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# Quantifying Greenhouse Gas Mitigation Levers In Niger's Gorou-Banda Power Plant

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## ABSTRACT

This study presents the first comprehensive carbon assessment in the Gorou Banda thermal power plant in Niger. The study applies the ADEME carbon accounting method to scopes 1, 2, and 3 as defined by the reference standard for emissions, ISO 14064. The results show an average emission factor of 0.75 kgCO2/kWh due to the combustion of diesel and heavy fuel oil at around 80%. The proposed mitigation scenario, which includes the installation of 30 MW of solar PV, a battery storage system, turbine modernization, regular preventive maintenance, and intelligent load management, would enable a reduction in emissions of 17% and 45%, respectively, in the first and second years of its implementation, compared to the reference scenario, where emissions would continue to grow at an average rate of 7% each year. The results obtained made it possible to develop practical guides for emission reduction and to define a trajectory enabling the power plant to achieve low-carbon goals. The conclusions highlight the need for social, institutional, and financial support in order to accelerate the transition to a lower-carbon electricity mix in Niger and other developing African countries.



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## 1. Introduction

Greenhouse gas (GHG) emissions, whether of natural or anthropogenic origin, have a significant impact on climate change (Dandois-Fafard, 2023). In Africa, where industrialization is rapidly growing, emissions related to human activities, particularly in the energy sector, account for an increasingly larger share of total GHG emissions (Mostefaoui et al., 2024). Niger, facing a heavy reliance on fossil fuels and supply deficits, illustrates this dilemma. The Gorou-Banda thermal power plant, the main hub of national production, contributes significantly to $CO_2$ emissions due to its massive consumption of heavy fuel oil and diesel. At the same time, Niger, like other African countries, faces major energy challenges, particularly recurring power outages caused by production and distribution problems. These issues are exacerbated by growing energy demand linked to industrialization and urbanization.

The overall challenge is therefore to reconcile the issues of economic and social development, which require increased access to energy, with the need to reduce GHG emissions to limit the impacts of climate change (Yang et al., 2025; Yang, Shafiq, Sharif, et al., 2024). How then can the Gorou Banda thermal power plant optimize its production while reducing its carbon footprint, in order to contribute to the energy transition in Niger and improve access to energy sustainably? One of the possible solutions is examined in this study, based on the objectives of COP 28, which aim to accelerate the energy transition by optimizing production while drastically reducing GHG emissions, in order to contribute to Niger's energy security and the achievement of the Sustainable Development Goals (Wang et al., 2025; Wood, 2023). This wording highlights the need to align the actions of the Gorou Banda power plant with global objectives and to emphasize the importance of a just and fair transition that can be based on innovation and technological solutions incorporating social and economic dimensions and the involvement of local stakeholders. This study aims to establish an assessment of GHG emissions resulting from the operation of the Gorou-Banda thermal power plant and to quantify the main mitigation levers to reduce these emissions. The implementation of these measures would strengthen the energy resilience of the power station while aligning its operations with sustainable development requirements. This represents a step towards an effective and responsible energy transition in line with the commitments made at COP 28 (International Renewable Energy Agency, 2023).

In the literature, there is a notable absence of carbon assessments carried out on West African thermal power stations, with the exception of the Kossodo plant in Burkina Faso (Zongo et al., 2025). Based on this existing documentation, the integration of local data, consideration of specific technological features and examination of various mitigation levers (modernization, energy substitution, renewables, carbon capture) are recommended for future studies. This justifies the choice of the Gorou-Banda thermal power plant due to its special status in the Nigerien energy system. It’s one of the few sites in West Africa that operates solely on heavy fuel oil (HFO) or diesel. Furthermore, Gorou-Banda suffers from a very high scarcity of data due to institutional constraints, the fragmentation of information and data collection systems and the absence of regulatory requirements for carbon monitoring. Conducting a complete carbon assessment as part of this study would therefore provide a reference documentation for other studies on West African thermal power plants facing similar constraints.

In this context, the three objectives of this study are, among others: (i) to diagnose GHG emissions from the Gorou-Banda power plant, taking into account scopes 1, 2 and 3; (ii) to evaluate the two prospective scenarios (Reference versus Mitigation) over the period 2024–2025; and (iii) to discuss the feasibility and impact of the levers for action identified for a reduction trajectory compatible with Niger's energy transition. This contribution is the first carbon assessment of a thermal power plant in Niger and aims to inform national decisions on energy and climate policy.

## 2. Literature Review

The literature review conducted as part of this study analyses recent studies on emissions diagnosis and mitigation strategies applicable to thermal power plants, particularly in contexts similar to the Gorou-Banda power plant (Niger). Three main themes and one gap emerge from this literature review.

## 2.1. Emission Quantification Methods

(i) The ADEME carbon footprint method is one of the most widely used methods because it provides a comprehensive, standardised assessment that is compatible with the ISO 14064 reference standard (Zongo et al., 2025).

(ii) Some studies rely entirely on life cycle assessment (LCA), which is a highly effective method that is widely used and recommended in more complex industrial contexts (Mfetoum et al., 2023).

(iii) Other methods require the inclusion of local emission factors that are better suited to the reality, fuels and technologies of developing countries (Nana et al., 2023; Sun et al., 2025; Xie et al., 2025; Yang, Shafiq, Nazir, et al., 2024).

## 2.2. Technological Determinants

(i) Thermal power plants using liquid fuels, particularly heavy fuel oil and diesel, have the highest emission factor per kilowatt hour of electricity produced (Sethi, 2015).

(ii) Energy efficiency plays a crucial role, as older and less efficient thermal power plants with an efficiency rating of less than 30% emit proportionally more $CO_2$ in line with their efficiency ratings (STEEN, 2000).

(iii) The lack of modernisation is also a factor that amplifies the carbon footprint of thermal power plants in developing countries, particularly in Africa (Tamba et al., 2013; Zongo et al., 2025).

## 2.3. Mitigation Levers

(i) Fuel substitution, such as switching to natural gas, could be a highly effective strategy, but it is limited because it requires a robust infrastructure that is currently lacking in Niger (Wu & Hua, 2022).

(ii) Technological modernisation, namely upgrading the turbines, also improves the efficiency of these facilities by around 10 to 20% (Li et al., 2024).

(iii) The integration of renewable energies, especially the deployment of solar photovoltaics coupled with battery storage systems, is one of the most realistic alternatives that is attracting increasing interest from African countries (Yamegueu et al., 2024).

(iv) Hybrid systems combining diesel, solar PV, wind turbines and batteries would ultimately reduce dependence on fossil fuels, improve energy efficiency and reduce local emissions while optimising facilities operating costs (Kelly et al., 2023; Mulenga et al., 2023).

(v) Intelligent load management is a solution for reducing emissions from older power stations by around 5 to 10% overall, which is well suited to African power stations where data is incomplete (Zuo et al., 2024).

(vi) Carbon capture and storage (CCS) is a very costly solution and therefore not feasible for small power stations in Africa (Momodu et al., 2022).

The advantage is that all these measures are perfectly in line with West Africa's regional energy and climate policy, but they require immediate, substantial and ongoing investment to implement regional plans for diversifying the electricity mix and the policy levers needed to accelerate and successfully achieve a rapid transition to lower-carbon electricity systems (International Renewable Energy Agency, 2023).

## 2.4. Literature Gaps and Positioning of this Study

The summary of the literature review presented above identified the following gaps: (i) the lack of studies specific to Niger and a notable shortage of such studies in the West African sub-region, apart from similar cases such as Burkina Faso; (ii) the few cases studied have mainly focused on coal and gas-fired power plants, whereas Gorou Banda operates mainly on liquid fuels, notably heavy fuel oil and diesel; (iii) the weak integration of economic and social dimensions into reduction scenarios. This study therefore explores a field that has been little studied in West Africa, providing a comprehensive carbon assessment and evaluating realistic levers for Gorou-Banda. This study therefore presents itself as a solution to two major issues, namely: (i) on the one hand, the documentation of West African heavy fuel oil and diesel-fired thermal power plants and (ii) on the other hand, the investigation of a solid methodological framework for carbon diagnostics in contexts with multiple constraints.

## 3. Methodology

This study aims to assess GHG emissions linked to the operation of the Gorou-Banda thermal power plant located in Niamey, Niger and to identify the main reduction levers that can be implemented to mitigate its environmental footprint. To this end, the appropriate methodology is based on the main steps described below:

(i) The literature review critically and thoroughly analyses documents from the power station's operating pool, as well as scientific documents dealing with similar relevant topics.
(ii) The collection, analysis and processing of operating data (2019-2023) from internal power station reports, a survey of 50 randomly selected agents, interviews with stakeholders, and international databases such as ADEME and IPCC.
(iii) The methodological approach of the study is based on the ADEME carbon footprint method, which quantifies direct and indirect GHG emissions by taking into account the three scopes (1, 2 and 3) defined by ISO 14064.
(iv) An uncertainty analysis in accordance with IPCC recommendations and the nature of the data, followed by a sensitivity analysis testing ±10% growth in electricity demand and mission factors with the aim of defining a trajectory for reducing the power station's carbon footprint.

### 3.1. Conceptual Framework

Figure 1 below presents the conceptual framework model adopted in this study. It combines the main elements that interact in order to clearly see how mitigation measures could contribute to a responsible transition of Niger's energy mix, in line with the theories of transitions to sustainability defined by Geels (2002).

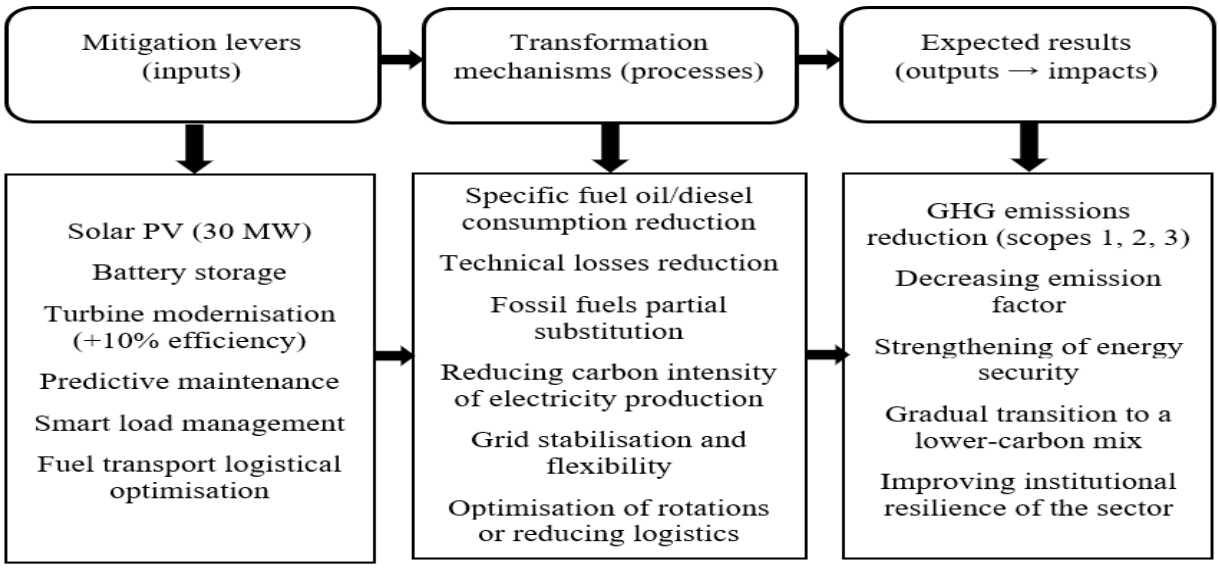



***Figure 1: Conceptual Framework Model***

### 3.2. Carbon Footprint Method

The carbon footprint method is used to assess GHG emissions generated by all processes necessary for the existence of a human activity or organization (Zuo et al., 2024). It is an Excel spreadsheet tool developed by ADEME and periodically updated since 2004. It can be used to assess the direct and indirect GHG emissions associated with a site, company, community or territory, generally over the course of a year (Zongo et al., 2025). The method is also compatible with the ISO 14064 standard for assessing GHG emissions (Intergovernmental Panel on Climate Change, 2024). The scientific unit of GHG measurement is the gram of carbon equivalent (g eq.C). The $CO_2$ equivalent (g eq.$CO_2$) is also sometimes used as in this study. The conversion is done as follows:

$$1\ \mathrm{g\ eq.CO_2} = \frac{12}{44}\ \mathrm{g\ eq.C} \quad (1)$$

Where: 44 g/mol is the molar mass of $CO_2$ and 12 g/mol that of carbon (C).
The GHG emissions are calculated using:

$$\mathrm{GHG\ balance} = \sum \mathrm{AD_i} \cdot \mathrm{EF_i} \quad (2)$$

The global warming potential (GWP) of each gas, is calculated using the equation (3):

$$\mathrm{Emissions\ in\ tCO2e} = \sum(\mathrm{emission\ gas} \times \mathrm{GWP\ gas}) \quad (3)$$

**Table 1**
***Emission factors (EF) and global warming potentials (GWP) (IPCC, 2024)***

| Gaz | $CO_2$ | $CH_4$ | $N_2O$ | Unité | I EF |
|---|---|---|---|---|---|
| Diesel | 3.63 | 0.0613 | 0.0576 | $kgCO_2/l$ | 0.1 |
| Petrol | 2,71 | 0.0525 | 0.0389 | $kgCO_2/l$ | 0.1 |
| Electricity | 0.469 | - | - | $kgCO_2/kWh$ | 0.1 |
| R22 (refrigerant) | 1812 | - | - | $kgCO_2/kg$ | 0.3 |
| R410a (air conditioner) | 1924 | - | - | $kgCO_2/kg$ | 0.3 |
| Commuting | 0.17 | - | - | $kgCO_2/km$ | - |
| GWP | 1 | 28 | 265 | - | - |

## 3.3. Study Site and Data Collection

The Gorou-Banda energy complex, located on the outskirts of Niamey, is Niger's main electricity production centre. It includes major infrastructure for national supply and regional interconnection. The site includes a 100 MW thermal power plant fuelled by heavy fuel oil or diesel (the subject of this study) and a 132/66 kV HV/MV substation connecting: (i) 80 MW from the Birnin Kebbi interconnection (Nigeria), (ii) 132 MW from the Kandadji hydroelectric power plant, and (iii) 600 MW from the future Salkadamna coal-fired power plant. Gorou Banda also transmits energy to other Niamey substations (industrial zone, Goudel, Kollo, Say) and Ouagadougou (Burkina Faso) via the West African Power Pool (WAPP) network.

The data collected on the site covers the period 2019–2023 and comes from: (i) internal power station reports (production, fuel consumption, maintenance); (ii) surveys of 50 randomly selected agents; (iii) interviews with local stakeholders; and (iv) international databases (ADEME, IPCC). The 50 employees are an essential stakeholder group representing all departments of the power plant and include maintenance technicians (mechanical, electrical and lubrication), power plant supervision engineers (energy and electrical engineers), fuel transport and logistics personnel and administrative staff. According to the joint requirements of the ADEME method and ISO 14064, in order to effectively assess Scope 3 emissions, it is necessary to collect information from these stakeholders on the power plant's life cycle, particularly with regard to equipment replacement, waste management, staff commuting and the overall logistics chain for all power plant activities.

The items taken into account are: (i) fuel consumption (HFO, diesel, oil); (ii) auxiliary electricity consumption; (iii) fuel transport by lorry; (iv) refrigerants (R22, R410a, R600a); (v) staff commuting; and (vi) solid and liquid waste management. Data reliability was assessed using a validation process in accordance with ADEME and IPCC recommendations, which includes consistency checks on operating data, treatment of inconsistencies in inaccessible data and treatment of uncertainties according to the nature of the data.

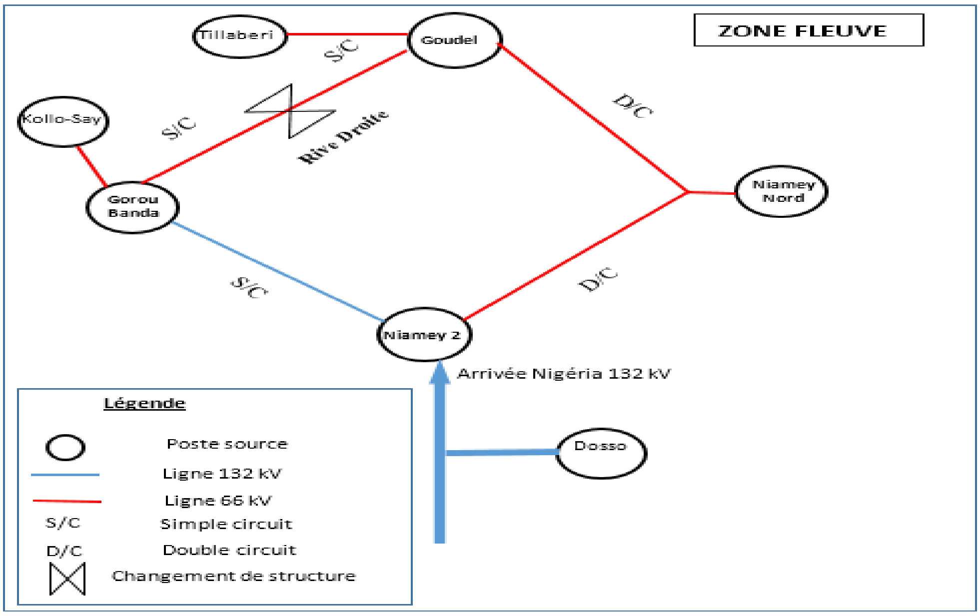



***Figure 2: Gorou Banda configuration (Nigerien Electricity Society (NIGELEC), 2025)***

## 3.4. Methodological Approach

The study is based on the carbon footprint method developed by ADEME. This method quantifies direct and indirect GHG emissions in accordance with the three scopes defined by the ISO 14064 standard for GHG quantification (Zongo et al., 2025).

**Table 2**

***Significant GHG emission items for Gorou-Banda***

| Category | Significant sources | Elements |
|---|---|---|
| **Scope 1** | Direct emissions from stationary combustion sources | Diesel generators |
| | Direct emissions from mobile combustion sources | Heavy goods vehicles and light goods vehicles |
| | Indirect emissions linked to electricity consumption | Power station assistants on the Nigeria line |
| **Scope 2** | Generated waste | Ordinary waste and sewage sludge |
| | Upstream fuel transport | Distances travelled for each type of transport and the type of fuel used |
| **Scope 3** | Indirect emissions linked to downstream electricity consumption | Electricity generated and sent to the Gorou banda substation |
| | Commuting between home and work | Mileage and fuel consumption |

(i) Scope 1: Covers direct emissions produced by fixed and mobile sources necessary for the power plant's electricity generation activities.

(ii) Scope 2: Covers indirect emissions from electricity consumption from the Nigerian line and waste generated by the power station's own activities.

(iii) Scope 3: Covers extended indirect emissions, those produced by all downstream electricity consumption, upstream fuel transport and employee commuting.

## 3.5. Data Analysis

This section analyses the energy performance of the Gorou Banda thermal power plant in terms of electricity generation and fuel consumption from 2019 to 2023. This analysis, shown in Figures 3 to 6 and Tables 3 to 4, demonstrates the operational dynamics, the substitution between diesel and heavy fuel oil and the sequences associated with the plant's emissions. Such an analysis is necessary in order to ultimately measure the coverage of the current trend and the impact of the proposed mitigation measures.

Figure 3 below shows the evolution of energy performance data at Gorou Banda. The power station showed steady growth in production between 2019 and 2021 (166.38 to 183.37 GWh), reflecting normal operation. In 2022, a drastic drop (-55% vs 2021) was observed, followed by a rebound in 2023 with a record of 272.14 GWh. The evolution of energy delivered closely follows that of production: gradual increase (2019-2021), collapse in 2022, then recovery in 2023. This confirms efficient distribution (minimal losses). Auxiliary consumption is proportional to production (operating logic), with a stable self-consumption rate (4 to 5%), typical of a thermal power plant. In 2023, the efficiency rate reaches its highest level (~3.2%). The energy received is very low from 2019 to 2021 (150.9 to 165.19 MWh), but jumps in 2022 (1.12 GWh), suggesting a need for external support due to the local shutdown. The return to 348.98 MWh in 2023 coincides with the resumption of production.

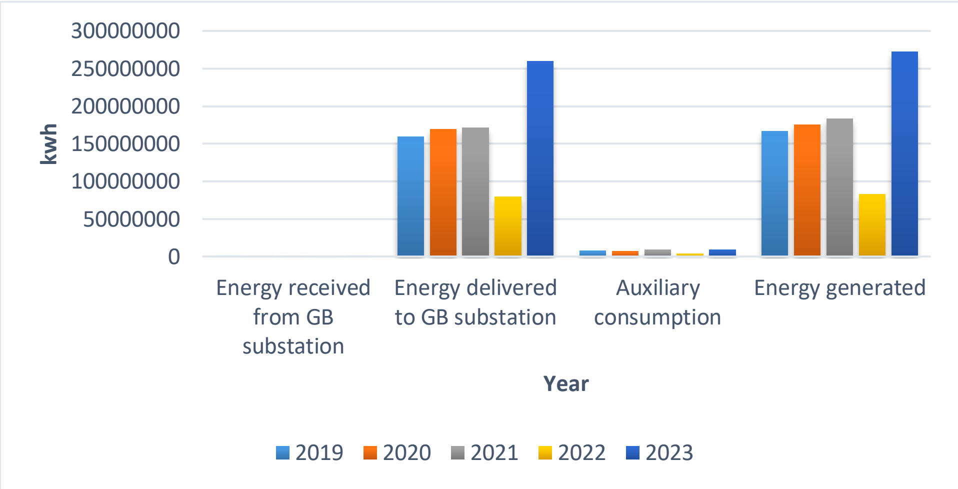



***Figure 3: Gorou Banda energy performance***
*Source: Analysed data*

Figure 4 illustrates the evolution of annual consumption data (diesel, HFO, oil). From 2019 to 2020, diesel consumption remained high and stable (~38 to 33 million liters). In 2021, it fell to 11 million litres due to the switch to HFO. A slight increase to 20 million litres occurred in 2022, followed by a significant peak in 2023 (over 66 million liters), suggesting a massive return to diesel. Consumption of HFO (heavy fuel oil) was marginal in 2019 (2 million liters). Between 2020 and 2021, it increased to 14 million litres, before falling back to 1 million in 2022. No consumption was recorded in 2023. Oil consumption decreased from 2019 to 2021 (from 17,000 to 42,000 liters), stabilised in 2021–2022, then jumped to 126,075 liters in 2023. This trend follows the operating load: the more the machines run, the more oil they consume. The threefold increase in 2023 corresponds to the peak in production that year. For specific daily consumption, between 2019 and 2020, levels are normal (0.37 to 0.96 million liters). In 2021–2022, an abnormal spike was observed (16.8 and 8.9 million liters), followed by a return to 0.5 million liters in 2023. These peaks in 2021–2022 could indicate a decline in energy efficiency (high consumption for low production).

Figure 5 summarises the number of lorries used to transport fuel by fuel type. From 2019 to 2021, the number of diesel lorries fell from 1,820 to 207. This dramatic decline is due to the gradual replacement of diesel with HFO. However, this trend reversed in 2022 with an increase to 698 lorries, before returning to a record level of 1,820 lorries in 2023, reflecting the total abandonment of HFO. HFO transport peaked between 2020 and 2021, rising from 33 to 491 lorries, during which time it replaced diesel as the main fuel. HFO use then declined in 2022 (314 lorries) before being completely abandoned in 2023 (192 lorries). The total number of transport lorries directly followed the volumes of fuel consumed. The sharp increase in the total number of lorries in 2023 is a direct consequence of the abandonment of HFO and the return to diesel, which required a much higher number of rotations.

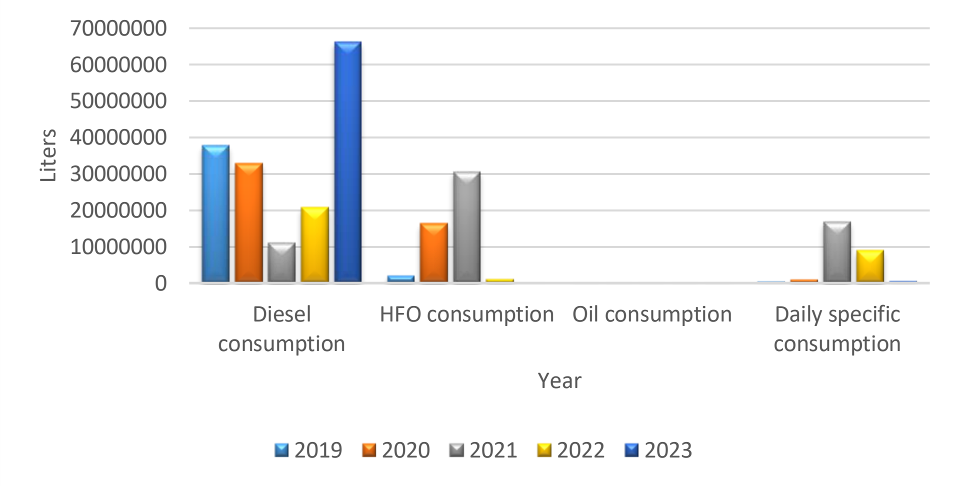



***Figure 4: Gorou Banda fuel consumption data***
*Source: Analysed data*

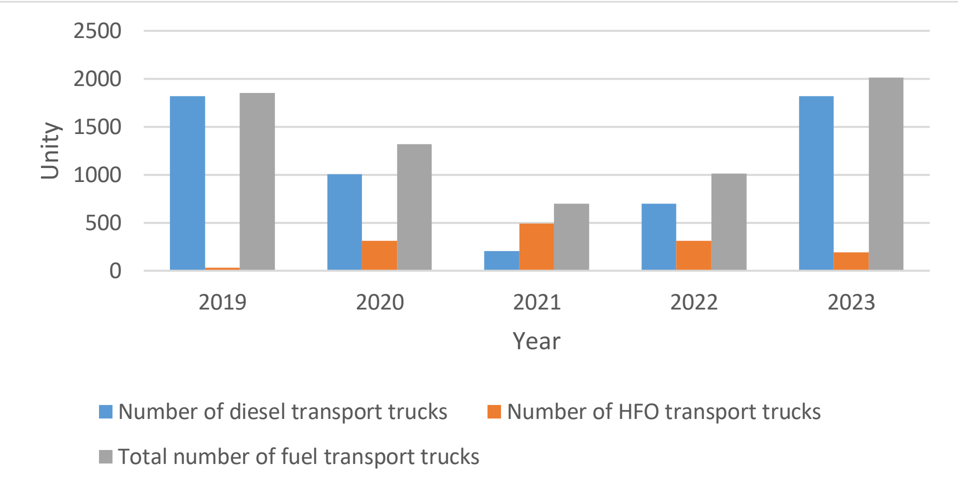
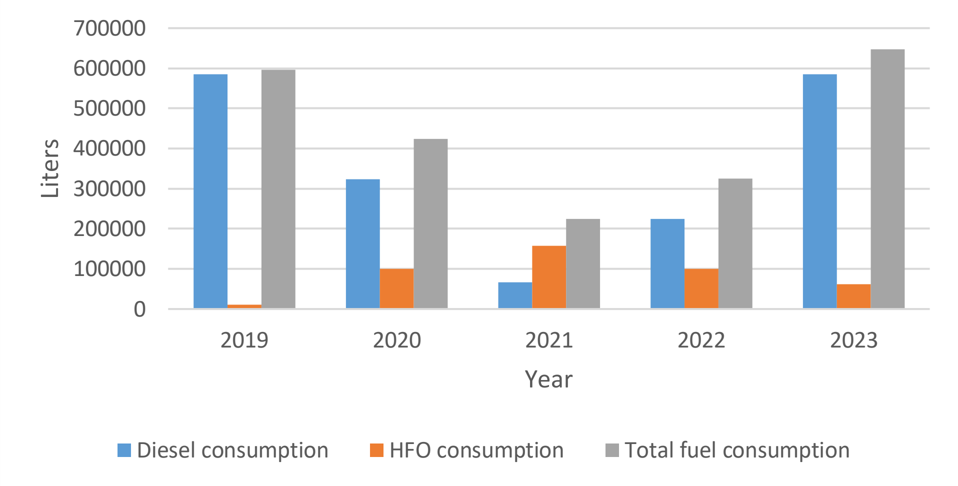



***Figure 5: Truck fleet by fuel type***
*Source: Analysed data*

Figure 6 shows the evolution of annual fuel consumption. Analysis of fuel consumption trends at the Gorou Banda power station from 2019 to 2023 highlights a temporary substitution of diesel with heavy fuel oil (HFO) before a return to the initial configuration. Between 2019 and 2021, diesel consumption fell significantly, from 585,275.6 liters in 2019 to 66,567.06 liters in 2021, a reduction of 88%. From 2022 to 2023, a gradual recovery was observed, reaching the 2019 level of 585,275.6 liters in 2023. This return is linked to the resumption of energy production and the abandonment of HFO. From 2019 to 2021, HFO consumption grew sharply, from 10,612.14 liters to a peak of 157,895.78 liters. This increase corresponds to a strategy of substituting diesel fuel. From 2022 to 2023, consumption declined, finally collapsing in 2023, confirming the abandonment of this fuel. Total fuel consumption follows variations in energy production. The drop in consumption in 2021 is followed by a strong recovery in 2023, consistent with the evolution of the power plant's activity: production falls and then rebounds strongly in 2023.

Table 3 shows fugitive emissions from refrigerants (R22, R410a, R600a). It should be noted that R22 (HCFC) is a gas with a high global warming potential (GWP) that is still widely used. Although R410a is often presented as an alternative, it also has a significant impact on the climate. R600a is the most environmentally friendly and compliant solution, with a very low GWP. Table 4 summarises $CO_2$ emissions linked to worker travel according to mode and type of transport. It should be noted that pedestrians have zero environmental impact. Although motorcycles have moderate emissions per kilometre (0.17 kg $CO_2$/km), they are the most polluting mode of transport in absolute terms (approximately 264 tonnes of $CO_2$ per year) due to their widespread use. Petrol cars have the highest impact per kilometre, while diesel cars are the biggest emitters per vehicle due to their intensive use.




***Figures 6: Fuel consumption***
*Source: Analysed data*

**Table 3**
***Fugitive emissions of refrigerant fluids***

| Equipment type | Refrigerant gas | Gas (kg) | Quantity | Leakage rate | EF (GWP) (kgCO₂) | Total emissions (kgCO₂) |
|---|---|---|---|---|---|---|
| Air conditioners | R22 | 3 | 19 | 5% | 1760 | 5,016 |
| | R22 | 3.2 | 35 | 5% | 1760 | 9,856 |
| | R22 | 2.8 | 8 | 5% | 1760 | 1,971.2 |
| | R22 | 0.85 | 1 | 5% | 1760 | 74.8 |
| | R410a | 2.3 | 5 | 5% | 1924 | 1,106.3 |
| | R410a | 1.42 | 3 | 5% | 1924 | 409.812 |
| Refrigerators | R600a | 0.02 | 2 | 5% | 3 | 0.006 |

**Table 4**
***$CO_2$ emissions related to employee commuting***

| Mode of transport | Number of employees | Round-trip distance (km) | Emissions factor (kg $CO_2$/km) | Total emissions (kg $CO_2$) |
|---|---|---|---|---|
| Pedestrians / Cyclists | 0 | 0 | - | |
| Motorcycles | 34 | 1,550,989.29 | 0.17 | 263,668.18 |
| Gasoline cars | 10 | 261,965.71 | 0.193 | 50,559.38 |
| Diesel cars | 4 | 459,900 | 0.190 | 87,381 |

## 3.6. Uncertainty Analysis

Based on highly heterogeneous data (activity data and emission factors), GHG emission estimates are often inaccurate. It is therefore important to determine the level of uncertainty and take it into account when interpreting the results so as not to exceed the level of significance of the figures obtained (Intergovernmental Panel on Climate Change (IPCC), 2024). This approach is in line with the IPCC's recommendations on good practice and uncertainty management. According to the carbone balance spreadsheets, error ranges are classified as follows:

(i) 0–5% for data obtained from direct measurement (bills, meters);
(ii) 15% for reliable data that has not been measured;

(iii) 30% for recalculated data (extrapolation);
(iv) 50% for approximate data (statistical data);
(v) 80% for data known to be of a certain order of magnitude.

Each emission factor is therefore documented with its source and level of uncertainty, which is important for assessing the quality of the carbon footprint. Table 5 below shows the specific uncertainties associated with the activity data used.

**Table 5**
***Activity data uncertainty (IPCC, 2024)***

| Elements | Activity data uncertainty |
|---|---|
| Petroleum and gas products | 5% |
| Diesel and gasoline | 10% |
| Refrigerant gases | 10% |
| Electricity | 10% |
| Sludge from septic tanks | 50% |
| General waste | 15% |
| Statistical data | 50% |

The combined uncertainty (CU) per category is calculated as:

$$\boldsymbol{CU} = \sqrt{\mathrm{ADU}^2 + \mathrm{EFU}^2} \quad (4)$$

Following this, a sensitivity analysis was carried out. This tested the effect of a variation of plus or minus (±10%) on the growth in annual electricity demand (+7%/year) and mission factors related to heavy fuel oil and diesel. The aim of this approach is to verify the robustness and reliability of the results and will enable a better assessment of the feasibility of the scenarios.

## 3.7. Greenhouse Gas Emission Reduction Scenarios

Based on the current constraints and opportunities of Niger's energy sector, two scenarios have been developed: (i) the Reference Scenario (RS) and (ii) the Mitigation Scenario (MS).

### 3.7.1.Reference Scenario (RS)

The RS is based on the assumption that current trends in electricity demand will continue, growing at an average rate of more than 7% per year, while the emission factor remains constant at 0.75 kg $CO_2$/kWh. The development of renewable energies remains marginal, leading to the continuation of production largely dominated by thermal power plants, with significant associated environmental impacts.

### 3.7.2.Mitigation Scenario (MS)

The MS, meanwhile, incorporates a set of measures designed to reduce GHG emissions that are fully in accordance with national and regional policies and green investments for sustainable energy, including:

(i) The accelerated deployment of 30 MW of solar photovoltaic power by 2025, which is in line with the Sustainable Development and Inclusive Growth Strategy (SDDCI NIGER 2035), ECOWAS Regional Climate Strategy (RCS) and Action Plan 2022-2030, West African Power Pool (WAPP) network, the Confederation Investment Bank for Development (CIBD) of the Alliance of Sahel States (SSA) through its energy component, which places unparalleled value on innovative solutions aimed at achieving energy independence in the Sahel.
(ii) The integration of battery storage systems, which is seen as a strategy for improving both grid flexibility and stability, is in line with the New Energy

Deal for Africa and Desert to Power projects, all of which are flagship initiatives supported by investments from climate finance institutions such as the Green Climate Fund and the African Development Bank (AfDB).

(iii) The modernisation of turbines, enabling an efficiency gain of around 10% combined with a reduction in fuel consumption of between 10% and 15%, represents the first key component of the Project to Improve Energy Efficiency in Niger's Thermal Power Stations via NIGELEC.

(iv) Regular predictive maintenance to limit technical losses and extend the service life of equipment is the second key component of the Project to Improve Energy Efficiency in Niger's Thermal Power Plants via NIGELEC.

(v) Intelligent load management, contributing to an additional 5% reduction in emissions and improved stability of the electricity grid, is a highly relevant strategy in light of the digitalisation projects currently underway in the region (ECREEE, AFREC (Detailed Energy Balance, Energy Information System), SCADA, Smart Meters, Distribution Automation).

## 4. Results

The results of this study show that emissions from the Gorou Banda thermal power plant are dominated by $CO_2$, which accounts for 90% of total emissions. $CH_4$, $N_2O$ and refrigerants also contribute to emissions, albeit to a lesser extent, but not insignificantly. Scope 1, through its emissions from fuel combustion, is by far the largest source of emissions, estimated at over 80%, followed by scope 3, through its emissions from fuel transport, which accounts for approximately 13.5%. Figures 7 to 12 show the detailed breakdown of emissions. The total GHG emission sequences shown in Figures 7 and 8 indicate that under the RS, emissions will continue to increase by approximately 7% per year in line with the growth in electricity demand. Under the MS, however, a partial reduction of 17% is already observed in 2024, and in 2025, the full implementation of mitigation measures would lead to a significant reduction of 45% in total emissions.

**Table 6:**
***Scenario assumptions and expected impact on GHG emissions***

| Indicators | Reference Scenario (RS) | Mitigation Scenario (MS) | Expected Impact on emissons |
|---|---|---|---|
| Electricity demand growth | +7 %/an | +7 %/an (optimized) | RS: proportional increase / MS: moderate increase |
| $CO_2$ emission factor | 0,75 kg$CO_2$/kWh (constant) | Reduced via efficiency | MS: reduction of 5 to 10% in the emission factor |
| Solar PV by 2025 | Very limited | 30 MW installed | MS: 8–12% reduction in emissions by 2025 |
| Battery storage capacity | None | Present | MS: indirect reduction of 2 to 4% via production optimisation |
| Turbine modernisation | None | +10% efficiency, reducing 10 to 15% of fuel use | MS: direct reduction of 10 to 15% from turbines $CO_2$ emissions |
| Predictive maintenance | Not applied | Applied | MS: 2–3% reduction in emissions via reduction of technical losses |
| Intelligent load management | Not applied | Applied | MS: additional 5% reduction in emissions |
| Share of thermal production in 2025 | > 80% | <70 % | MS: reducing emissions by 15-20% and dependence on thermal power |

In 2023, there is no difference between the RS and the MS (Figure 7), as mitigation measures have not yet been implemented. $CO_2$ remains the dominant gas and therefore the main target of emission reduction strategies. From 2024 onwards, the difference between the two scenarios becomes substantial, confirming the effectiveness of the measures implemented. $CH_4$ and $N_2O$ emissions follow similar downward trends, showing that mitigation strategies also target emissions of other gases. Overall, total GHG emissions decrease proportionally for all gases, confirming the internal consistency of the MS.

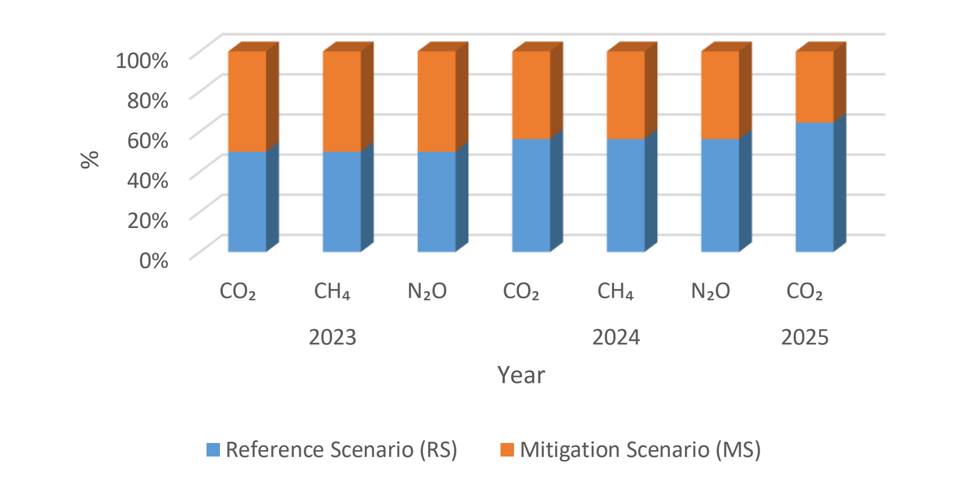



***Figure 7: Total GHG emissions by gas type (2023–2025)***

Analysis of GHG emissions by source between 2023 and 2025 (Figure 8) reveals contrasting trends depending on the scenario. For fuel transport, emissions increase slightly in the RS (+4%), while they decrease by around 19% in the MS, reflecting improvements in efficiency and logistics optimisation. Diesel combustion remains stable in the RS, but decreases by around 20% in the MS due to a decline in diesel use in favour of cleaner alternatives. Emissions from imported electricity decrease significantly (−45%) in the MS, compared to a slight increase in the RS, indicating partial decarbonisation of the imported energy mix. Electricity generation remains the main source of emissions; although it increases in both scenarios, the MS limits this increase by about half, highlighting the positive impact of mitigation measures.

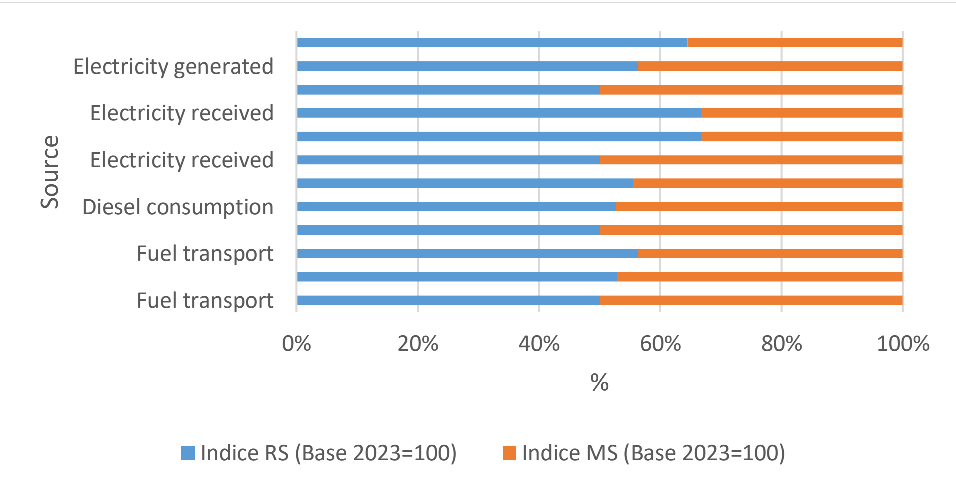



***Figure 8: Total GHG emissions by source (2023–2025)***

Fuel transport accounts for approximately 13.5% of total $CO_2$ emissions in 2023 (compared to 85% for combustion). Between 2023 and 2025, the MS will enable a cumulative reduction of 19% in $CO_2$ emissions. Similar reductions are observed for $CH_4$ and $N_2O$. Under the RS, emissions increase slightly (≈2% per year), while under the MS, they decrease by around 10-11% per year, confirming the continued effectiveness of the measures implemented.

Figure 10 shows that emissions from combustion remain virtually constant in the RS (due to existing regulations), but decrease moderately in the MS, reaching a 20% reduction in 2025 compared to 2023. The proportional decreases in $CO_2$, $CH_4$ and $N_2O$ suggest a comprehensive emissions reduction strategy. Mitigation efforts result in a 10% reduction in 2024 and a 20% reduction in 2025 compared to the 2023 baseline. Under the RS, emissions linked to imported electricity increase between 2023 and 2024, then stabilise. In contrast, the MS enables a drastic 50% reduction in $CO_2$ emissions and total GHG emissions from 2024 onwards, with this reduced level being maintained in 2025.

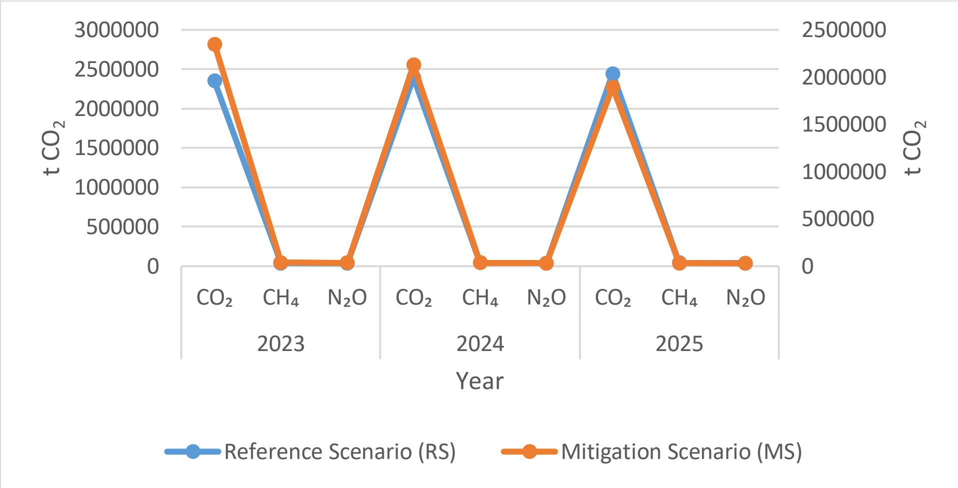



***Figure 9: GHG emissions from fuel transport (2023-2025)***

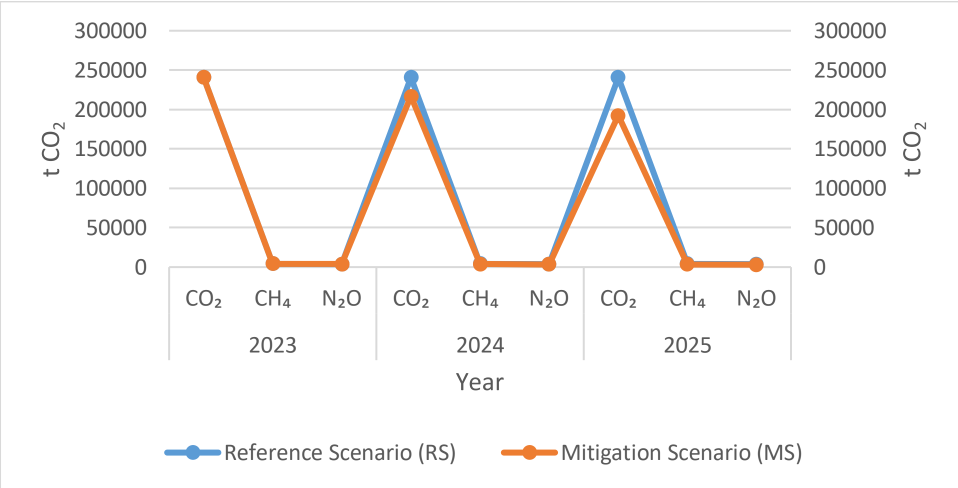



***Figure 10: GHG emissions from diesel combustion (2023-2025)***

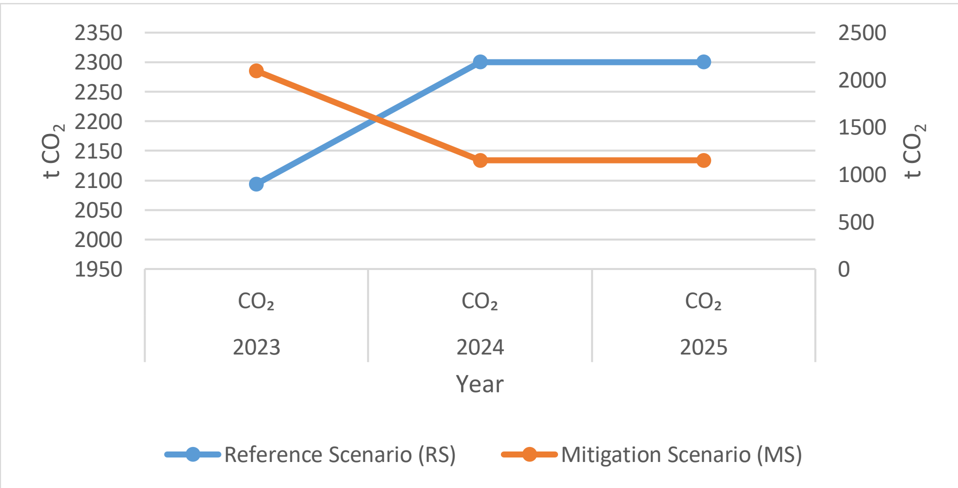



***Figure 11: $CO_2$ emissions from imported electricity (2023-2025)***

Figure 12 below highlights the continued growth in $CO_2$ and GHG emissions under the RS. Conversely, under the MS, emissions decrease significantly in 2024 (by approximately 17 to 22.5 per cent) and even more sharply in 2025 (by approximately 45 per cent) compared to the RS. This corresponds to a decrease in the emission factor from 0.75 to 0.65 kg $CO_2$/kWh, confirming the increasing effectiveness of mitigation measures. The results remain robust, with only a few minor potential inconsistencies in the RS data for 2025.

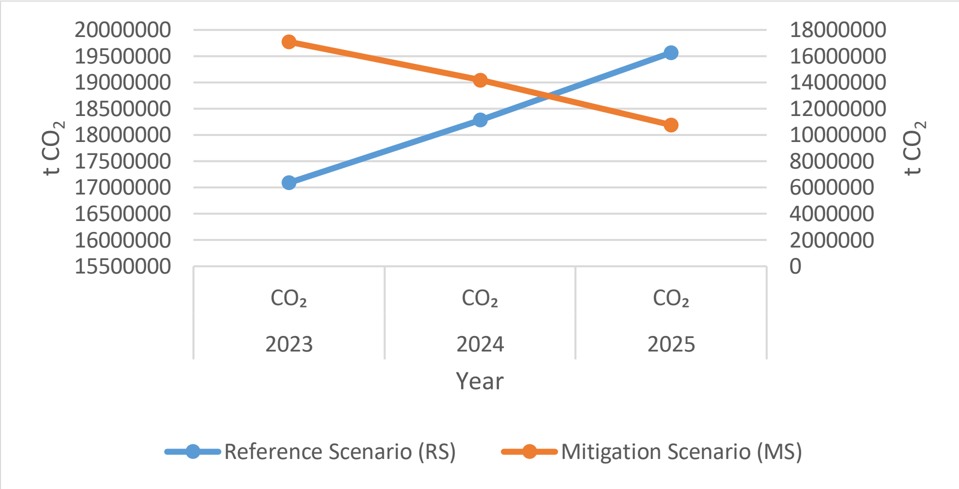



***Figure 12: $CO_2$ emissions from electricity generation (2023–2025)***

The sensitivity analysis conducted on these results confirms that a variation of plus or minus ±10% in electricity demand growth changes total emissions by plus or minus ±7%. Whereas the same variation in the emission factors for diesel and HFO results in a variation of ±5% in overall emissions. This also means that the results obtained at the end of this study are relatively robust, even when faced with the constraint of data uncertainty.

## 5. Discussion

Thanks to the integration of 30 MW of solar PV with storage and improved energy efficiency, the proposed MS enabled the Gorou Banda power plant to reduce its emissions by almost half in 2025. The results obtained for Gorou Banda are consistent with those of several similar studies carried out in West Africa, as well as on thermal power plants using liquid fuels, particularly heavy fuel oil and diesel, at the international level.

For example, the results from the Kossodo power plant in Burkina Faso (Zongo et al., 2025) showed that liquid fuels (fuel oil, diesel) largely dominate the carbon footprint. In Cameroon, the results of Mfetoum et al. (2023); Tamba et al. (2013) also highlight the major impact of oil-fired thermal power plants and the importance of modernising equipment to reduce their emissions. In Ghana, the ECOWAS (Economic Community of West African States) report (2022) shows that solar-thermal hybridization can reduce emissions from thermal power plants by 20 to 30%. All these results are consistent with the MS predictions in this study. Similarly, the emission factor for Gorou-Banda (0.75 kg$CO_2$/kWh) falls within the range of emission factors for liquid fuel thermal power plants worldwide. By way of comparison, the Kossodo power plant (Zongo et al., 2025) in Burkina Faso (0.70 to 0.73 kg$CO_2$/kWh), power plants in Cameroon (0.68 to 0.72 kg$CO_2$/kWh) (Mfetoum et al., 2023; Tamba et al., 2013). Diesel-fired thermal power plants in India (Sethi, 2015) and Indonesia (STEEN, 2000) (0.75-0.80 kg$CO_2$/kWh). This comparison reinforces the consistency and reliability of the MS in this study. Thus, from an energy perspective, Gorou-Banda is comparable in terms of efficiency to similar West African facilities, but its emission levels are mainly due to its heavy dependence on diesel in 2023 and the significant variations observed between 2021 and 2022. These results reveal that the power plant is not inherently less efficient than its regional counterparts, but that it operates in a very challenging logistical and technical context, hence the importance of the proposed MS.

Secondly, Gorou Banda's MS is in line with one of the most important levers for decarbonization outlined in the IPCC's 6th Assessment Report, which suggests that urgently reducing emissions from electricity production using liquid fuels in developing countries such as Niger is an essential strategy for limiting temperature rise. Furthermore, this MS is in line with the guidelines of the African Development Bank (AfDB), which encourages investment in low-carbon, technically feasible and financially viable solutions, particularly through its "New Energy Deal for Africa" and "Desert-to-Power strategies, which recommend the rapid integration of solar energy, solar-thermal hybridization and battery storage to limit emissions and dependence on fossil fuels in African electricity systems. It is important to note that this MS is also in line with the guidelines of the Confederation Bank for Investment and Development of the Sahel Alliance (CIBD/SSA), which has been added as a financing institution for sustainable energy projects aimed at achieving immediate energy independence for the countries of the alliance (Niger, Mali, Burkina Faso). Finally, the Gorou-Banda SA goes beyond a local exercise and is fully in line with international mitigation efforts, Niger's climate commitments and African regional energy transition strategies (WAPP, ECREEE, AFREC...).

The socio-economic implications of the proposed MS include: job creation in the conventional and renewable electricity sector, opening up opportunities for other income-generating activities (IGAs), improving electricity services and, above all, improving environmental and public well-being through permanent emissions reductions. However, the success of this MS depends heavily on the institutional framework, as coordination between regulators, operators and donors, as well as the adoption of harmonized emission monitoring tools, such as carbon credits, are essential for the effective implementation of the transition. The main limitations of this study are the uncertainties surrounding certain extrapolated data, the short time horizon (2025) and the lack of an in-depth cost-benefit analysis. Nevertheless, this discussion shows that this MS is technically feasible and potentially aligned with Niger's commitments, but requires significant financial, institutional and social efforts to be effectively implemented.

## 6. Conclusion

This paper has enabled the first comprehensive carbon assessment of the Gorou Banda thermal power plant in Niger to be carried out using the ADEME carbon footprint method across the three scopes defined by ISO 14064. Analysis of the results shows that the power station can reduce its emissions by around 45% after only two years of implementation thanks to an effective mitigation scenario incorporating a strategic combination of renewable energy and energy efficiency. This is the very first step towards Niger's energy transition. This study shows that emissions from the combustion of fossil fuels (diesel and heavy fuel oil) are the primary source of emissions at the Gorou Banda power plant, accounting for 80%, followed by emissions from fuel transport, accounting for 13%. The RS leads to a continuous increase in emissions of 7% per year, dominated by $CO_2$, while the MS would allow for a 17% reduction in 2024 and a 45% reduction in 2025 in the plant's total emissions compared to the RS. The plant could become a pilot laboratory for energy transition in West Africa, provided that international funding, technological innovations and inclusive governance can be mobilised. The economic feasibility of solutions, institutional capacity to implement transition policies and social acceptability of reforms in the energy sector are the main challenges to such success. However, several alternatives could help overcome these challenges: (i) introduction of feed-in tariffs for renewable or hybrid electricity from Niger's SDDCI 2035, which is attracting particular interest from independent and private producers to accelerate the installation of solar PV; (ii) carbon or fossil fuel pricing and carbon credits granted to green solutions currently being implemented in the WAPP policy, which is particularly reorienting African economic interests towards solar and battery storage; and (iii) financing mechanisms via the AfDB, the Green Climate Fund, the SSA Confederation Bank and the NIGELEC energy efficiency improvement project would constitute reliable sources of financing for turbine modernization and preventive maintenance. Finally, Niger's energy policy goodwill combined with these measures is necessary to establish a realistic framework for the MS and position Gorou Banda on the international path to emissions reduction. An in-depth cost-benefit analysis over a longer time horizon (2030-2050) would be a useful addition to this study in order to identify the real impacts of the MS in concrete terms.

**Authors Contribution**

Arouna Saley Hamidou: Conceptualization, Visualization, Writing, Reviewing, Editing, Validation and Research Project Administration.

Mohamed Aboubakar Amadou Y: Investigation, Writing original draft, Methodology and Data curation.

Ahmed Issoufou Imadan: Editing, Reviewing, Supervision and Validation.

Makinta Boukar: Methodology reviewing, Data Analysis, Editing, Revision, Validation and Project Supervision.

**Conflict of Interests/Disclosures**

The authors declared no potential conflicts of interest w.r.t. the research, authorship and/or publication of this article.

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