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Assessment of Greenhouse Gas Emissions from the Kossodo Thermal Power Plant Using the Carbon Balance Method: Financial Year 2022

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Abstract

In light of the increasing recognition of the necessity to evaluate and mitigate the environmental impact of human activities, the aim of this study is to assess the greenhouse gases emitted in 2022 by the Kossodo thermal power plant as a consequence of its electricity production. The specific objective was to identify the emission sources and quantify the gases generated, with the purpose of proposing effective solutions for reducing the plant's ecological footprint. In order to achieve the objectives set out in the study, the Bilan Carbone® method was employed. Following an analysis of the plant's activities, seven emission items were identified as requiring further investigation. The data was gathered from the plant's activity reports, along with measurements and questionnaires distributed to employees. The data collected was subjected to processing in order to produce the sought activity data. The Bilan Carbone® V7.1 spreadsheet was employed to convert the activity data into equivalent quantities of CO_2. The full assessment indicates that the majority of the power plant's emissions come from the combustion of HFO and DDO, accounting for 96.11% of the Kossodo power plant's total GHG emissions in 2022. The plant produced 280,585,676 kilowatt-hours (kWh), resulting in emissions of 218,492.785 ± 10,924.639 tCO_2e, which yielded an emission factor of 0.78 $kgCO_2e/kWh$ for the year 2022. In order to reduce this rate, recommendations for improved energy efficiency have been issued to management and all staff.

Keywords

Energy, Bilan Carbone®, Thermal Power Plant, Emissions, Greenhouse Gases, Kossodo, SONABEL

1. Introduction

The reduction of greenhouse gases represents a significant global development challenge, given the detrimental impact of climate change [1]. Over the past decade, and particularly in 2013, the concentration of CO_2 in the atmosphere has exceeded the symbolic 400 parts per million (ppm) threshold, reaching an unprecedented level that has never previously exceeded 280 ppm [2]. As stated by the Intergovernmental Panel on Climate Change (IPCC), the observed increase in the concentration of greenhouse gases (GHGs) in the atmosphere since the industrial era is linked to human activities, including industry, transport, housing, and agriculture [3]-[5]. This increase in CO_2 levels in the atmosphere is contributing to global warming, with a projected rise in the average long-term global temperature of between 2˚C and 6˚C. The combustion of fossil fuels for transport, electricity generation in thermal power stations and in many other sectors of activity accounts for almost 80% of global greenhouse gas emissions [3] [6] [7]. While developed countries have been able to negotiate an energy transition that makes them less and less dependent on fossil fuels, developing countries are still heavily dependent on fossil fuels [3] [8]. The Center for Global Development (CGD, 2015) has estimated that in the year 2011, developing countries were responsible for approximately 63% of the world's total carbon dioxide (CO_2) emissions, in comparison to 37% generated by developed countries [9].

Burkina Faso is a landlocked country situated within the Sahel region. The country's energy context is defined by the predominant use of biomass energy sources, reliance on fossil fuels, limited and inequitable access to modern energy sources, and minimal utilization of endogenous renewable energy sources [10] [11]. Biomass represents the country's most widely utilised energy resource, with an estimated exploitable future volume of 2515 million m^3 [11]. It is employed primarily as a traditional fuel. It is estimated that approximately 90% of households rely on wood as their primary source of energy. For many years, Burkina Faso's energy policy has been based on the use of thermal energy, which is a source of pollution as the demand for energy continues to grow, given the discrepancy between the current output and the rising demand. This deficit is largely attributed to the expansion of economic activities and the rapid growth of the population [12] [13]. The country is unable to meet the increasing demand for energy consumption. Burkina Faso's electricity production is largely dependent on thermal energy, accounting for 88% of the total [10] [13] [14]. Despite the fact that the country's high potential for solar energy is considerable, with an average of 5.5 $kWh/m^2/d$ of sunshine reaching the area for between 3000 and 3500 hours a year, renewable energies account for only 12.2% of Burkina Faso's electricity production [10] [11] [13].

In order to satisfy the growing demand for electricity in urban areas, the government has established four thermal power plants, which are overseen by the Société Nationale d'Électricité du Burkina Faso (SONABEL), in addition to another privately managed facility. Then, the extensive usage of fossil fuels to meet urban energy challenges has led to increasing greenhouse gas (GHG) emissions that might adversely affect numerous sustainable development goals. The Kossodo plant is the largest of the aforementioned facilities, with an aggregate capacity of approximately 114 MW [13]. The overwhelming majority of GHG emissions can be attributed to energy consumption, accounting for 81% of the total. These power generation units use Heavy Fuel Oil (HFO) and Distillate Diesel Oil (DDO) as fuel [13]; engine oils for lubrication and heat transfer; chemical products such as Xylene, Sulphuric Acid, Nalco 2000, Z122LN, AB13, etc. for analysis of fuels, engine oils and cooling water as well as protection of cooling circuits. The consumption of these inputs generates liquid and gaseous substances, which have a detrimental impact on society due to their inherent quality and potential adverse effects on the environment and human health. However, there has been a dearth of official assessments of these emissions and a lack of comprehensive studies examining their impact.

In accordance with the United Nations Framework Convention on Climate Change (UNFCCC), each country is obliged to compile a national inventory of GHG emissions. This process has become a fundamental component of the global effort to combat climate change [15]. In light of the aforementioned context, the preparation of a greenhouse gas emissions balance sheet (GHG balance sheet) represents the initial step in attaining a more comprehensive understanding of the interrelated issues pertaining to energy and climate [16]. An increasing number of developing countries have now produced a national inventory of greenhouse gas emissions. Furthermore, in order to achieve the national targets for the reduction of GHG emissions, a number of countries have implemented measures which encourage or require organisations to reduce their emissions. The objective of these measures is to engage all relevant parties in the process of reducing their emissions and achieving the target set out in the Kyoto Protocol. Consequently, an increasing number of stakeholders, both public and private, and across all sectors of activity, are now obliged to conduct a GHG assessment. In order to achieve this objective, the primary objective of this study is to assess the greenhouse gases emitted in 2022 by the Kossodo thermal power station in its electricity production. This assessment will be carried out in order to meet a number of specific objectives, including: assessing the plant's carbon dependency, implementing an action plan to reduce its energy bill and reducing its carbon footprint. In order to assess emissions and achieve the study's objective, this study uses the Bilan Carbone® methodology.

2. Materials and Method

2.1. Study Site

Figure 1 is a map of the Kossodo thermal power station showing the plant components.

The Kossodo thermal power plant was constructed in 2000. The facility is situated within the Kossodo industrial zone, to the northeast of the city of Ouagadougou. The plant has eleven (11) generating units with a total installed capacity of approximately one hundred megawatts, which will be progressively installed and commissioned between 2000 and 2021. It consists of five (05) modules: the 1st module consists of one (01) 3.8 MW generator; the 2nd module consists of four (04) 6.25 MW generators; the 3rd module consists of two (02) 7 MW generators; the 4th module consists of one (01) 18 MW generator; the 5th module consists of three (03) 18 MW generators.

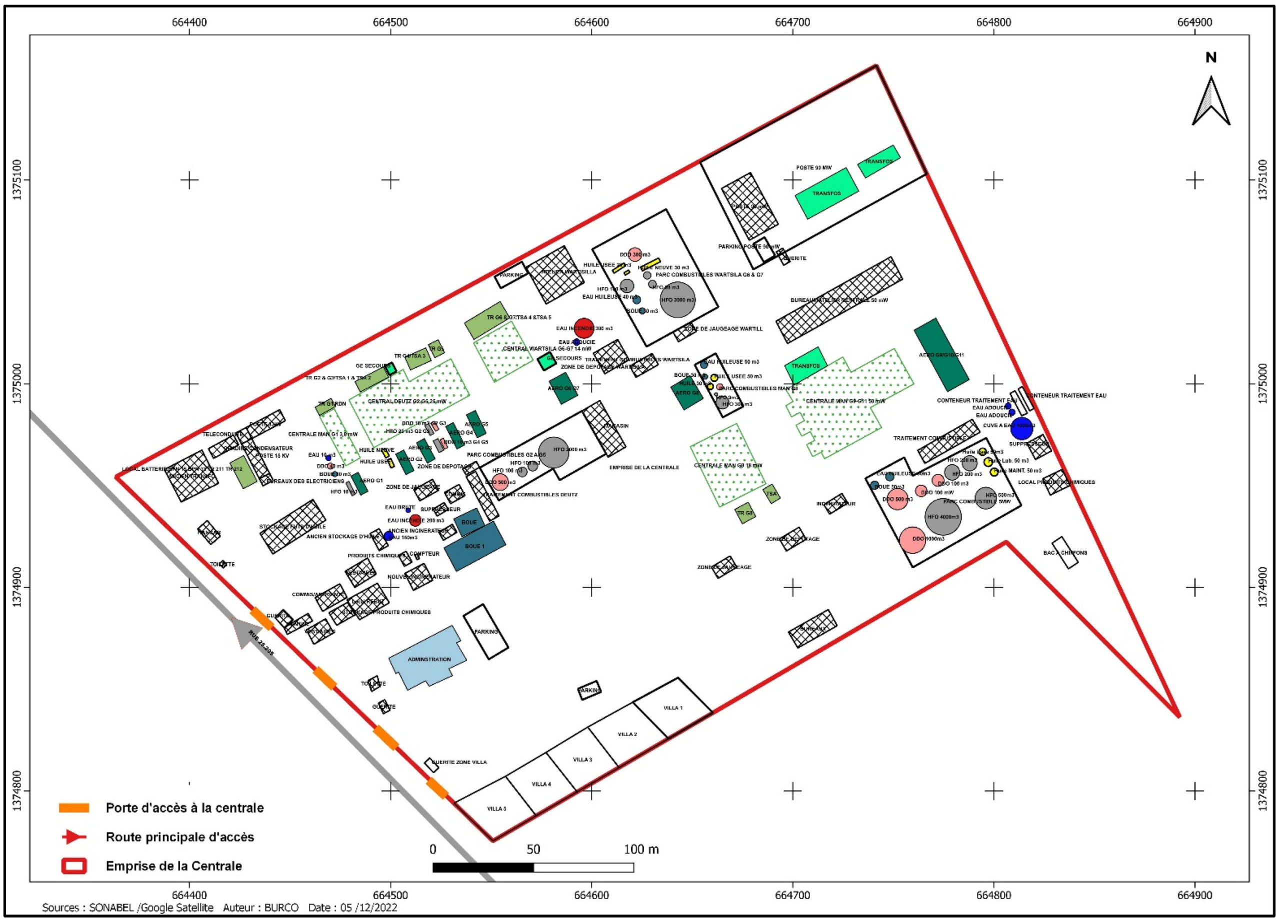

Figure 1. Location map of the Kossodo thermal power station.

2.2. Bilan Carbone® Method

Bilan Carbone® is the most widely recognised carbon accounting method used in France. It is employed to evaluate the GHG emissions generated by all the physical processes involved in an activity or organisation, and to ascertain its dependence on fossil fuels. This methodology considers three categories of emissions: - Direct GHG emissions (Scope 1): these are emissions that occur directly within the scope of the analysis. - Indirect emissions linked to energy (scope 2): these take place outside the company's boundaries and are linked to energy. Other GHG emissions (scope 3): these are other emissions associated with the company. This category is very broad and includes, for example, emissions associated with the company's suppliers, the transport of employees and customers, and the recycling and end-of-life of the company's products.

The principal greenhouse gases associated with the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are emitted from both energy and non-energy sources. Additionally, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are included, which have relatively high global warming potentials but are emitted in small volumes and are, for the most part, not energy-related. The greenhouse effect of the different gases is expressed as CO_2 equivalent, based on a similar global warming (GW) potential over a 100-year period. The approach is participatory and the process is structured into five stages, each of which is of equal importance. These are: the appointment of a pilot and the definition of the objectives of the assessment; the definition of the perimeter to be accounted for; the collection and processing of data; the action plan to reduce the assessment; and the summary of the process.

2.3. Method for Calculating Emissions

A greenhouse gas assessment is defined as an evaluation of the total mass of greenhouse gases emitted into the atmosphere over a one-year period, as a result of the activities conducted by an organization. The process entails the identification and quantification of greenhouse gas (GHG) emissions generated by the organization's activities and services. The calculation of total emissions, divided into distinct categories, is based on the application of an emission factor to activity data, as illustrated by the following formula.

$$\text{GHG balance} = \sum_{i=1}^{n} \text{Activity data}\left(A_i\right) \times \text{Emissions factors}\left(EF_i\right) \times \text{GWP}$$

where

GHG balance = refers to the quantity of gas emitted in tCO_2e;

***A_i*:** activity data for flow *i* expressed in physical units (e.g. liter of petrol, kWh of electricity, tonnes of steel, tonnes.km of road freight, surface area built, etc.);

***EF_i*:** emission factor applicable to flow *i*;

GWP: Global Warming Potential;

***n*:** number of flows taken into account in the balance.

Table 1 shows the GWP of some of the gases identified by the Kyoto Protocol.

Table 1. GWP of certain Kyoto gases.

Gas name	Chemical formula	GWP at 100 5th report IPCC
Carbon dioxide from fossil fuels	CO_2f	1
Methane of fossil origin	CH_4f	30
Methane of biogenic origin	CH_4b	28
Nitrogen Protoxide	N_2O	265
Sulphur hexafluoride	SF_6	23,500
Nitrogen fluoride sorting	NF_3	16,100

Source: ABC, 2013.

2.4. Emission Items Identified, Data Collection and Processing

To determine the parameters of accountability, a comprehensive examination was conducted of the various activities and operations undertaken within the facility, as well as external activities and actions that are directly associated with its operations. A meeting was held with the plant's managers to discuss energy and climate issues, as well as the main principles of the Bilan Carbone® methodology. The objective of this meeting was to gather information from the managers in order to define the scope of the assessment. Following discussions with the plant's initial managers, the approach adopted for the organizational perimeter was to consider all activities carried out within the plant, as well as any other activities carried out outside the plant but which have a direct link with the plant's activities. Following a comprehensive analysis of Kossodo plant's operational procedures, seven emissions points were identified. The aforementioned points are enumerated in **Table 2** below.

Table 2. Emission sources identified at Kossodo Thermal plant.

Emission sources	Products responsible for emission
Energy	Fuel (HFO, DDO)
Non-energy	Refrigeration system
Inputs	Chemical products, working clothes, lubricants, paper, spare parts, plastic
Travel	Domestic work, employees at work
Direct waste	paper, metal waste, waste water
Fixed assets	Buildings, machinery, furniture, IT equipment, vehicles
Utilization	Electricity consumed by auxiliaries

The data collection process involved the gathering of information pertaining to the activities undertaken within the specified organizational perimeter. This information was collated from a variety of sources, including direct observation, document analysis and interviews with key personnel. Then, the data was gathered from the central office's activity reports, along with measurements and questionnaires that were distributed to agents. The data collected was subjected to processing in order to produce the sought activity data. The Bilan Carbone® V7.1 spreadsheet was employed to translate the activity data into equivalent quantities of CO_2 in accordance with the specifications set forth. The activity data are presented in **Tables 3-8**.

2.4.1. Energy Data

The Kossodo plant uses two types of fuel to power its generators. These are DDO and HFO. According to data collected from the plant's office, the quantities of DDO and HFO consumed in 2022 are shown in **Table 3**.

Table 3. Energy data and specific emission factors.

Type of fuel	Monthly quantity (kg)	Annual consumption (kg)
HFO	4,227,557.5	50,730,690
DDO	582,127.25	6,985,527

2.4.2. Non-Energy Data

Direct emissions resulting from non-energy processes pertain primarily to the refrigeration and air conditioning systems within the plant. Such emissions are the result of leakage and loss within the air conditioning system. An inventory of the plant's air conditioning and refrigeration units was conducted, and their load capacities were documented. The 2020 version of the ADEME document on emission factors in the Base Carbone® provides values for the annual leakage rate of the various types of gas charged in air conditioners. The aforementioned values have been employed in this assessment to calculate the mean leakage amount as a function of air conditioner load capacities. Diverse types of gas present in the air conditioners, accompanied by their respective load capacities (in kg), have been recorded. These data were used to determine the average annual mass of leaks on the basis of the leak rate proposed by ADEME [17]. A summary of all these leaks is given in **Table 4**.

Table 4. Non-energy data.

Type	Quantity emitted annually (tonnes)
Non-Kyoto gases	0.214753
Kyoto halocarbons	0.01556525

2.4.3. Inputs Data

The input data consist of maintenance parts, lubricants, plastics, paper, chemicals, herbicides and Working clothes. The monetary ratio method was used to calculate the emissions from chemicals and Working clothes, and the mass method was used to calculate the emissions from herbicides. The mass method was also used to calculate emissions from paper, spare parts and plastics at the plant. For lubricants, the emissions were determined using the emission factor of the Bilan Product tool published by [18] in his Bilan Carbone® report for the DIR Massif Central. These data are shown in **Table 5**.

Table 5. Inputs data.

Type	Quantity emitted annually (tonnes, liters, Euros)
Spare parts	10.2 tonnes
Lubricant	268,871.11 liters
Plastic material	1.5 tonnes
Paper	0.075 t
Chemical products	108,516.90 euros
Insecticides	155 Kg
Working clothes	25,085.95 euros

2.4.4. Travel Data

The travel undertaken at the Kossodo thermal power plant has been categorized into two distinct groups. The first category encompasses the journeys made by employees between their place of residence and their place of work, which in this case is the aforementioned power plant. The second category comprises the journeys made in departmental vehicles in the course of their work.

Travel home-work

The act of travelling from one place of residence to another as part of one's daily routine is referred to as commuting.

The home-work sub-item represents a substantial source of emissions. In order to obtain data on activities related to this sub-item, a survey was conducted using an individual questionnaire distributed to the plant's employees. A total of 126 employees were surveyed. The questionnaire encompassed a range of variables, including fuel consumption for the home-work journey, the approximate distance between each employee's residence and their place of work (the plant), and the average cost of fuel per unit of time (in this case, per week). The distance between each agent's place of residence and the plant, as well as the number of working days in a typical week, were self-reported by the agents. The round-trip distance for each employee was related to the number of days worked per week and then to the number of days worked in the year, less thirty days of annual leave. However, the estimation of average home-work distances for the purpose of calculating emissions did not take into account certain parameters such as the age of the vehicle, which can influence consumption and therefore emissions. Table 6 illustrates the distances travelled by employees by various modes of transport in the year 2022.

Table 6. Distances travelled by employees by means of transport in 2022.

Type of vehicle	Number	Daily average distance (km)	Annual days of service	Total distance (km)	Liters of petrol consumed (L)
Motorbikes	92	2830.84	237	670,909.08	23,481.82
Car	15	441	237	104,517	9406.53

Work-related travel

The calculation of work-related travel was conducted using two vehicles utilized by staff for such purposes. This encompasses a range of journeys within the city, in addition to missions to other cities within the country. In order to account for the emissions linked to travel in this way, the variable quantity of fuel consumed was used as activity data. Thus, the monthly fuel allowance is CFA F 100,000 for the on-call vehicle and CFA F 150,000 or each service vehicle. It has been assumed here that this sum is used in full for the purchase of fuel. In order to contextualize this figure, it has been related to the current price of fuel in 2020. The annual fuel consumption for this category of travel is 8307.62 liters.

2.4.5. Direct Waste Data

This item includes greenhouse gas emissions related to the final treatment of ordinary or hazardous solid or liquid waste generated directly in the power plant. These wastes include wastewater, fuel sludge, rags and wood or metal leather, etc. The production and treatment of direct waste at the plant are monitored by the Mechanical Department, which is also the plant's technical structure for environmental matters. Table 7 listed quantities of direct waste and their specific emission factors.

Table 7. Direct waste data.

Type	Quantity emitted annually (tonnes)
Wastewater	28,086 DBO5 of 298.6 mg/l
Wooden rags and leather	80.722
Plastic	1.3
Paper	2.006
Cardboard	4.206

2.4.6. Fixed Assets Data

This item includes investments in assets that are subject to depreciation and the production of which generates greenhouse gas emissions in the same way as any other material production. Plant and buildings include vehicles, machinery (gensets), office furniture, IT equipment, car parks and buildings. The m^2 method was used to estimate the emissions from the buildings at Kossodo Power Plant. Emissions from the plant's vehicles, machinery and office furniture were calculated using the mass method. Table 8 presents data for fixed assets and specific factors.

Table 8. Fixed assets data.

Type of fixed asset	Weight (tonnes)/Numbers
Industrial metal buildings	3652.32 m^2
Housing	600 m^2
Offices, shops and gatehouse	1473.75 m^2
Industrial concrete fencing	2220 m^2
Parking	3
Generator sets	231.82 tonnes × 11
Vehicles	2.01 tonnes × 3
Office furnishings	9.030 t
Information technology equipment	
Office computer	36
Laptop computer	16
Printers	10
Photocopiers	1

2.4.7. Utilization Data

The Kossodo Thermal Power Plant is an electrical energy production unit that also relies on electrical energy to power its auxiliary equipment. To do so, it consumes a considerable amount of energy. In 2022, the plant will consume a total of 7,540,433 KWh. The Bilan Carbone® table does not include an emission factor for electricity consumption. The specific emission factor associated with electricity production is 0.88 kg CO_2/KWh and a GWP of 1.08.

2.5. Uncertainty Calculation

The Bilan Carbone® methodological guide assigns uncertainties to the activity data collected. These uncertainties vary according to the method of data collection. For each item of activity data, the guide assigns an uncertainty ranging from. 0% to 5% for data derived from direct measurement (invoices or meters); 15% for reliable data not measured, 30% for calculated data (extrapolation), 50% for approximate data (statistical data); 80% for data known to an order of magnitude [19]. In order to carry out this assessment, the uncertainties have been assigned, taking into account the grid established by the Guidance Document.

3. Results

This section presents the results of the study and discusses them in light of the results of other studies. It also proposes the reduction measures needed to make the plant more economical and, above all, more environmentally friendly. The results were obtained using the Bilan Carbone® spreadsheet and the activity data collected. The results are presented here in detail for each emission item. These results are then presented globally by emission item.

3.1. Fuel-Related Emissions

To calculate emissions from the combustion of DDO and HFO, DDO was assimilated into diesel of European origin and HFO into European heavy oil. The uncertainties for these fuels are the same as for diesel and heavy fuel oil (5%). The emissions associated with the combustion of DDO and HFO in the power plant in the year 2022 amount to 209,987,955 ± 10,499,398 tCO_2e.

3.2. Non-Energy Emissions from Internal Processes (Excluding Energy)

The data collected and the leakage estimate based on the annual leakage rate show that the plant's air conditioning system will generate 230 kg of gas from air conditioning in 2022. With a 30% uncertainty, the emissions associated with gas leakage are 5881 ± 1764 tCO_2e for non-Kyoto gases and 388,703 ± 116,611 tCO_2e for Kyoto halocarbons.

3.3. Emissions Related to Inputs

Raw materials or finished products are physically delivered to the power plant, excluding fuel whose emissions are accounted for elsewhere. At Kossodo Thermal Power Plant, inputs are mainly products such as spare parts, lubricants, plastics, paper, chemicals and staff uniforms. Table 9 summarizes emissions related to different input items.

Table 9. Emissions corresponding to inputs.

Type	Equivalent CO_2 emissions (tCO_2e)
Spare parts	32.538 ± 16.269
lubricant	258.92 ± 38.838
Plastic material	3.575 ± 1.788
paper	0.099 ± 0.0297
Chemical products	39.826 ± 11.948
Insecticides	1.4 ± 0.42
Working clothes	9.207 ± 2.762

Emissions from inputs are dominated by very high emissions from lubricants and very low emissions from paper and herbicides.

3.4. Emissions from Travel

Travel at head office level includes travel between home and work (head office) and work-related travel in company cars. Employees using motorcycles as a means of transport travelled a total of 670,909.08 km in 2022 and used 23,481.82 liter of Super 91, based on an estimated consumption of 3.5 liter/100 km. Employees driving their own cars travelled a total of 104,517 km and consumed 9406.53 liter of diesel, based on an estimated consumption of 9 liter/100 km. Fuel expenditure for the three vehicles was CFAF 3,908,555 per year, corresponding to the consumption of 8307.62 liter of diesel. Table 10 presents the annual emission from travel in Kossodo thermal plant for the year 2022.

Table 10. Emission from travel.

	Number of kilometer travelled/ price of fuel	Equivalent consumption	emissions associated
From home to work	670,909.08[a]	23,481.82	98.9 ± 49.45 tCO_2e
	104,517[b]	9406.53	
Business travel	CFA F 3,908,555[c]	8307.62	24,369± 12,185 tCO_2e

a: motorbikes travel, b: cars travel, c: 1 CFA F= 0.0015 Euro.

3.5. Direct Waste Emissions

Wastewater related emissions were estimated to be 2943 ± 1472 tCO_2e using the Bilan Carbone® spreadsheet. The uncertainty is 50%, as this is an estimate.

The emissions related to the treatment of hazardous and non-hazardous waste are 3781 ± 1891 tCO_2e and 57,354 ± 28,677 tCO_2e respectively, with an uncertainty of 50%. Table 11 summarizes emissions related to Direct waste.

Table 11. Emissions CO_2 equivalent of direct waste.

Type	Equivalent CO_2 emissions (tCO_2e)
Waste water	2.943 ± 1.472
Wooden rags and leather	57.354 ± 28.677
Plastic	
Paper	3.781 ± 1.891
Cardboard	

3.6. Emissions from Fixed Assets

As mentioned above, this item includes investments in depreciable assets, the production of which generates GHG emissions in the same way as any other material production. Fixed assets include vehicles, machinery (generators), office furniture, IT equipment, car parks and buildings. The results obtained in terms of emissions for each component are summarized in Table 12.

Table 12. Emissions from fixed assets by asset type.

Type of fixed asset	Equivalent CO_2 emissions (tCO_2e)
Industrial metal buildings	
Housing	121.506 ± 60.753
Offices, shops and gatehouse	
Industrial concrete fencing	
Parking	0.749 ± 0.373
Generator sets	271.118 ± 135.559
Vehicles	
Office furnishings	3.31 ± 1.655
Information technology equipment	
Office computer	
Laptop computer	14.223 ± 7.112
Printers	
Photocopiers	

3.7. Emissions Related to Internal Energy Consumption

This consumption is responsible for the emission of 7166.428 ± 358.321 tCO_2e. The specific emission factor associated with electricity production is 0.88 kg CO_2/KWh and a GWP of 1.08. The uncertainty is estimated to be 5%.

Overall summary of assessment results

This section presents the overall results of the assessment of GHG emissions from the Kossodo Thermal Power Plant for the accounting year 2022. Table 13 below shows the overall situation of the greenhouse gas emissions of the KOSSODO thermal power plant in 2022 by emission item.

Table 13. Summary of emissions by item.

Emission item	Mass of GHGs in tCO_2e
Energy	209,987.955
Non-energy	394.584
Inputs	345.565
Travel	123.269
Direct waste	64.078
Fixed assets	410.906
Utilization	7166.428
Total emissions	218,492.785

Accordingly, following the calculation of emissions associated with the operation of the Kossodo Thermal Power Plant within the specified perimeter, it can be ascertained that the total emissions attributable to the plant's operation are 218,492,785 ± 10,924,639 tCO_2e. The total uncertainty associated with these emissions is ±5%. The energy item is the primary source of greenhouse gas emissions within the plant, accounting for 96.11% of the total emissions with a value of 209,987.955 tCO_2e. Subsequently, consumption accounts for a mere 3.28% of total emissions. The final category in terms of emissions was waste, with a total of 64,078 tCO_2e. In the absence of specific emission factors for electricity and lubricants, the remaining emission factors were derived from the Bilan Carbone® spreadsheet.

3.8. Discussion

The comprehensive evaluation indicates that the majority of emissions from the power plant originate from the energy sector, primarily through the combustion of HFO and DDO. This represents the largest single source of emissions, with a total of 209,987,955 ± 10,499,398 tCO_2e generated, accounting for 96.11% of Kossodo plant's total GHG emissions in 2022.

As demonstrated in **Table 14** below, a comprehensive overview is given of fuel consumption, installed capacity, and energy production over the preceding five-year time period [20]. It is evident that a significant proportion of SONABEL's installed capacity is thermal, accounting for over 84% of the total. Furthermore, it is noteworthy that more than 87% of the energy produced by SONABEL is of thermal origin. The analysis indicates a substantial consumption of HFO and DDO over the past five years, accompanied by a decline in the quantities of fuel and lubricants, and a decrease in production by thermal power stations. The decline in production by thermal power stations can be attributed to two factors: the increase in production by photovoltaic solar power stations and the rise in imports facilitated by the commissioning of the interconnection line with Ghana (Bolgatanga-Ouagadougou). This phenomenon effectively elucidates the significant contribution of emissions attributable to fossil fuel consumption. The significant contribution of lubricants to emissions is attributable to the escalation in oil usage, which can be ascribed to the augmentation in production capacity at specific thermal power stations (Gaoua, Dédougou, Ouaga I and Ouaga II). These stations are distinguished by their comparatively high oil and fuel consumption (2018).

Table 14. SONABEL's fuel consumption, installed capacity and energy production over the last five years [20]-[22].

	2018	2019	2020	2021	2022
SONABEL	**Consumption of fuels and oil (t)**				
Total HFO	163,631	108,515	70,734	126,806	101,087
Total DDO	23,173	17,546	15,809	19,801	17,848
Specific consumption (g/kwh)	213.45	214.35	215.02	213.60	210.28
Total oil	**827**	**604**	**415**	**632**	**540**
Specific consumption (g/kwh)	0.95	1.03	1.03	0.92	0.96
SONABEL	**Power installed (MW)**				
Thermal	288	291	300	350	350
Hydroelectric	32	32	32	32	32
Solar	34	34	34	34	34
Total	**354**	**357**	**366**	**416**	**416**
SONABEL	**Energy generated at national level (MWh)**				
Thermal	1,020,713	588,100	402,487	686,356	565,620
Hydroelectric	91,447	105,317	112,393	127,496	82,386
Solar	54,092	58,840	57,152	58,274	57,444
Total	**1,166,252**	**752,257**	**572,032**	**872,126**	**705,450**

Although the largest emitter in this study is energy derived from the combustion of fossil fuels, this is not the sole source of greenhouse gas (GHG) emissions. In other contexts, however, this may not be the case. Indeed, a study conducted by [20] on oil production units demonstrated that the primary source of GHG emissions in these units is the input. In the year 2022, the active energy production recorded by the operation of the Kossodo thermal power plant was 280,585,676 kilowatt hours (kWh). It can be thus concluded that the aforementioned production is responsible for the emission of 218,492.785 tCO_2e, or 218,492,785 $kgCO_2e$. This is equivalent to a specific emission factor of 0.78 kilograms of CO_2 emitted per kilowatt-hour produced (0.78 $kgCO_2$/KWh) at this power station. This specific emission factor is lower than the national specific emission factor of 0.88 $kgCO_2$/KWh found in 2010 by another study. Recently, Nana Bernard *et al.* studied an assessment of CO_2 emission factors from power generation for 2018 in

Burkina Faso and an assessment of the contribution of renewable energy to the reduction of CO_2 emissions. The estimation of emission factors for combustion was based on an analysis of fuels which are characterized in terms of molecular composition, density and water content. The findings showed that for CO_2, the emission factor is 76,903 kg/TJ for the combustion of Heavy Fuel Oil (HFO) and 73,525 kg/TJ for that of Distillate Diesel Oil (DDO) [23]. Finally, they found an emission factor for CO_2 of 0.663 kg/kWh for thermal power generation and 0.569 kg/kWh for electricity generation mix [23]. The findings of this study demonstrate a good agreement in results when compared to those previously reported by Sanogo *et al.* [24]. Sanogo *et al.* conducted an evaluation of the emission factor (EF) of the electricity network in Burkina Faso. The factor was evaluated using production data from the Société Nationale Burkinabé d'Électricité (SONABEL) and the tool entitled "Tools to Calculate the Emission Factor for an Electricity System, Version 07". They found that the mean emission factor (EF) of the Burkinabe electricity network is 0.606 tCO_2/MWh, which equates to 0.606 kg/kWh [24]. This elevated value was attributed to the considerable proportion of thermal generation and the advanced age of the thermal power stations within the electricity network. Furthermore, it was highlighted that SONABEL's emission factor is among the highest observed in the sub-region [24]. A comparison of the emission factor for the Kossodo power plant in this study with other emission factors obtained from other studies reveals that, although not all these studies evaluate the same emission factor and use different methods, the emission factor is broadly acceptable. It should be noted, however, that the advantage of this study is that it uses activity data and an internationally recognized reliable method.

On initial examination, it appears that the specific emission factor associated with the generation of electricity at the Kossodo thermal power plant is more environmentally friendly than that of the national level. It is important to note, however, that the application of various restrictions (exclusion of certain activities from the balance sheet) during the calculation process contributed to an improvement in this emission factor.

4. Emission Reduction Plan for Kossodo Thermal Power Plant

The following recommendations are made in the context of CO_2 emissions linked to the activity of the Kossodo power plant in the context of energy production. Burkina Faso has formally accepted the terms set forth in the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement, and has expressed its intention to pursue the objectives set out in these international instruments. Subsequently, Burkina Faso has developed and adopted a number of policy and strategy documents pertaining to climate change, in response to certain provisions set forth in the aforementioned protocols. From 2001 to 2020, Burkina Faso produced three national communications (NCs), three greenhouse gas inventories (GHGs), and a biennial update report

(BUR) in 2001, 2008/2014, and 2019, respectively [25]-[27]. The pursuit of these objectives is already contributing to a reduction in the level of greenhouse gas emissions at the national level. Nevertheless, as part of this study, it is also necessary to put forward proposals for the reduction of greenhouse gas emissions.

The value of this assessment lies in its capacity to transcend the mere quantification of gases, offering realistic recommendations that can effectively address emission trends in the short, medium, and long term. Furthermore, the Bilan Carbone® is an integral component of an environmental management strategy. The assessment of greenhouse gases (GHGs) at the Kossodo thermal power plant has enabled us to determine that, overall, the plant contributed to an increase in the quantity of GHGs in the atmosphere of 218,492.785 ± 10,924.639 tCO_2e in 2022. The aforementioned quantity, derived from the seven emission items included in this assessment, can be reduced through the implementation of recommended actions. Proposals for specific, itemized actions, and occasionally for sub-items, have been put forth and are likely to result in a reduction of greenhouse gas emissions.

4.1. Recommendation for the Energy Item

The Kossodo power station represents a component of Burkina Faso's comprehensive energy sector. Despite not being a significant emitter of greenhouse gases, Burkina Faso is proactively implementing adaptation and mitigation strategies in alignment with the requirements set forth by the United Nations Framework Convention on Climate Change (UNFCCC). As a consequence of the planned measures in the energy sector, Burkina Faso will be able to reduce its GHG emissions from the energy sector by 84% by 2030 [28]. Furthermore, the production of renewable energy, to which Burkina Faso is already committed, will prevent the emission of 3000 Gg Eq-CO_2 of greenhouse gases, which represents 30% of the emissions in the reference scenario [28]. A study was conducted by Rice Verouska Nono Seutche *et al.* on the assessment of CO_2 emission reduction in the context of renewable energy and energy efficiency projects in Burkina Faso [29]. The findings indicated that 68,709.424 MWh and 9430.446 MWh were conserved and displaced by EE and RE initiatives, respectively, on an annual basis. This equates to a reduction of 48,157.668 tCO_2e in emissions, representing a 63.12% decline in emissions compared to the baseline scenario [29].

In the specific case of the Kossodo power plant, the actions that can be proposed to reduce emissions de GHS are twofold:

In order to reduce emissions linked to fuel combustion, it is essential to implement the following measures:

It is necessary to reinforce the regreening of the power plant site with the ultimate goal of increasing the power plant site's sequestering power. It has been demonstrated that, on average, a single tree is capable of sequestering 30 kg of CO_2e per annum. In order to reduce the amount of fuel consumed, it is necessary to improve boiler efficiency. Furthermore, the operating time of the plant can be reduced by creating solar power plants. Regular servicing and maintenance of the units will also help to reduce emissions. Finally, monitoring fuel quality will assist in reducing the amount of fuel sludge as it passes through the separators.

In order to address the 3.28% of emissions that can be attributed to the consumption of the plant's auxiliaries, it is imperative to implement an energy efficiency policy. This should begin with an energy audit, which will identify the stations that are consuming the most energy.

It is recommended that workspaces be optimized in relation to the number of employees, with a view to reducing the need for lighting and air conditioning. This improvement in space management helps to reduce energy consumption.

- The use of IT equipment should be rationalized and should be switched off when not in use.

- The number and power of air conditioning units installed in the headquarters should be rationalized and should be switched off when offices are not occupied

- Incandescent bulbs should be replaced with energy-efficient LED lights.

- All-in-one printers and photocopiers with network management should be used instead of multiple standalone devices.

- Staff should be regularly informed of energy and global warming issues and regularly reminded of simple ways to save energy.

4.2. Recommendation for Non-Energy Items

This sector is not significant in the assessment as it accounts for 0.18% of total estimated emissions in 2022. However, there are a number of possible measures that could further reduce emissions in this area. These are as follows:

- Rationalizing the number and power of refrigeration units installed;
- Regular maintenance of refrigeration equipment;
- Carrying out leak checks when installing equipment;
- Systematically removing all refrigerant when refrigeration equipment is decommissioned;
- When purchasing equipment, give preference to refrigerants with a low global warming potential such as R134A, R410 and R600a; Replace R22 with R134A.

4.3. Recommendation for Inputs Item

The inputs used to operate the Kossodo power plant account for 0.16% of the estimated emissions in 2022. This amount of GHG could be reduced if certain actions were taken in the procurement and use of these inputs.

For example, we could reduce the use of paper in the operation of the plant:

- Prefer double-sided printing for the various documents (monthly reports, statement sheets, the various indexes in the operations, laboratory and depot departments);
- Limit printing to the strict minimum by systematically adding a message at the bottom of each e-mail, such as "Do not print this message unless necessary";
- Set up and display an indicator to monitor paper consumption at departmental level, for example, the number of reams used per week;
- Encourage mobile collection for daily paperwork.

In order to reduce emissions associated with the purchase of spare parts, it is important to include environmental clauses in public procurement contracts, giving priority to the choice of environmentally friendly products or products whose production respects ecological conditions. To this end, the concept of carbon footprint could be included in future contracts.

4.4. Recommendation for Travel Item

Emissions related to business travel will amount to 123,269 ± 61,635 tCO_2e, *i.e.*, 0.05% of the estimated emissions in 2022. This amount of emissions can be reduced by adopting the following behaviours:

- Awareness-raising and training of employees on economical driving practices;
- Replacing certain car journeys with soft modes (walking, cycling).
- Developing teleworking and videoconferencing for administrative tasks that do not necessarily require physical presence;
- Investigate the feasibility of a dedicated transport shuttle for staff living within a sufficiently close proximity to the site;
- Encourage the use of public transport (bus) for daily travel;
- Encourage the use of soft modes of transport (bicycles, walking) for employees living near the plant.

4.5. Recommendation for Direct Waste

The production and management of waste at Kossodo Thermal Power Plant accounts for 0.03% of the total emissions estimated for 2022. In fact, direct waste is the item with the lowest GHG emissions. However, it is possible to reduce these emissions slightly in the future by taking the following measures

- Limit the use of single-use products;
- Reducing waste at source to reduce the amount emitted;
- Moving towards plastic recycling.

4.6. Recommendation for Fixed Assets

With regard to fixed assets, which account for 19% of total estimated emissions in 2022, the following recommendations would make it possible to significantly reduce the amount of emissions:

- Encourage the purchase of eco-designed equipment;
- Encouraging the purchase of greener vehicles and buildings (via certified factories that have taken measures to reduce their environmental impact) and to reduce their environmental impact);
- Integrate the carbon criterion in the future construction of buildings on the site and in the choice of materials.

5. Conclusion

This study is an assessment of the greenhouse gas emissions generated by the Kossodo thermal power plant in 2022. The Bilan Carbone® method was used to assess the emissions of the seven items listed. The Bilan Carbone® spreadsheet is a tool that meets the need to estimate the greenhouse gas emissions generated by the operation of the Kossodo Thermal Power Plant. The data relating to the quantity of fuel and lubricants used in the plant have been capitalized by the department through its activity report. The same applies to data on waste and chemicals. With regard to travel data, the data on staff travel was obtained by interviewing staff and estimating distances. The Bilan Carbone® V7.1 spreadsheet was used to convert the activity data into CO_2 equivalents. The results demonstrate that the power plant generated 280,585,676 kilowatt hours (kWh) and emitted 218,492,785 ± 10,924,639 tCO_2e, resulting in an emission factor of 0.78 ± 0.01 $kgCO_2e/kWh$ for the year 2022. The combustion of DDO and HFO at the power plant in 2022 resulted in emissions of 209,987.955 ± 10,499.398 tCO_2e, representing 96.11% of the total emissions.

Upon completion of the assessment, a series of reduction proposals were put forth, encompassing the seven (7) items that were the subject of the assessment. It is thus possible to posit that the implementation of the aforementioned actions will result in a reversal of the current trend in GHG emissions at this plant. It can thus be concluded that there are measures that can be taken to reduce the quantity of greenhouse gases emitted by the Kossodo thermal power plant.

The absence of data in specific sectors has resulted in an underestimation of emissions in certain areas. Implementing the procedures required to refine the data is necessary in order to conduct a more exhaustive assessment at a later date. In order to conduct a more comprehensive assessment of greenhouse gases in the future, it is essential that the plant enhances its system for generating and storing data, builds the capacity of the personnel responsible for maintaining environmental quality within the plant, organizes a training session on the Bilan Carbone® method for the plant's personnel, builds the capacity of the personnel on issues related to climate change, and improves the quality of the data.

Conflicts of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

References

[1] Neya, T., Abunyewa, A.A., Neya, O., Zoungrana, B.J., Dimobe, K., Tiendrebeogo, H., *et al.* (2020) Carbon Sequestration Potential and Marketable Carbon Value of Smallholder Agroforestry Parklands across Climatic Zones of Burkina Faso: Current Status and Way Forward for REDD+ Implementation. *Environmental Management*, **65**, 203-211. https://doi.org/10.1007/s00267-019-01248-6

[2] Gills, B. and Morgan, J. (2019) Global Climate Emergency: After COP24, Climate Science, Urgency, and the Threat to Humanity. *Globalizations*, **17**, 885-902. https://doi.org/10.1080/14747731.2019.1669915

[3] Atedhor, G.O. (2023) Greenhouse Gases Emissions and Their Reduction Strategies:

Perspectives of Africa's Largest Economy. *Scientific African*, **20**, e01705. https://doi.org/10.1016/j.sciaf.2023.e01705

[4] Filonchyk, M., Peterson, M.P., Zhang, L., Hurynovich, V. and He, Y. (2024) Greenhouse Gases Emissions and Global Climate Change: Examining the Influence of CO_2, CH_4, and N_2O. *Science of the Total Environment*, **935**, Article ID: 173359. https://doi.org/10.1016/j.scitotenv.2024.173359

[5] Calvin, K., *et al.* (2023) IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC.

[6] Perera, F. (2017) Pollution from Fossil-Fuel Combustion Is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. *International Journal of Environmental Research and Public Health*, **15**, Article 16. https://doi.org/10.3390/ijerph15010016

[7] Lindstad, E., Ask, T.Ø., Cariou, P., Eskeland, G.S. and Rialland, A. (2023) Wise Use of Renewable Energy in Transport. *Transportation Research Part D: Transport and Environment*, **119**, Article ID: 103713. https://doi.org/10.1016/j.trd.2023.103713

[8] Mutezo, G. and Mulopo, J. (2021) A Review of Africa's Transition from Fossil Fuels to Renewable Energy Using Circular Economy Principles. *Renewable and Sustainable Energy Reviews*, **137**, Article ID: 110609. https://doi.org/10.1016/j.rser.2020.110609

[9] Hasan, M.A., Abubakar, I.R., Rahman, S.M., Aina, Y.A., Islam Chowdhury, M.M. and Khondaker, A.N. (2020) The Synergy between Climate Change Policies and National Development Goals: Implications for Sustainability. *Journal of Cleaner Production*, **249**, Article ID: 119369. https://doi.org/10.1016/j.jclepro.2019.119369

[10] Ministère de l'energie (2018) Tableau de bord 2017 du Ministère de l'Energie.

[11] Ministère de l'Energie (2015) Plan d'Action National des Energies Renouvelables (PANER) du Burkina Faso.

[12] Ouédraogo, I.M. (2010) Electricity Consumption and Economic Growth in Burkina Faso: A Cointegration Analysis. *Energy Economics*, **32**, 524-531. https://doi.org/10.1016/j.eneco.2009.08.011

[13] Ministère de l'Energie (2018) Stratégie dans le domaine de l'Energie 2019-2023.

[14] ProGreen Burkina-Faso (2021) Evaluation des Energies Renouvelables.

[15] Stephenson, M. (2018) Energy and Climate Change. Elsevier.

[16] European Commission (2023) Climate Action: Progress Report 2023.

[17] ADEME (2020) Documentation des facteurs d'émissions de la Base Carbone ®Version 19.0.0.

[18] Rotger, J.C. (2010) Bilan Carbone. DIR Massif Central, 86.

[19] Association Bilan Carbone (2017) Guide méthodologique—Version 8.

[20] SONABEL (2022) Rapport d'activités 2022 de la SONABEL.

[21] SONABEL (2020) Rapport d'activités 2020 de la SONABEL.

[22] SONABEL (2018) Rapport d'activités 2018 de la SONABEL.

[23] Nana, B., Zallé, H., Ouarma, I., Daho, T., Yonli, A. and Béré, A. (2023) Assessment of Carbon Dioxide Emission Factors from Power Generation in Burkina Faso. *Clean Air Journal*, **33**. https://doi.org/10.17159/caj/2023/33/2.15701

[24] Oumar, S., Haro, K., Charles Maturin, C.R., Pélagie, K.R. and Kalifa, P. (2022) Évolution du Facteur d'émission électrique des réseaux électriques des pays de l'Afrique

Subsaharienne: Cas du Burkina Faso. *Revue semestrielle de la recherchedu Centre National de la Recherche Scientifique et Technologique* (*CNRST*), **6**.

[25] Global Green Growth Institute (2021) Manuel MRV IGES du Burkina Faso.

[26] GGGI (2020) Elaboration d'un Système de Mesurage, de Rapportage et de Vérification (MRV) au Burkina Faso.

[27] Burkina Faso (2021) Premier Rapport Biennal Actualisé (PRBA) du Burkina Faso.

[28] Burkina Faso (2022) Troisième communication nationale sous la convention-cadre Des nations unies sur les changements climatiques (CCNUCC).

[29] Seutche, R.V.N., Sawadogo, M. and Ngassam, F.N. (2021) Valuation of CO_2 Emissions Reduction from Renewable Energy and Energy Efficiency Projects in Africa: A Case Study of Burkina Faso. *International Journal of Renewable Energy Development*, **10**, 713-729. https://doi.org/10.14710/ijred.2021.34566