumption. This suggests that optimizing these two areas could have a significant impact on reducing consumption. Lighting (15%), then air conditioning (11%) contributes a significant share. Household appliances, ventilation and others, although representing a smaller share, their sum is still significant.

IV.2. Overall efficiency

Table 3 : Balance sheet of losses of the power plan

	Hot season		Winter season	
Designation	Power (kW)	Energy (kWh)	Power (kW)	Energy (kWh)
Irradiance	0	0	8,204701	68,0990183
Temperature	0	0	0	0
Dust	4,2170625	35,0016188	1,686825	14,0006475
Shading	1,56	12,948	1,56	12,948
Degradation	2,53	20,999	2,53	20,999
Functioning	2,7	22,41	2,7	22,41
Functioning	1,8	14,94	1,8	14,94
Self-consumption	0,02	0,166	0,02	0,166
Cables	0,68	5,644	0,68	5,644
Total	13,5070625	112,108619	19,181526	159,206666

The analysis clearly shows that the BIT’s photovoltaic plant suffers significant losses, particularly due to environmental conditions (dust, irradiance), panel degradation, and losses in cables and inverters. These losses, combined with a high demand for energy in hot periods, lead to an energy deficit that does not allow the plant to cover the institute's energy needs.

CHAPTER III: OPERATING OPTIMIZATION AND ENVIRONMENTAL ANALYSIS

I. Summary and recommendation

I.1. Summary

During the winter period, consumption is less significant due to the holidays and therefore the absence of students. We will consider the hot period since it corresponds to the period of high demand and that outages are recurrent. The plant produces approximately **700.032 kWh** of energy per day for a daily consumption of **604.3535714 kWh,** which indicates a significant consumption but lower than the production. The total losses of the system, approximately **112,108619 kWh,** are a significant proportion of the total production. The balance shows an energy deficit of **-16.4301904 kWh,** indicating that the losses greatly influence the final efficiency of the plant especially during consumption peaks.

Table 4: Overall efficiency

Designation	Values (kWh)
Energy produced	700,032
Energy consumed	604.3535714
System loss	112,108619
Remaining energy	-16.4301904

I.2. Optimization recommendations

- ✓ **Orientation and optimal panel inclination:** Choosing the right orientation is important. Indeed, the more solar rays are captured, the more electricity is produced. To optimize their orientation, some have had the idea of creating solar trackers; which allow the panels to follow the sun's trajectory throughout the day. Some types of solar trackers can also tilt the panels more or less depending on the season. These trackers allow a yield of 25% to 40% higher than conventional solar panels, however, they have a high cost [21] . In the northern hemisphere, the ideal orientation is due south. Given Burkina Faso's latitude, the optimal tilt angle is between 10° to 20° due south depending on the local topography. Here's a purely geometric table that estimates the optimal tilt angle depending on the orientation. It assumes an angle of 15° i.e., 96% efficiency, which is applicable for the BIT plant.

	Inclinaison						
Orientation	0	15	25	35	50	70	90
Est	0,88	0,87	0,85	0,83	0,77	0,65	0,50
Sud-est	0,88	0,93	0,95	0,95	0,92	0,81	0,64
Sud	0,88	0,96	0,99	1	0,98	0,87	0,68
Sud-ouest	0,88	0,93	0,95	0,95	0,92	0,81	0,64
Ouest	0,88	0,87	0,85	0,82	0,76	0,65	0,50

Figure 10 : Estimated angle of inclination table

- ✓ **Integration of Power optimizers:** A power optimizer is a module-level power electronic (MLPE) device that increases the solar panel system's energy output by constantly measuring the maximum power point tracking (MPPT) of each individual solar panel and adjusts DC characteristics to maximize energy output. They are especially useful when the performance of the power generating components in a system will vary widely, such as due to differences in equipment, shading of light or wind, or being installed facing different directions or widely separated locations.

Figure 11 : Power Optimizer

- ✓ **Shading:** partial shading due to a tree has been observed on some panels of the plant, this causes losses that reduce electricity production. There are possible solutions such as the installation of anti-shading devices (with micro-inverters or power optimizers) or simply eliminating this source of shading, not forgetting to replace it by planting trees on another site for ecological reasons.
- ✓ **Cabling:** We found significant losses in the cable. To alleviate this problem, we suggest a more suitable cable section:

$$\boldsymbol{S} \geq \frac{2\rho L I}{\Delta V_L \times U} \qquad (12)$$

ρ = 0.017 Ω mm² /m for copper; U = Vpm = 31.25V; L = 300 m; Imp =8.33*3 = 24.99 A

$\boldsymbol{S} \geq \frac{2*0,017*300*24,99}{0,03\times 31,25} \rightarrow$ $\underline{\mathbf{S} \geq 271.89\ \text{mm}^2}$ a cable cross section of 300mm² to considered

Failing that, we could consider relocating the equipment room closer to the photovoltaic field to reduce cables distance, and hence losses.

- ✓ **Surge Protection and Fire Safety:** We strongly recommend that the institute equip its installations with lightning rods and surge arresters to avoid the dangers associated with surges. It should also install automatic and manual fire detectors in all rooms, as well as BAES, BAEA for evacuation and RIA and dry column for fire extinguishing.
- ✓ **Preventive maintenance:** A real-time monitoring system helps detect anomalies and optimize equipment performance. A preventive maintenance plan, including panel cleaning and regular equipment checks, is essential to maintain optimal performance.
- ✓ **Energy-consuming posts:** office automation is a necessary and unavoidable consumption items. Optimization should be done at other levels such as timers for air conditioners, solar lamps for lighting and energy saving culture. We've noticed a lack of lighting throughout the school ground and main walkway, and solar street lamps would be a good alternative to this.

II. Carbon footprint

Any energy production, however renewable, generates a more or less significant ecological impact. This is demonstrated by solar electricity, and more particularly the installation necessary for its production. Indeed, the environmental impact of photovoltaics is mainly induced during panel manufacturing. China, the leading producer, is at the origin of 90% of the offers. Unfortunately, complaints about harsh working conditions and pollution caused by silicon refining operations have been denounced and documented over the last ten years. The impact of photovoltaic cells production is therefore both an environmental problem and an ethical one. [24]

II.1. Carbon footprint

II.1.1. Calculating the carbon footprint of the bit plant

The carbon footprint corresponds to the direct or indirect greenhouse gas (GHG) emissions emitted by an activity or a sector; and is expressed in grams of CO_2 equivalent (gCO_2 eq / kWh).

For the carbon footprint of the solar power plant, the calculation involves carrying out the Life Cycle Analysis (LCA) of a photovoltaic panel. This analysis is framed at the international level by the ISO 14040 and ISO 14044 standards of 2006, and takes into account the energy and emissions generated throughout the life cycle of the installation: extraction of raw materials, manufacturing and assembly, transport, use, and recycling. The Kyoto Protocol has established several GHG: Carbon dioxide (CO_2); Methane (CH4); Halocarbons (HFCs and PFCs); Nitrous oxide (N2O); Sulfur hexafluoride (SF6). All converted into CO2 equivalent.

According to ADEME, the French Agency for Ecological Transition, taking into account the materials used, the model and the energy mix of the country of manufacture, the carbon footprint of photovoltaics is estimated at:

- 43.9 g CO_2eq/kWh for Chinese panels, since most of the electricity used in their manufacture comes from coal. And a coal-fired power plant emits 0.85 tons of CO2 per MWh of electricity produced;
- 32.3 gCO_2eq/kWh for European panels; and 25.2 gCO_2eq/kWh for French panels , thanks to their low-carbon energy mix. [25]

Today, the majority of solar panels come from China. That's why we'll use 43.9 gCO_2 eq/kWh as a standard value [24] . For a daily production of 700.032 kWh and an estimated lifetime of 25 years, we'll have a carbon footprint of:

Total energy produced in 25 years:

$$total\ energy = annual\ Energy * 25 \qquad (13)$$

Energy = (700.032 * 365) * 25 = 6387792 kWh

$$carbone\ Footprint = \ total\ energy * Emissions \qquad (14)$$

Footprint = 6387792 * 43.9 = 280424068.8 g CO_2 eq/kWh or 280.4240686 t CO_2 eq/kWh

In the distribution of emissions from the plant to the different stages we have: equipment manufacturing: 96.2%; project development: 0.2%; transport: 1.2%; construction: 0.9%; operation: 0.9%; and recycling: 0.6%.

II.1.2. Avoided emissions

Admittedly, solar panels are not carbon neutral. However, their carbon footprint is minimal compared to that of fossil fuels. Not to mention that beyond the GHG emissions generated, fossil fuels contribute to deforestation, deplete resources, and weaken ecosystems, animal and plant species. The emission factor for fossil-fired power plants is approximately 600 gCO_2/kWh *(see reference table in Appendix n°7).* One of the most important aspects of the carbon balance is the estimation of CO_2 emissions avoided through the use of RES:

- Calculation of emissions avoided annually:

$$Avoided\ emissions = Energy(jour) * 365 * fossil\ emissions \quad (15)$$

Avoided emissions = 700.032 * 365 * 600 = 153307008 gCO_2eq

Over 25 years:

$$Avoided\ emissions\ (25 years) = Avoided\ emissions(1\ year) * 25 \quad (16)$$

Avoided emissions over 25 years = 420019.2 gCO_2eq/day × 365 days × 25 years = 3832675200 gCO2eq or 3832.6752 tCO_2eq

II.2.The return times

II.2.1. Energy return time

For an energy to be considered renewable, it must produce much more energy than it needs during its life cycle. The energy return time corresponds to the ratio between the total energy consumed during its manufacture and the energy produced annually. For photovoltaics, the Energy return time is 1 to 1.5 years, adjusted to the French climate and sunshine. The lifespan of a photovoltaic system is 25 to 35 years on average, which means that depending on the amount of sunshine and the duration of use, it will produce between 17 and 35 times the energy required for its use over its entire life cycle [27]. According to the CNRS, *"in total, 2933 kWh of electricity are required to produce 1 kg of silicon wafer*[3]". However, silicon production is mainly located in China. Since the Chinese energy mix is primarily supported by fossil fuels (57.6% coal in 2019), panels manufacturing emits a lot of CO_{2s}. Because a coal-fired power station emits 0.85 t CO_2/MWh of electricity produced.

[3]However, this figure must be taken with a grain of salt since it dates from 2010. It is likely that production techniques have evolved and involve less energy.

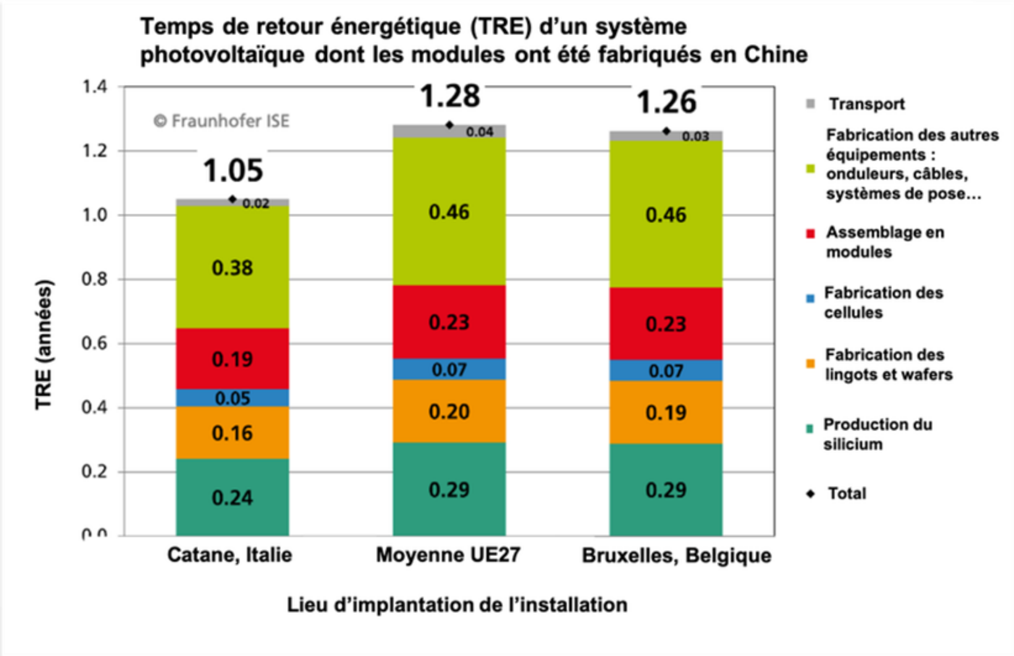


Figure 12 :Return time for modules manufactured in China and installed in Europe

II.2.2. Carbon payback time

The manufacture, operation and dismantling of a photovoltaic system have a carbon footprint. When this equipment avoids CO_2 emissions, as can be the case with renewable energies, it is possible to calculate the time required to repay the carbon "debt". The carbon payback time is equal to the ratio between the carbon footprint over its entire life cycle and the emissions avoided by it over one year.

$$Carbon\ payback\ time = \frac{carbon\ footprint\ over\ 25years}{avoided\ Emission\ over\ 1year} \tag{17}$$

$$Carbon\ payback\ time = \frac{280424068{,}8}{153307008} = 1{,}83\ years \tag{18}$$

The BIT plant is expected to repay its carbon debt after about 2 years of operation. Having been in service for 6 years now (2018), it is supposed to have paid off this debt.

- **Overall carbon balance**

Table 5: Overall carbon balance

Emissions	**Values**
Development and operation	280.4240686 t CO2 $_{eq}$ /kWh
Avoided emissions	3832.6752 tCO_2eq
Carbon payback time	1.83 years

BIT's photovoltaic plant, with its emissions of 43.9gCO_2/kWh, is significantly cleaner than a typical fossil power plant, which emits an average of 600g CO_2/kWh. Over a 25-year period, the solar plant avoids the emission of more than 3832.6752 tCO_2eq. This plant significantly reduces the campus's carbon footprint, thus actively participating in the fight against climate change.

II.3.Emissions in Burkina Faso

MRV (Measuring, Reporting and Verification) system is a mechanism for monitoring and capitalizing on adaptation and mitigation actions to assess each country's efforts in terms of greenhouse gas emissions and reductions. Burkina Faso is one of the first least developed countries (LDCs) to comply with decision 5/CP.17 on national climate change adaptation plans. This section presents a summary of Burkina Faso's greenhouse gas emissions based on the latest available data. National GHG emissions are mainly due to the AFAT sector (agriculture, foresterie et Autre utilisation des Terres) uses with 86.6%) followed by energy (6.9%) then PIUP (industrial processes and product uses with 0.8%) and waste (2.7%). The estimate covers direct emissions (CO_2, CH_4, N_20) and indirect emissions (CO, NO_x, Non-Volatile Organic Methane Compounds (NMVOCs), and SO_2).

CO_2 emissions in 2017 in the energy sector were 3,896.1 Gg with transport as the main polluting sector (58%) followed by residences (18.5%) then electricity production (16.4), institutions (5%) and industries (1.3%). Projections by 2030, still in the same vein, predict an increase in emissions in the land transport sector [28]. *(See appendix n°8 and n°9)*

Table 6: Table 17/CP8 GHG emissions for 2017

Emissions in Gg	CO2	CH4	N2O	NOx	CO	NMVOCs	SO2
Energy	814.4	1.9	0.25	0	0	0	0
Industries and	65.6	0	0	0	0	0	0
Transport	2754.9	0.6	0.15	0	0	0	0
Others	261.2	36.8	0.45	0	0	0	0
Total	**3896.1**	**39.3**	**0.85**	**0**	**0**	**0**	**0**

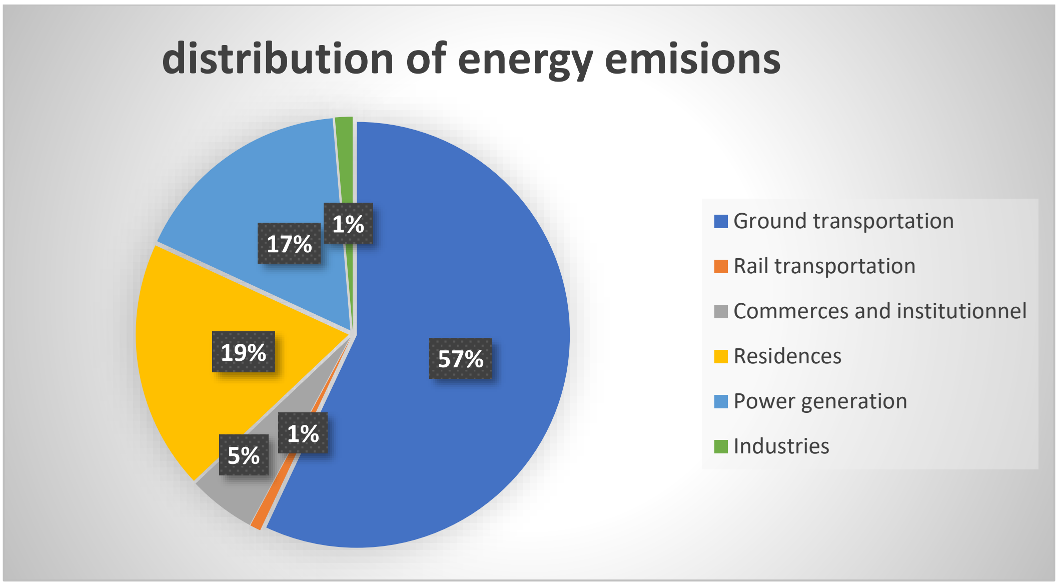


Figure 13 : Distribution of emissions in energy

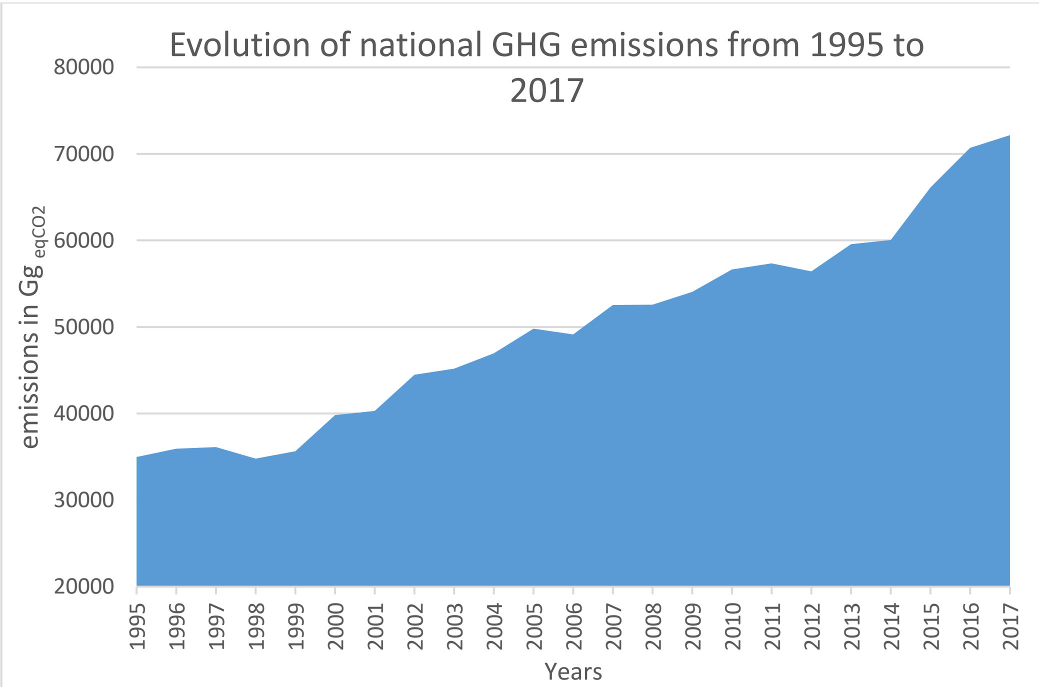


Figure 14 : Evolution of national GHG emissions from 1995 to 2017

National GHG emissions are on an upward trend. Emissions increased from 36,647 Gg eq-CO2 in 1995 to 72,169 in 2017, an increase of 97% in 12 years. This increase is largely caused by the increase in emissions from the AFOLU sector, which contributed 70% to this growth, the energy sector contributed 11%, waste contributed 2% and finally the IPUP sector contributed 1%. The increases in emissions are explained, among other things, by the increase in agricultural areas, the decrease in forest land and the increase in livestock numbers.

III. Outlook

III.1. Mitigation of carbon emissions

In a context where the energy transition has become a major priority, measuring and reducing the carbon footprint of solar projects is essential. CO_2 emissions due to the consumption of fossil fuels represent the largest share (> 2/3) of greenhouse gas emissions attributable to human activities. The Kyoto Protocol has outlined the path to follow to reduce these emissions: Replace oil and coal for electricity production with gas that generates less CO_2; Significantly reduce energy consumption in all uses (industry, residential, tertiary, transport) and adopt more energy-efficient lifestyles.

In December 2015, COP21 set the goal of stabilizing global warming due to human activities below 2°C compared to the pre-industrial era temperature by 2100. This requires reducing global greenhouse gas emissions by 40% to 70% by 2050 compared to 2010 levels, and achieving a nearly carbon-neutral economy during the second half of the 21st century. To optimize the carbon footprint of photovoltaic power plants, several strategies can be implemented:

1. **Optimizing materials and equipment:** by using materials with a lower carbon impact and promoting technological innovations in the manufacture of modules and structures: The use of recycled or “green” materials (e.g., green steel produced with green hydrogen or steelworks with CO_2 capture in fumes).
2. **Sourcing equipment from countries with lower carbon energy mixes:** modules and structures are energy-intensive and their origins have an impact on the fleet's footprint (e.g.: Indian recycled steel is much more carbon intensive than European recycled steel because the electricity used to produce it is more carbon intensive). In fact, to manufacture low-carbon panels, it is necessary to relocate production, particularly assembly. in France [4] which emits less CO_2 than abroad, since France benefits from a very low-carbon energy mix.
3. **Optimizing end-of-life plant management:** by providing solutions for recycling and reusing materials to minimize the carbon footprint at the end of the life of photovoltaic

[4]France was the first (and for a long time, the only!) country to ask module manufacturers to communicate and certify the carbon footprint of their modules (in kgCO2/kWc), and to impose a ceiling.

plants. Reuse and recycling will also reduce the impact of the supply of future plants that will benefit from it [5].

III.2. The future of RES

Global electricity production is growing faster and faster. Between 2010 and 2022, it increased by 50%. Between 2022 and 2040, it is expected to grow by 100%, i.e., double. Then increase by another 25% between 2040 and 2050. This "electrification of the world" is due to the development of electric vehicles, residential heating, electronic devices, the robotization of factories, and of course the growth of the world population. This spectacular growth will be accompanied by a profound transformation of production sources, which will shift from fossil sources to renewable sources, especially solar and wind according to the IEA.

A significant part of the photovoltaic footprint is linked to the electricity used for the production of modules and intermediate products (silicon ingots, wafers, cells). Nowadays, the electricity used is less and less carbon-intensive. Thus, the carbon footprint of photovoltaics tends to decrease over time. Ultimately, despite an emissive panel manufacturing phase, the production of solar electricity remains an effective solution against global warming. The impact on the environment is not the same between a fossil energy and a renewable one; in comparison with fossil fuels, whose greenhouse gas emissions are significant (more than triple). In an approach towards collective carbon neutrality, the installation of a photovoltaic system remains a solution, to be coupled of course with other energy and ecological transformation actions. There are for these Emerging technologies: some exploit the energy of the seas (wave swell, currents, etc.). The heat of the Earth at great depth (Geothermal energy) which can also be used to produce electricity. Concentrated solar thermal power plants capture the heat of the sun to heat a fluid and turn a turbine. Hydrogen, usable in fuel cells and many others, opens up vast perspectives [29].

[5] The carbon footprint of new steel is on average 7 times lower than that of new aluminium, but 10 times higher than that of wood and the use of recycled steel instead of new steel makes it possible to reduce the carbon footprint of the structure by a factor of 2.5 on average.

General conclusion

The study of the energy efficiency and optimization for BIT’s mini solar photovoltaic power plant made it possible to draw up a precise inventory of the installation's performance, as well as the various factors that influence its energy production. By identifying and analyzing losses at several levels (solar panels, inverters, cabling, and environmental conditions), this study highlighted the main obstacles to optimal production. The analyses show that energy losses, particularly due to shading, dust, weather conditions and inefficiencies in conversion systems, significantly impact energy production, especially during periods of high heat. These losses not only affect energy efficiency, but also the stability of the electricity supply, causing frequent outages. Optimization solutions have been proposed to mitigate these losses, such as adjusting the tilt of the panels, installing anti-shading devices, and preventive maintenance.

On the environmental level, the carbon footprint assessment highlighted the positive impact of the plant on reducing greenhouse gas emissions. Although the production of photovoltaic panels generates emissions during their manufacture and transport, these emissions are largely offset by the clean energy produced throughout their life cycle. The plant thus contributes to a significant reduction in CO_2 emissions compared to fossil energy sources. The carbon footprint of solar panels tends to improve over time; the carbon footprint of photovoltaics tends to decrease over time. More recent estimates thus provide figures below $30gCO_2/kWh$, including for installations whose equipment was manufactured in Asia

In conclusion, this thesis demonstrates that optimizing photovoltaic systems in developing areas is not only feasible but also necessary to improve energy resilience and reduce environmental impact. It is recommended to further this research by integrating more advanced technologies, such as solar trackers, to maximize energy production throughout the year.

Bibliography and Webography

[1] « Our Team | BIT ». Consulté le: 13 août 2024. [En ligne]. Disponible sur: https://bit.bf/about-us/

[2] « Unternehmen », hep solar. Consulté le: 14 août 2024. [En ligne]. Disponible sur: https://hep.global/unternehmen/

[3] manon.bauce@gdsolaire.com, « Une centrale photovoltaïque, c'est quoi ? Et comment ça fonctionne ? », Générale du Solaire. Consulté le: 14 août 2024. [En ligne]. Disponible sur: https://www.gdsolaire.com/une-centrale-photovoltaique-cest-quoi-et-comment-ca-fonctionne/

[4] « Solaire photovoltaïque : fonctionnement, panneau et centrale ». Consulté le: 14 août 2024. [En ligne]. Disponible sur: https://www.connaissancedesenergies.org/fiche-pedagogique/solaire-photovoltaique

[5] « Principe de fonctionnement d'un panneau solaire », Solaris - Expert de l'autonomie solaire. Consulté le: 14 août 2024. [En ligne]. Disponible sur: https://www.solaris-store.com/content/42-principe-de-fonctionnement-panneau-solaire

[6] « Winaico WST-260P6 (260W) Solar Panel ». Consulté le: 14 août 2024. [En ligne]. Disponible sur: http://www.solardesigntool.com/components/module-panel-solar/Winaico/2792/WST-260P6/specification-data-sheet.html

[7] « Comprendre le stockage de l'énergie solaire - Technique Solaire ». Consulté le: 14 août 2024. [En ligne]. Disponible sur: https://techniquesolaire.com/solaire-photovoltaique/comment-stocker-lenergie-solaire/

[8] « TRIO-20.0/27.6-TL-OUTD NA data sheet ». Consulté le: 22 octobre 2024. [En ligne]. Disponible sur: https://search-ext.abb.com/library/Download.aspx?DocumentID=9AKK106103A4856&DocumentPartId=

[9] « Eaton carte Web/SNMP et MODBUS-MS ». Consulté le: 15 août 2024. [En ligne]. Disponible sur: https://www.eurocapa.com/modbus-ms.html

[10] « Onduleur chargeur SOLAR TECHNOLOGY 5000 VA/48 VDC avec AVR MPPT 60A », POWER TECHNOLOGY. Consulté le: 15 août 2024. [En ligne]. Disponible sur: https://pwrt.mg/produit/onduleur-chargeur-solar-technology-5000-va-48-vdc-avec-avr-mppt-60a/

[11] « SMA Sunny Island 6.0H (SI6.0H-13) ». Consulté le: 20 août 2024. [En ligne]. Disponible sur: https://solarshop.baywa-re.fr/SMA-Sunny-Island-60H-32-011463

[12] « SUNNY ISLAND 4.4M / 6.0H / 8.0H - L'onduleur polyvalent le plus fiable – d'une simplicité inégalée ».

[13] Y. Azoumah, E. W. Ramdé, G. Tapsoba, et S. Thiam, « Siting guidelines for concentrating solar power plants in the Sahel: Case study of Burkina Faso », *Sol. Energy*, vol. 84, nº 8, p. 1545-1553, août 2010, doi: 10.1016/j.solener.2010.05.019.

[14] I. Fire, « What is an Addressable Fire Alarm System? (+5 Key Benefits) ». Consulté le: 29 août 2024. [En ligne]. Disponible sur: https://resources.impactfireservices.com/addressable-fire-alarm-system

[15] W. S. D.-Wsd.-L. W. Autrement, « Les Plans NFS 60-303 - Plan Incendie | Plan incendie », PFI & Sécurihop. Consulté le: 29 août 2024. [En ligne]. Disponible sur: https://protect-france-incendie.fr/plan-incendie/plan-d-evacuation-et-intervention-suivant-la-norme-nfs-60-303

[16] jadetech, « Qu'est-ce que le coefficient de température d'un panneau photovoltaïque ? », JADE Technologie. Consulté le: 4 septembre 2024. [En ligne]. Disponible sur: https://www.jade-technologie.com/coefficient-de-temperature-panneau-photovoltaique/

[17] « Le ratio de performance PR pour une installation photovoltaïque autonome ». Consulté le: 27 août 2024. [En ligne]. Disponible sur: https://www.photovoltaique.guidenr.fr/informations_techniques/conception-photovoltaique-autonome/ratio-performance-installation-photovoltaique-autonome.php

[18] « Quelle est la durée de vie d'un panneau solaire | Guide 2024 », Otovo Blog. Consulté le: 3 septembre 2024. [En ligne]. Disponible sur: https://www.otovo.fr/blog/le-solaire-et-vous/duree-vie-panneau-solaire/

[19] « Pertes par échauffement des câbles ». Consulté le: 27 août 2024. [En ligne]. Disponible sur: https://www.photovoltaique.guidenr.fr/informations_techniques/conception-photovoltaique-autonome/perte-echauffement-cables.php

[20] « ATMOS 41 - Groupe METER ». Consulté le: 26 août 2024. [En ligne]. Disponible sur: https://metergroup.com/products/atmos-41/

[21] « Ensoleillement », Energie Plus Le Site. Consulté le: 21 août 2024. [En ligne]. Disponible sur: https://energieplus-lesite.be/theories/climat8/ensoleillement-d8/

[22] « Memoire Online - Développement et gestion d'un système d'énergies renouvelables multisources avec stockage pour les télécommunications et l'habitat - Bertrand Olivier ETOUNGOU », Memoire Online. Consulté le: 25 août 2024. [En ligne]. Disponible sur: https://www.memoireonline.com/11/13/7728/m_Developpement-et-gestion-d-un-systeme-d-energies-renouvelables-multisources-avec-stockage-pour-le37.html

[23] « Quelle est l'orientation idéale d'un panneau solaire ? » Consulté le: 14 août 2024. [En ligne]. Disponible sur: https://mypower.engie.fr/conseils/pose-installation-panneaux-solaires/orientation-panneau-solaire-photovoltaique.html

[24] I. Rakotonavahy, « Quel bilan carbone pour le photovoltaique ? », Carbo. Consulté le: 1 septembre 2024. [En ligne]. Disponible sur: https://www.hellocarbo.com/blog/calculer/quel-bilan-carbone-pour-le-photovoltaique/

[25] « Quel bilan carbone pour la production d'électricité solaire ? » Consulté le: 1 septembre 2024. [En ligne]. Disponible sur: https://greenly.earth/fr-fr/blog/actualites-ecologie/empreinte-carbone-electricite-solaire

[26] C. Dusanter, « Bilan carbone des panneaux solaires : définition et calcul », Opéra Energie. Consulté le: 10 septembre 2024. [En ligne]. Disponible sur: https://opera-energie.com/bilan-carbone-panneau-solaire/

[27] « Photovoltaique.info - Temps de retour énergetique ». Consulté le: 2 septembre 2024. [En ligne]. Disponible sur: https://www.photovoltaique.info/fr/info-ou-intox/les-enjeux-environnementaux/temps-de-retour-energetique/

[28] « Émissions par secteur - MRV Burkina Faso ». Consulté le: 2 septembre 2024. [En ligne]. Disponible sur: https://mrv-burkina.bf/emissions-par-secteur.html

[29] « Production d’électricité et émissions de CO2 ». Consulté le: 1 septembre 2024. [En ligne]. Disponible sur: https://www.planete-energies.com/fr/media/article/production-delectricite-ses-emissions-co2

[30] ALy, D. Y. (2021-2022). *Diagnostic électrique de la Société de Gestion du Patrimoine Ferroviaire du Burkina (SOPAFER-B OUAGADOUGOU).* ISGE-BF, Pour l'obtention du DIPLÖME DE Technicien Supérieur.

[31] DEOREL, K. A. (2019-2020). *Diagnostic des installations électrique de l'Institut Superieur de Génie Electrique du BURKINA FASO.* ISGE-BF, Pour l'obtention du DIPLÖME DE Technicien Supérieur.

[32] OUEDRAOGO, R. F. (2017-2018). *Audit énergétique d’un bâtiment administratif dans la ville de Ouagadougou : cas du siège d’Ora Bank, Mémoire de fin de cycle Master Energie Electrique 2IE.*

Appendix

Appendix 1: WINACO panel technical sheet

Designation	Value	Units
Maximum Power (Pmax)	260	Watt
Nominal voltage	24	Volt
Open Circuit Voltage (Voc)	37.92	Volt
Short Circuit Current (Isc)	8.67	Ampère
Maximum Power (Vmp)	31,25	Volt
Maximum Power Curent (Imp)	8,33	Ampère
Cell Temperature	25	Degree
Length, Width, Depth	1665*999*35	Minimeter
PTC Power Rating	239	W
Peak Efficiency	15,63	%
NOCT	45	°C
Temp. Coefficient of Power	-0.43	%/K

Appendix 2: Charging inverter technical sheet

Designation	**Value**	**Unit**
Nominal DC voltage	48	V
Nominal DC input current	103	A
DC Output current	90	A
Nominal AC voltage	230	V
Nominal power	4600	W
Nominal alternating current	20	A
Max alternating current	50	A

Appendix 3 : Average irradiance data (W/m²) for the periods studies

Days	MARCHS	APRIL	MAY
05 :00	0	0,10833	1,1290323
06 :00	18,29333	40,525	60,717742
07 :00	143,1767	183,883	207,81061
08 :00	348,1433	397,742	400,90054
09 :00	545,5967	590,761	587,74194
10 :00	721,2267	742,078	724,25269
11 :00	839,5833	839,056	813,0672
12 :00	864,67	844,144	798,23387
13 :00	813,3697	788,247	762,16667
14 :00	691,25	675,088	634,86559
15 :00	515,8333	492,997	486,82796
16 :00	304,17	289,449	308,76344
17 :00	112,46	108,869	112,74242
18 :00	6,91	7,41667	10,268817

Days	June	July	August
05 :00	1,130556	0,21774	0,047101
06 :00	49,65278	36,3011	30,33696
07 :00	176,2167	157,903	146,6638
08 :00	360,3933	316,935	286,2029
09 :00	519,9444	452,063	434,1862
10 :00	670,905	558,952	483,4384
11 :00	743,075	617,694	563,558
12 :00	790,2822	670,624	587,0659
13 :00	689,4556	689,917	562,9167
14 :00	601,2322	529,382	537,3478
15 :00	462,5906	424,688	378,2942
16 :00	290,4056	255,946	235,8254
17 :00	120,7917	113,941	100,9739
18 :00	14,35278	16,0511	12,08696

Appendix 4 : Average temperature data (°C) for periods studied

Days	MARCHS	APRIL	MAY
1er		36,5928571	37,6214286
2		37,3190476	37,9630952
3		37,8720238	38,1625
4		38,1315476	38,2446429
5		38,1654762	38,2791667
6		37,9755952	38,2285714
7	33,8464286	37,6333333	38,0309524
8	33,9410714	37,1970238	37,6529762
9	34,8946429	36,6261905	33,2859848
10	29,4285714	35,9869048	35,3178571
11	28,8047619	35,2386905	36,3613095
12	37,1279762	34,4553571	34,6488095
13	36,9684524	33,6755952	28,5309524
14	35,7494048	32,9940476	32,0071429
15	29,489881	32,5083333	33,8297619
16	30,1434524	32,3136905	28,4291667
17	35,4136905	32,4291667	32,0863095
18	34,7380952	32,7208333	35,089881
19	35,1208333	33,2125	34,9410714
20	34,7517857	33,8982143	35,2702381
21	34,9744048	34,6440476	35,8553571
22	34,3202381	35,4041667	30,102381
23	34,6738095	36,175	34,3809524
24	33,3452381	36,9125	35,4142857
25	36,3203463	37,6422619	31,8958333
26	34,8791667	38,2583333	32,1424784
27	36,2744048	38,7178571	34,9291667
28	36,7267857	39,0511905	36,4404762
29	37,8988095	39,1279762	35,3559524
30	31,2589286	38,9821429	36,1768939
31	30,0410714		34,5172619

Days	June	July	August
1er	35,514881	30,9940476	28,6880952
2	33,9833333	32,310119	26,8613095
3	33,6119048	24,3220238	28,422619
4	32,0464286	28,0791667	26,1785714
5	33,25	29,6041667	28,7255952
6	34,6375	31,222619	29,389881
7	33,389881	28,7922619	26,6178571
8	33,0684524	30,439881	26,664881
9	35,1714286	24,8672619	28,8827381
10	30,2267857	28,1636905	28,4345238
11	31,4428571	28,8071429	28,4464286
12	30,3714286	28,260119	26,4547619
13	33,1797619	29,9113095	27,4613095
14	33,6958333	30,7468615	27,977381
15	27,5809524	27,427381	27,689881
16	31,4011905	28,352381	26,1948718
17	29,8738095	28,0089286	26,1607143
18	33,2744048	28,314881	26,9886905
19	32,3488095	29,7154762	28,9416667
20	32,7470238	25,8083333	25,6702381
21	28,4017857	27,9803571	26,402381
22	30,3511905	26,9982143	28,8291667
23	32,8061688	25,8803571	24,7327381
24	26,1464286	27,6577381	23,6944444
25	28,5755952	29,0654762	
26	31,1654762	29,3267857	
27	32,785119	29,4428571	
28	30,614881	25,8845238	
29	32,2029762	25,7279762	
30	29,3422619	27,2505952	
31		28,2619048	

Appendix 5: Institute equipment for power assessment

Level	Designation	Quantity	Unit power (W)	Total power (W)	Operating time (h)	energy in Wh
lighting	led 120	74	22	1628	10	16280
	led 120	129	22	2838	12	34056
	led 120	1	22	22	24	528
	led 60	13	10	130	12	1560
	spot	11	20	220	12	2640
	grid lamps	52	54.5	2834	10	28340
	projector lamps	6	100	600	12	7200
office automation	pc	326	75	24450	10	244500
	benq projector	6	245	1470	10	14700
	epson projector	2	210	420	10	4200
	Hp printer	4	550	2200	8	17600
	Photocopier	1	1500	1500	8	12000
air conditioning	sharp air conditioning	1	892,857	892,857	10	8928.57
	Roch air conditioning	1	393,929	393,929	10	3939.29
	Union air conditioning	1	2150	2150	24	51600
	NASCO air conditioning	1	528,571	528,571	10	5285.71
ventilation	humidifier	3	170	510	10	5100
	binatone fan	3	70	210	8	1680
	panasonic brewers	27	75	2025	10	20250
	HASMAX fan	8	40	320	8	2560
household appliances	boreal refrigerator	2	80	160	24	3840
	hasmax refrigerator	1	95	95	24	2280
	Samsung TV	1	150	150	10	1500

	Samsung TV	1	320	320	10	3200
	tele Syinix	2	100	200	2	400
	philips water heater	1	2400	2400	2	4800
audio and video equipment	logitech speaker	1	500	500	10	5000
	cisco server	1	1500	1500	24	36000
	JBL Speaker	2	1000	2000	10	20000
	Audio Mixer	1	1700	1700	10	17000
	Remote Controller	4	500	2000	3	6000
	cisco equipment	2	820	1640	10	16400
other	Mercury regulator	1	50	50	24	1200
	moov router	10	12	120	24	2880
	binatone regulator	1	35	35	24	840
	counterfeit bill detector	1	22	22	3	66

Appendix 6: CO2 emissions by plant type

Source: IPCC, 2018	
Type of power plant	Emissions ($gCO2_e$/kWh)
Coal	820
Oil (fuel oil)	600
Natural gas	490
Photovoltaic	48
Hydraulic	24
Nuclear	12
Wind	11-12

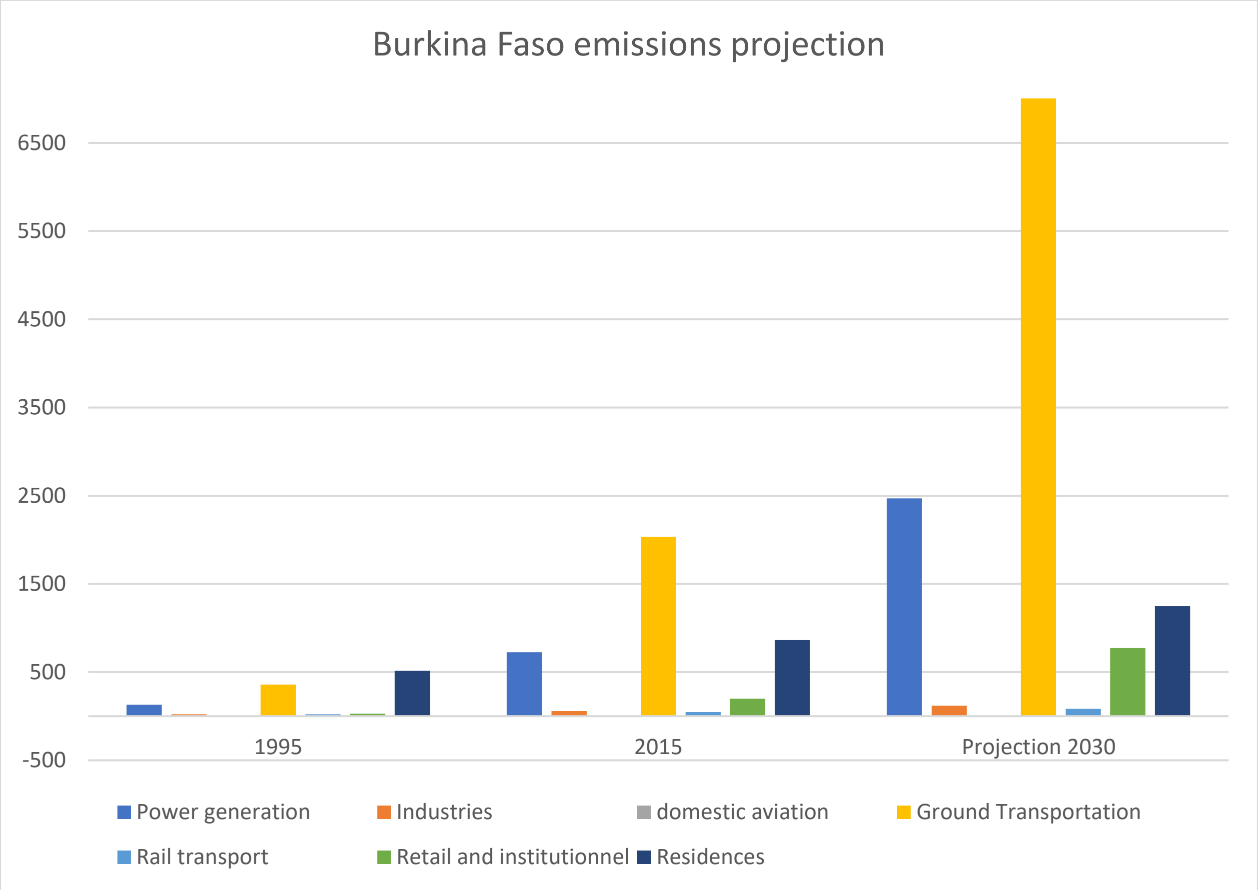
Appendix 7: Shares of energy sources in global electricity production (IEA scenario)

Source: IEA, 2023		
Energy sources	2022	2050
Coal	36%	0%
Natural gas	22%	0%
Oil (fuel oil)	2%	0%
Nuclear	9%	8%
Hydraulics	15%	11%
Wind	7%	31%
Photovoltaic	4%	41%

Appendix 8: Table 1 of Decision 17/CP.8 for the year 2017 Burkina Faso

Categories	**Net CO2**	**CH4**	**N2O**	**NOx**	**CO**	**NMVOCs**	**SO2**	**HFCs**
Total national emissions and removals	48 196	647	32	102	1,872	0	0	466
1 - Energy	3,896	39	1	0	0	0	0	0
2 - Industrial processes and use of products	87	0	0	0	0	0	0	466
3 - Agriculture, forestry and other land uses	44 212	530	31	102	1,872	0	0	0
4 - Waste	0	78	1	0	0	0	0	0
5 - Others (holds)	82	0	0	0	0	0	0	0

Appendix 9: Projection of Burkina Faso's emissions to 2030



Abstract

This thesis evaluates the energy efficiency of BIT's mini-PV power plant. Installed in 2018, the plant's mission is to meet the institute's energy needs. The study focuses on losses at various levels: solar panels, inverters, cabling, losses due to shading, temperature, irradiance and dirt. Simulations have been used to compare performance in hot and cold weather, highlighting the impact of weather conditions on efficiency. In hot weather, losses due to dust and shading are greater, while winter conditions result in a reduction in irradiance. Finally, recommendations were made for optimizing the system's performance, including adjusting the inclination of the panels. The environmental analysis of the plant demonstrates its positive impact in terms of reducing CO_2 emissions compared with fossil fuels, thereby helping to combat climate change.

Key words: Energy efficiency, Renewable energy sources, Energy losses, Optimization.

Résumé

Ce mémoire évalue l'efficacité énergétique de la mini centrale PV de BIT. Installée en 2018, cette centrale a pour mission de répondre aux besoins énergétiques de l'institut. L'étude se concentre sur les pertes à divers niveaux : panneaux solaires, onduleurs, câblage, pertes liées à l'ombrage, à la température, à l'irradiance, et à la saleté. Des simulations ont permis de comparer les performances en périodes chaudes et hivernales, mettant en évidence l'impact des conditions météorologiques sur l'efficacité. En période chaude, les pertes liées à la poussière et à l'ombrage sont plus importantes, tandis que les conditions hivernales montrent une diminution de l'irradiance. Des recommandations ont été formulées pour optimiser les performances du système, notamment l'ajustement de l'inclinaison des panneaux. L'analyse environnementale de la centrale démontre son impact positif en termes de réduction des émissions de CO_2 par rapport aux énergies fossiles, contribuant ainsi à la lutte contre le changement climatique.

Mots clés : Efficacité énergétique, Energies renouvelables, Pertes d'énergie, Optimisation.