

# Technical article

## Assessment of carbon dioxide emission factors from power generation in Burkina Faso

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### Abstract

Power generation is the second largest source of greenhouse gases (GHGs), particularly carbon dioxide (CO<sub>2</sub>), in Burkina Faso's energy sector. When preparing the National Communications on Climate Change, Burkina Faso uses the default emission factors of the Intergovernmental Panel on Climate Change (IPCC) to estimate emissions from power generation. This study presents an assessment of CO<sub>2</sub> emission factors from power generation for 2018 in Burkina Faso and an assessment of the contribution of renewable energy to the reduction of CO<sub>2</sub> emissions. The national electricity company of Burkina Faso was chosen as the scope for this study. The estimation of emission factors for combustion is based on an analysis of fuels which are characterised in terms of molecular composition, density and water content. For CO<sub>2</sub>, 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). Using these emission factors, the CO<sub>2</sub> emissions attributable to power generation in 2018 were estimated at almost 580 Gg. The CO<sub>2</sub> emission factor for thermal power generation was estimated at 0.663 kg/kWh and that of the electricity generation mix at 0.569 kg/kWh. Finally, the use of 14.25% renewable energy in electricity generation avoided 16.7% of CO<sub>2</sub> emissions in 2018. The emission factor of electricity production decreases with the increase in the share of renewable energy in the energy mix.

### Keywords

power generation, greenhouse gases, emission factor, carbon dioxide, thermal generation.

### Introduction

Increasing anthropogenic emissions of greenhouse gases (GHGs), particularly carbon dioxide (CO<sub>2</sub>), are the main cause of global warming (IPCC 2021). In 2019, the Intergovernmental Panel for Climate Change (IPCC) estimated global net anthropogenic GHG emissions (75% of which was attributed to CO<sub>2</sub> emissions) at 59 GtCO<sub>2</sub>-eq (IPCC 2022). GHG emissions from anthropogenic sources come from several sectors of activity, including the energy sector. In the energy sector, GHG emissions come mainly from the use of primary fossil fuels for electricity generation and transport. According to a report by the International Energy Agency (IEA), in 2018, energy-related CO<sub>2</sub> emissions reached about 33.1 Gt, an increase of 1.7% compared to 2017, the majority of which comes from electricity generation (IEA, 2019).

In the face of climate change, reducing CO<sub>2</sub> emissions is a major priority. An important step in the search for solutions to reduce emissions is to identify the most significant sources of

GHG emissions. This is done through compiling an inventory of GHG emissions on the one hand, and on the other hand, the development of programmes to reduce anthropogenic GHG emissions through the reduced consumption of fossil fuels and to increase the use of low GHG-emitting technologies such as renewable energy sources.

The most commonly used method of calculating emissions is based on emission factors (EFs), verifiable activity data and global warming potentials (GWPs). The IPCC provides three tiers for estimating GHG emissions from stationary sources in the energy sector (IPCC 2006a): Tier 1 uses the fuel combustion from national energy statistics and default emission factors. Tier 2 uses the fuel combustion from national energy statistics, together with country-specific emission factors where possible, derived from national fuel characteristics. Tier 3 uses the fuel statistics and data on combustion technologies applied together with technology emission factors; this includes the use of models and facility-level emission data where available.

GHG emission factors depend on the characteristics of the fuels including carbon content and calorific value (IPCC 2006a). According to the IPCC, CO<sub>2</sub> emissions can be calculated at the more detailed level provided that complete statistics on fuel consumption and the typical carbon content of these fuels are available, as combustion conditions are relatively unimportant for the EF of CO<sub>2</sub> compared to that of CH<sub>4</sub> and N<sub>2</sub>O (IPCC 2006a). The emission factor for electricity generation depends on the country's electricity generation fleet and the fuel mix used. For fossil fuel power plants, the efficiency of conversion of fuel to electricity and the load factor both influence the GHG emission rate during combustion (Spadaro et al. 2008).

Burkina Faso, a member of the United Nations Framework Convention on Climate Change (UNFCCC) and a non-Annex I country, is committed to reducing GHG emissions. Indeed, it has prepared National Communications under the UNFCCC. These Communications show that in 2015 the energy sector was the second largest emitter of anthropogenic GHGs after the Agriculture, Forestry and Other Land Use (AFOLU) sector (PRBA 2021). Burkina Faso's electricity production was the second largest contributor to GHG emissions in the energy sector after transport in 2015 (PRBA 2021, TCN 2022). GHG emissions from the energy sector in Burkina Faso have an increasing trend from 1995 to 2015. Indeed, GHG emissions from the energy sector have increased from 3.0% of Burkina Faso's total GHG emissions in 1995 to 6.1% in 2015. (PRBA 2021). CO<sub>2</sub> alone accounts for more than 99% of emissions from electricity production in Burkina Faso in 2015 (PRBA 2021).

So far, Burkina Faso assesses its GHG emissions from electricity generation using the IPCC default EFs (IPCC's Tier 1 approach) due to lack of country-specific (IPCC's Tier 2 approach) or technology-specific (IPCC's Tier 3 approach) EFs. However, a rigorous estimation of the sector's contribution requires more refined EFs. It is therefore important to develop country-specific EFs for the Burkinabe power generation sector. It is in this context that this work focuses on the evaluation of the country-specific CO<sub>2</sub> emission factors of electricity production in Burkina Faso in 2018 and the evaluation of the contribution of renewable energies to the reduction of carbon dioxide emissions from the Burkinabe electricity production sector.

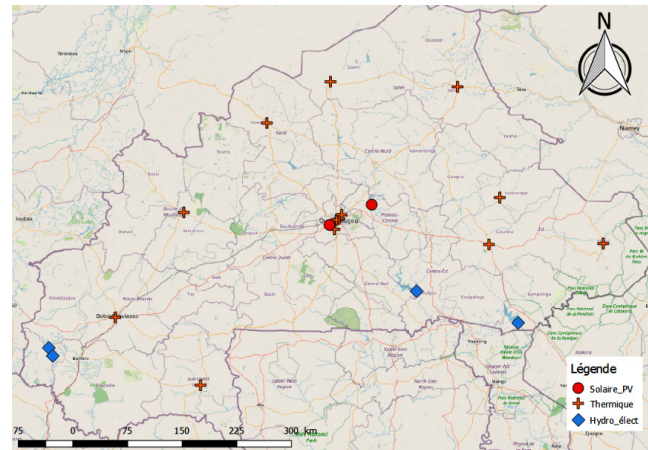
## Materials and methods

### Study area

Burkina Faso, a West African country, is located between 9° 20' and 15° 05' North latitude and between 5°20' West longitude and 2°03' East longitude and has a surface area of 273 187 km<sup>2</sup>. According to the preliminary results of the Fifth General Census of Population and Housing of Burkina Faso, its population is estimated at 20.5 million (INSD 2022). Burkina Faso is characterised by a tropical Sudanese climate. Burkina Faso's electricity network is composed of three subsystems: generation, transmission and distribution. Electricity generation is the subsystem that contributes most to anthropogenic GHG and air pollutant emissions.

**Table 1:** SONABEL's electricity production by source in GWh in 2018 (ME, 2018a)

Source of Production	Thermal	Hydroelectricity	Solar photovoltaic	Total electricity generation
Production Electrical	8.7	56.5	27.0	11.1



**Figure 1:** Location of SONABEL's power plants in Burkina Faso in 2018

### Sources and data collection

Data was collected from the Burkina Faso Ministry of Energy (ME 2018a, 2018b). The data collected covers 2018 and provides: i) the annual electricity production of all power plants (thermal and renewable), and ii) the amount of fuel consumed by thermal power plants by fuel type. The national electricity company of Burkina Faso (called SONABEL) is the main supplier of electricity in Burkina Faso with 98% of the electrical energy delivered in 2018. Electricity production is made up of thermal, hydro and solar power (Table 1). SONABEL's power production for 2018 was composed of 85.75% thermal energy; 8.95% hydroenergy and 5.3% solar photovoltaic energy (SONABEL 2018). There were nineteen (19) functional power plants in 2018 (ME 2018b) (Figure 1).

Heavy Fuel Oil (HFO) and Distillate Diesel Oil (DDO) are the petroleum products used to run SONABEL's thermal power plant fleet. In 2018, thermal power plants consumed 186 805 t of fuel (SONABEL 2018), 86.5% of this being HFO (161 586 t) and 13.5% DDO (25 219 t). SONABHY is the only distributor of hydrocarbons in Burkina Faso.

### Methodology

In this study, only the emissions related to the electricity production phase in 2018 are taken into account. The county-specific characteristics of the fuel takes into consideration the molecular structure and density of the fuel and the water content of the HFO.

### Molecular constituents by characterisation and elemental composition by mass of fuels

A sample of the two fuels (see Figure 2) consumed by the thermal power plants was taken from SONABEL's Ouaga II

thermal power plant and submitted for analysis in order to determine the molecular constituents of Burkinabe DDO and HFO. To prevent diffusion of hydrocarbon components, we used black plastic film to wrap the bottles and stored them in a cool, dark place at 20°C.



Figure 2: Photograph of HFO and DDO fuel samples

The samples analysis was performed by a Thermo Finningan Trace 2000 Gas Chromatography Mass Spectrometry (GC-MS) system. A DB-5 MS column from Agilent (30 m, ID 0.25 mm, df 0.25 μm) was used in the chromatograph. An initial oven temperature of 40°C was maintained for 5 minutes, then the temperature was increased at a rate of 10°C/min to a final temperature of 220°C for 15 minutes. Sample were injected (split mode) in an injector heated to 180°C. The MS transfer line was heated at 220°C and the ion source was operated at 200°C, electron energy 70 eV. American Chemical Society (ACS) grade reagents were used for hydrocarbon compounds calibration (external calibration). Total ion chromatogram (TIC) was used to identify compounds in the samples then SIM mode was used for compound quantification. Data were processed by Thermo Xcalibur 3.1 software.

If  $C_xH_yO_zN_uS_t$  is the chemical formula of the fuel, then the values of  $x, y, z, u$  and  $t$  are determined as the average value of the C, H, O, N and S atoms of its constituents respectively.

$$x = \sum_{i=1}^n p_i x_i ; y = \sum_{i=1}^n p_i y_i ; z = \sum_{i=1}^n p_i z_i ; u = \sum_{i=1}^n p_i u_i ; t = \sum_{i=1}^n p_i t_i \quad (1)$$

where  $p_i$  is the mass fraction of component  $i$  contained in the fuel and  $x_i, y_i, z_i, u_i$  and  $t_i$  represent the number of carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) atoms in component  $i$  respectively.

If  $M_{C_xH_yO_zN_uS_t}$  is the molar mass of the fuel, then:

$$M_{C_xH_yO_zN_uS_t} = \sum_{i=1}^n p_i M_i \quad (2)$$

$M_i$  is the molar mass (in g/mol) of compound  $i$  present in the fuel, i.e.,  $M_C=12$ ;  $M_H=1$ ;  $M_O=16$ ;  $M_N=14$ ;  $M_S=32$

### Experimental measurement of fuel density

The density of each fuel is determined experimentally by the density meter method (Figure 3). This method is based on NF T60-101 (Guillermic 1980). Given the high variability in HFO characteristics, three samples from different origins (Cotonou, Lomé and Abidjan) were taken and submitted for analysis. For DDO, only one sample from Cotonou was submitted for analysis. The equipment used consists of a 500 mL capacity graduated cylinder; a 0.950 to 1 graduated density meter for HFO and 0.800 to 0.900 for DDO; a HANNA Checktemp digital thermometer and a Stem. A volume of the fuel was taken from the 500 mL test tube and then the thermometer and density meter were inserted. After stabilisation of the density meter (about 15 to 20 minutes and without contact with the walls of the test piece), the temperature ( $T$ ) of the fuel and the measured density ( $d_4^T$ ) were read.

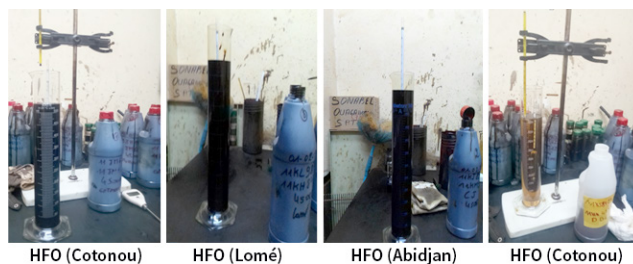


Figure 3: Measuring the density of each fuel

The following equation was used to estimate the density of HFO and DDO at 15°C (Guillermic 1980):

$$d_4^{15} = d_4^T + A (T - 15) \quad (3)$$

where:

$d_4^T$  is the measured density of the fuel at the temperature  $T$ ;

$d_4^{15}$  is the density at 15°C; and,

$A$  is the density correction factor.

The table given by Guillermic (1980) for the choice of the coefficient  $A$  was used. The density of HFO at 15°C was taken as the average of all three samples.

### Determination of water content

The determination of the water content was based on the NFT 60-113 standard (Guillermic 1980) (Figure 4). The water content of HFO was determined by taking the ratio of the volume of water contained in the fuel to the volume of the fuel considered. A mixture of 100 mL of xylene (non-disposable solvent) and 100 mL of HFO taken with the test tube was first poured into the

flask. Everything was stirred to obtain a homogeneous mixture. Then, we heated the mixture. The water in the sample was obtained by reflux distillation of the water-miscible solvent. After condensation, water separates from the solvent (xylene) and accumulates in the graduated recipe tube. Finally, the volume of water contained in the tube was read.



Figure 4: The water content test protocol

#### Determining the higher and lower calorific values of fuels

The higher calorific value (HCV) or gross heat (Q) of combustion of fuels consumed by thermal power stations (in cal/g) is estimated using equation (4) given by Speight (2006) which gives a fairly high accuracy of HCV with a deviation generally less than 1%.

$$HCV = Q = 12\,400 - 2100 d^2 \tag{4}$$

Where: d is the 60/60°F specific gravity or density at 15.6°C.

The HCV in kJ/kg is obtained by multiplying the above expression by 4.185 kJ.

In this study, the density at 15°C of the fuels is used to estimate the HCV.

The lower calorific value (LCV) of fuels (in kJ/kg) is estimated using equation (5) (Sawerysyn 1993):

$$LCV = HCV - m_{H_2O} L_v \tag{5}$$

where:

LCV: Lower calorific value of fuel consumed by thermal power plants in power plants (kJ/kg)

HCV: Higher calorific value of the fuel (kJ/kg)

$m_{H_2O}$ : Total mass of water in kg released by the combustion of 1 kg of raw fuel

$L_v$ : the latent heat of vaporisation of water.

The total mass of water ( $m_{H_2O}$ ) is estimated using equation (6) (Sawerysyn 1993).

$$m_{H_2O} = \frac{\%E}{100} + \frac{9\%H}{100} \tag{6}$$

where:

%E is the overall moisture content of the raw fuel; and, %H is the hydrogen content of the fuel.

These different percentages are related to the unit mass of the raw fuel. The following information was considered: 1 kcal = 4.185 kJ and  $L_v = 2.51$  MJ/kg at 0°C (Ibrahim et al. 2006).

#### Method of quantifying CO<sub>2</sub> emissions

The following assumptions were applied:

- The oxidation factor (OF) of carbon was assumed to be 100%;
- The results of the HFO and DDO analyses were valid for all fuels in the different thermal power plants.
- The CO<sub>2</sub> emission factors evaluated in this study are used to quantify CO<sub>2</sub> emissions for 2018.

The CO<sub>2</sub> emissions from combustion were estimated using the following equation (CITEPA 2020):

$$E_{CO_2} = \sum_{f=1}^n Q_f \times LCV_f \times EF_{CO_2,f} \tag{7}$$

where:

$E_{CO_2}$  is the total CO<sub>2</sub> emission from fuel combustion (in kg);

$Q_f$  is the quantity of fuel f (in kg); and,

$EF_{CO_2,f}$  is the CO<sub>2</sub> energy emission factor for the combustion of fuel f (in kg CO<sub>2</sub>/TJ or kgCO<sub>2</sub>/kWh).

The CO<sub>2</sub> energy emission factor for the combustion of fuel (f) was calculated using the following formula (Ramphull & Surroop 2017):

$$EF_{CO_2,f} = FE_{CO_2,f} = C_E \times OF \times 3,667 \tag{8}$$

$$C_E = \frac{\%C}{LCV_f} \tag{9}$$

where:

%C is the carbon content in kg carbon/kg fuel;

OF is the oxidation factor;

3.667 is the ratio of the molar mass of CO<sub>2</sub> to that of carbon or the conversion factor of C to CO<sub>2</sub>; and,

$C_E$  is the carbon content per energy of the fuel in kg/kJ or kg/GJ.

#### Assessment of the CO<sub>2</sub> emission factor of electricity generation

The CO<sub>2</sub> emission factor of the electricity production of thermal power plants was estimated as the ratio of the CO<sub>2</sub> emitted in 2018 to the thermal production in the same period.

$$EF_{th} = \frac{E_{CO_2}}{E_{el,th}} \quad (10)$$

Where:

$EF_{th}$  is the  $CO_2$  emission factor of thermal generation in  $kg\ CO_2/kWh$ ; and,

$E_{el,th}$  is the electricity production of thermal power plants.

The EF of the electricity generation mix was calculated by averaging the EFs of the different electricity generation sources.

$$EF_{el} = (EF_{th} \cdot \chi_{th}) + (EF_{hy} \cdot \chi_{hy}) + (EF_{PV} \cdot \chi_{PV}) \quad (11)$$

where:

$EF_{el}$  is the emission factor of electricity generation in the electricity mix (in  $kg\ CO_2/kWh$ ) in 2018;

$EF_{th}$ ,  $EF_{hy}$  and  $EF_{PV}$  are the  $CO_2$  emission factors for thermal, hydro and solar PV electricity generation (in  $kg\ CO_2/kWh$ ) respectively;

$\chi_{th}$ ,  $\chi_{hy}$  and  $\chi_{PV}$  represent the ratio of thermal, hydro and solar PV generation in the electricity generation mix (in kWh) respectively for the period 2018.

Hydroelectricity and solar photovoltaic do not emit  $CO_2$  during the electricity generation phase. Equation 12 can thus be simplified as follows:

$$EF_{el} = EF_{th} \cdot \chi_{th} \quad (12)$$

The EF of  $CO_2$  from electricity generation can be estimated using the following formula:

$$EF_{el} = \frac{E_{CO_2}}{E_{el}} \quad (13)$$

Where:

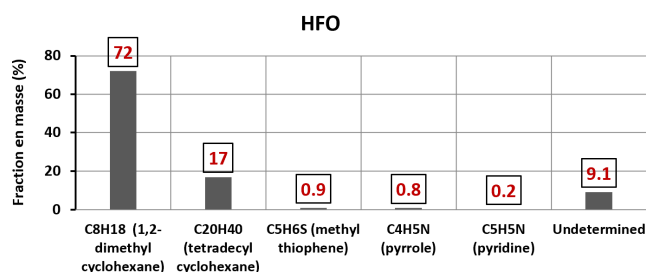
$E_{el}$  being is the total electricity production from all sources in kWh for the 2018 period.

## Results and discussion

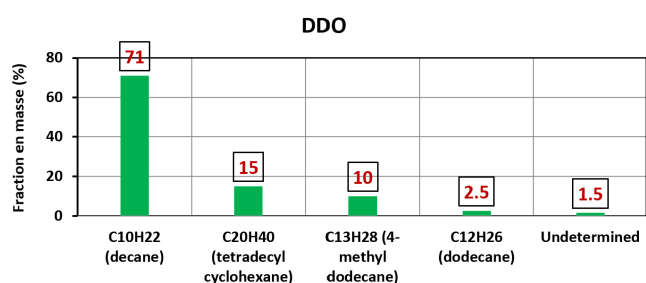
### Constituents and mass composition of fuels

1,2-dimethylcyclohexane ( $C_8H_{18}$ ) is the major molecular component present in HFO (72%) followed by tetradecyl cyclohexane ( $C_{20}H_{40}$ ) (17%) (Figure 5). HFO contains mainly cycloalkanes (or naphthenes) (89%) and small amounts of organic nitrogen compounds and sulfur. No oxides are present in HFO. The indeterminates in HFO are very high and this can be explained by several factors including the source of the fuel, as there are several varieties of heavy fuel oils. For DDO, the main molecular component is decane ( $C_{10}H_{22}$ ) (71%) followed by tetradecyl cyclohexane ( $C_{20}H_{40}$ ) (15%) (Figure 6). DDO contains 83.5% non-cyclic alkanes or paraffins and 15% cycloalkanes or naphthenes. It is also noticeable that sulfides, nitrates and

oxides are not present in DDO. The indeterminates in DDO are less significant than in HFO. Undetermined molecules (9%) in HFO are linear and branched alkanes with low percentages for each type of compounds. Thus n-alkane compounds are n-C10 (0.8%), n-C11 (0.7%), n-C13 (1.3%), n-C14 (2.2%), n-C15 (1.8%). The branched alkanes are C14 (1.2%), C15(0.5%) and C16(0.5%).



**Figure 5:** Molecular composition of HFO used for thermal power generation in Burkina Faso



**Figure 6:** Molecular composition of DDO used for thermal power generation in Burkina Faso

Previous studies have shown that petroleum hydrocarbons mainly contain paraffins, naphthenes, olefins and aromatic hydrocarbons (Gruyer et al. 2015). Crude oil and refinery products contain other elements such as sulfides (S), nitrates (N), oxides (O) and some metals including nickel and vanadium in low or trace concentrations especially the heavier fractions (Guibet 1997). Moreover, in HFO (heavy fraction compared to DDO), N compounds are present but in smaller quantities to the S compounds. This was correlated in the sampled SONABEL HFO and DDO results (Table 2).

**Table 2:** Elemental composition of HFO and DDO by mass and chemical formula of fuels

Fuel	Carbon (C)	Hydrogen (H)	Sulfur (S)	Nitrogen (N)	Chemical formula
HFO	84.54	15.13	0.22	0.11	$C_{9.247}H_{19.864}N_{0.01}S_{0.009}$
DDO	84.85	15.15	0	0	$C_{11.7}H_{25.07}$

The HFO consumed by thermal power plants contains a low sulfur content. The estimated C, S and N content of HFO and the C content of DDO are in line with the data provided by Speight (2006) and within the limits given by Guillermic (1980). The only exception is hydrogen for both fuels with a mass fraction above 14%. Indeed, in the literature, the mass fraction of hydrogen in petroleum fuels ranges from 10 to 14%

(Guillermic 1980, Speight 2006). This observed variance may be due to two reasons: i) differences in the origin of the oil and the refining conditions, and ii) difference in the fuel characterisation methodology. The results of the work of Kornelius et al. (2022) on the analysis of liquid and gaseous fuels used in South Africa gave a carbon content of  $85.93 \pm 1.58\%$  for Heavy Fuel Oil (HFO), and  $88.31 \pm 0.79\%$  in the summer period and  $87.00 \pm 0.38\%$  in the winter period for diesel. We found a difference of less than 2% between the carbon content value estimated in this study for Burkinabe HFO and South African HFO. The carbon content of sampled South African DDO was 3.92% and 2.5%, lower than that of diesel (in summer and winter respectively) as estimated by Kornelius et al. (2022).

### Density and water content of fuels

The density of HFO at 15°C is the average of the densities of the three HFO samples. It is evaluated at 0.964 kg/L (Table 3).

**Table 3:** Density of HFO and DDO at measured temperature and adjusted to 15°C

Fuel	HFO			DDO
	Provenance	Cotonou	Lomé	Abidjan
Temperature measured (°C)	28	29	29	29
Density $d_4^T$ (kg/L)	0.977	0.963	0.927	0.827
Correction coefficient A	$0.6 \times 10^{-3}$	$0.6 \times 10^{-3}$	$0.62 \times 10^{-3}$	$0.68 \times 10^{-3}$
Density $d_4^{15}$ (kg/L)	0.985	0.971	0.935	0.837

According to Gruyer et al. (2015), most hydrocarbons have densities between 0.7 and 0.99 kg/L at 15°C, and the calculated density for HFO and DDO are found to be in this range. In their work, Kornelius et al. (2022) found a density of  $0.994 \pm 0.12$  kg/L for HFO and  $0.826 \pm 0.002$  kg/L and  $0.825 \pm 0.002$  kg/L for diesel used in South Africa in the summer and winter periods, respectively. The density of DDO is 1.3% higher than that of diesel evaluated by Kornelius et al. (2022). HFO from Cotonou and Lomé are comparable to that from South Africa. The estimated density for HFO is in line with data from Wauquier (1994) and IPCC (2006b). Indeed, the density of HFOs is higher than 0.920 kg/L at 15°C (Wauquier 1994). For the IPCC, the density of heavy residual fuels, including those obtained by blending, always exceeds 0.90 kg/L.

In 100 mL of HFO, the volume of water measured is 0.05 mL, i.e. a water content of 0.05%. This result shows that the HFO consumed by SONABEL's thermal power stations has a very low water content. For DDO, the water content is considered to be zero because it is a cleaner fuel than HFO and even closer to diesel oil and its visual appearance shows that it contains no traces of water.

### Higher and lower calorific values of fuels

The total mass of water released by burning 1 kg of HFO is 1.3622 kg and for DDO it is 1.3635 kg. The HCV/LCV ratio is approximately 1.084 for HFO and 1.081 for DDO (Table 4). In this

study, the difference between HCV and LCV relative to HCV is about 7.5% for DDO and 7.8% for HFO. In general, calculations in the literature for different fuel categories show that the relative difference between HCV and LCV relative to HCV is in the order of 2-4% for coals, 5-8% for fuel oils and 0-15% for gaseous fuels (Sawerysyn 1993), and for the IPCC the LCV is about 5% lower than the HCV for coal and oil and 10% lower than the HCV for most forms of natural gas (IPCC 2006b). The estimated difference between HCV and LCV in this study is between 5 and 8%, a range given for fuel oils (Sawerysyn 1993). The LCV of HFO is slightly lower than the IPCC LCV for residual fuel oil. As shown in Table 4, the LCV of HFO is in the range of the LCV of residual fuel oils provided by the IPCC (39.8 and 41.7 TJ/Gg). Ramphull & Surroop (2017) estimated an LCV value of 40.6 MJ/kg for a viscosity of 380 cSt HFO and 41.1 MJ/kg for a viscosity of 180 cSt HFO consumed in Mauritius. For HFO with a viscosity of 180 cSt, the difference is less than 2%. The LCV of DDO (42.31 MJ/kg) is very close to that estimated for Mauritian diesel (42.3 MJ/kg) by Ramphull and Surroop (2017). The LCV of DDO is slightly lower than the IPCC LCV for diesel (with the estimated difference being 1.63%). The LCV of DDO is within the IPCC range of diesel LCV (41.4 - 43.3 MJ/kg). It is very close to that estimated by Ramphull & Surroop (2017) for diesel (42.3 MJ/kg). The calorific values evaluated for DDO are respectively close to those evaluated for diesel by Kornelius et al (2022). Indeed, the latter found the HCV to be  $45.93 \pm 0.09$  MJ/kg ( $45.85 \pm 0.043$  MJ/kg) and the LCV to be  $43.05 \pm 0.07$  MJ/kg ( $42.99 \pm 0.033$  MJ/kg) for diesel used in South Africa during the summer (winter) period. According to CITEPA (2022), the PCI of commercial heavy fuel oil in France is 40 MJ/kg and 42.6 MJ/kg for domestic fuel oil/gasoil.

**Table 4:** Estimated HCV and LCV for Burkinabe fuels

Fuels	HFO	DDO	Residual fuel oils (default LCV) (IPCC 2006b)	Gasoline/ Diesel (default LCV) (IPCC 2006b)
HCV (kJ/kg)	<b>43 726.88</b>	<b>45 737.05</b>	-	-
HCV (MJ/kg)	<b>43.73</b>	<b>45.74</b>	-	-
HCV (kWh/kg)	<b>12.15</b>	<b>12.70</b>	-	-
LCV (kJ/kg)	<b>40 307.76</b>	<b>42 314.67</b>	40 400	43 000
LCV (TJ/Gg ou MJ/kg)	<b>40.31</b>	<b>42.31</b>	40.4	43.0
LCV (kWh/kg)	<b>11.20</b>	<b>11.75</b>	-	-
Lower and upper limit of LCV (TJ/Gg) for 95% confidence interval	-	-	39.8 – 41.7	41.4 – 43.3

### Carbon content by energy and CO<sub>2</sub> emission factors for fuel combustion

Figure 7 presents the results of the carbon content per energy and energy emission factors for the combustion of HFO and DDO on a net calorific basis and the IPCC default. The carbon content per energy and energy emission factors for combustion on a net calorific value basis and the IPCC default values are

also provided. Figure 7 shows the CO<sub>2</sub> EFs assessed for fuel combustion and the IPCC default EFs for residual fuel oils and diesel/diesel on a net calorific basis (IPCC 2006a).

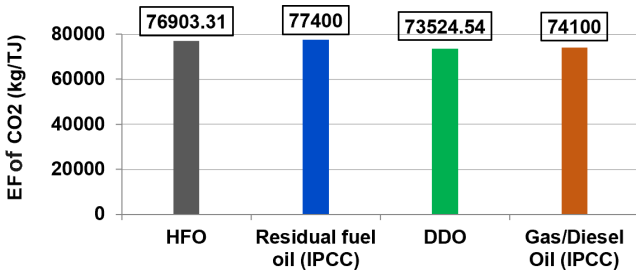


Figure 7: Energy-related CO<sub>2</sub> emission factors for HFO and DDO combustion and IPCC default factors for residual fuel oils and diesel/diesel in kg/TJ

The CO<sub>2</sub> EFs estimated for HFO and DDO combustion are slightly lower than the IPCC default EFs for residual fuel oils and gasoline/diesel respectively. The calculated EFs for HFO and DDO are within the IPCC 95% confidence interval for HFO (75 500 – 78 800 kg/TJ) and DDO (72 600 – 74 800 kg/TJ) respectively. According to the IPCC, when a country-specific EF falls within the 95% confidence interval, the emission factors can be considered consistent with the IPCC default values (IPCC 2006b). The calculated country-specific emission factors are therefore in agreement with the IPCC data.

### Contribution of the Burkinabe electricity sector to CO<sub>2</sub> emissions

Total calculated CO<sub>2</sub> emissions attributable to fuel combustion within Bukina Faso for the period 2018, using the developed counrty-specific emission factors, amounted to 580 Gg, i.e. 501 Gg from the combustion of HFO and 79 Gg from the combustion of DDO. This represents 86.5% for HFO and 13.5% for DDO. Using the IPCC default emission factor, SONABEL has estimated its CO<sub>2</sub> emissions for 2018 at 584 Gg (SONABEL 2018). The combustion of HFO emits more CO<sub>2</sub>, for the same energy production, than that of natural gas or lighter petroleum products (petrol, diesel, domestic fuel oil) but less than that of coal or petroleum coke (Soleille 2004). The Burkinabe power generation sector is a sector that contributes significantly to CO<sub>2</sub> emissions through the use of fossil fuels, particularly petroleum products.

### CO<sub>2</sub> emission factor for electricity generation

The emission factor of SONABEL's thermal electricity production is quite high, as 1 kWh of electricity produced by thermal power plants results in the release of 0.663 kg of CO<sub>2</sub> (Table 5). According to ADEME (2016), the emission factor of electricity production for the oil-fired power plant is 0.704 kg CO<sub>2</sub>-e per kWh. Afilal et al. (2019) state that the electricity generated from HFO has an emission factor of 0.73 kg CO<sub>2</sub>-eq per kWh for fuel oil. It is noted that the value estimated in this study is lower than the value provided by ADEME (2016) and Afilal et al. (2019) 5.8% and 9.2% for DDO and HFO respectively. The discrepancies are due to the fact that the EF of SONABEL's thermal production is for

CO<sub>2</sub> only and does not include other GHGs. It also does not take into account the emissions linked to the upstream fuels.

Table 5: CO<sub>2</sub> emission factor for thermal electricity generation and SONABEL's electricity generation

SONABEL's source of electricity generation	Thermal	Generation mix (thermal and renewable)
CO <sub>2</sub> emission factor (in kgCO <sub>2</sub> /kWh LCV)	0.663	0.569

The CO<sub>2</sub> emission factor of SONABEL's electricity production is quite high and highlights the largely carbon-based nature of the electricity produced in Burkina Faso by SONABEL. According to a feasibility study for the development of a regional electricity grid EF for the West Africa Power Exchange System (WAPES) in 2014, the EF of the regional electricity grid is estimated at 0.588 kgCO<sub>2</sub>/kWh and is also referenced to Burkina Faso in terms of SONABEL's interconnected grid (MEEVCC 2018). This EF is 3% higher than the one estimated in our study. This discrepancy is due to the fact that the value estimated in this work does not take into account emissions due to electricity exchanges at interconnections (electricity imports). In the West African sub-region, the electricity generated EF for Côte d'Ivoire, Niger and Benin are 0,402; 0.630 and 0.684 kgCO<sub>2</sub>/kWh respectively (Ritchie et al. 2022). In 2018, the global average carbon intensity of electricity generated was 0.475 kgCO<sub>2</sub>/kWh (CITEPA 2019).

### Assessment of the contribution of renewable energies to the reduction of CO<sub>2</sub> emissions in the electricity mix

#### Estimated CO<sub>2</sub> emissions avoided in 2018

In 2018, the share of renewable energy (RE) in SONABEL's electricity production was 145.5 GWh (SONABEL 2018), 14% of total production. The avoided CO<sub>2</sub> emissions (E<sub>CO<sub>2</sub>av</sub>) are evaluated by considering that the electricity production from RE sources (E<sub>ER</sub>) is instead generated by thermal power plants and by assuming the reference CO<sub>2</sub> EF (FE<sub>th</sub>) of 0.663 kg /kWh, estimated in this study.

$$E_{CO_{2}av} = E_{ER} \times FE_{th} \tag{14}$$

It is estimated that nearly 97 Mt of CO<sub>2</sub> were avoided, 16.7% of the total CO<sub>2</sub> emissions attributable to SONABEL's electricity production in 2018. RE in electricity production reduced the CO<sub>2</sub> emission factor by 14.2. The analysis of the results shows that the reduction of the concentration of anthropogenic GHGs in the atmosphere, in particular CO<sub>2</sub> in the electricity generation sector, can be achieved by increasing the share of RE in the Burkinabe electricity mix.

#### Evolution of the CO<sub>2</sub> emission factor of electricity generation according to the share of renewable energy

Natural resources that can be exploited for electricity production in Burkina Faso include sun (Bambara 2015), water (ECREE 2012),

biomass (Ministère des Mines et de l’Energie 2015) and wind (Landry, et al. 2011). In a context marked by the scarcity of fossil energy resources and the need to combat the harmful effects of climate change, the development of alternative energy sources is essential. In this context, one of the strategic objectives set by the Burkina Faso Ministry of Energy is to make electrical energy available and accessible to all through the development and mass use of RE in the energy supply.

In 2018, with 14.25% RE sources in the generation mix, the CO<sub>2</sub> emission factor of SONABEL’s electricity generation was estimated at 0.569 kgCO<sub>2</sub>/kWh LCV. The emission factor (FE<sub>el</sub>) of CO<sub>2</sub> for SONABEL’s electricity mix, as a function of the share of RE, was obtained using equation (13) with  $\chi_{th} = 1 - \chi_{ER}$ . Thus:

$$FE_{el} = FE_{th} \cdot (1 - \chi_{ER}) \tag{15}$$

Where:

$\chi_{ER}$  is the share of RE in SONABEL’s electricity generation mix

A projection of the CO<sub>2</sub> EF of SONABEL’s electricity mix according to the share of RE is presented in Figure 8.

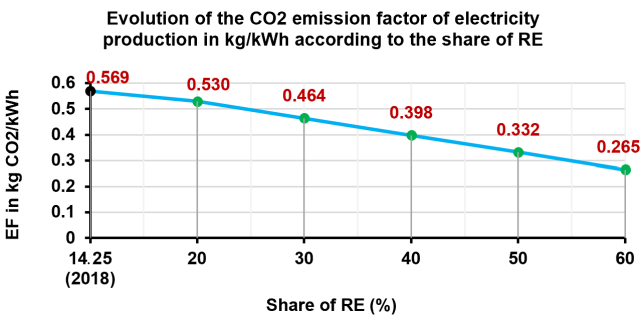


Figure 8: Evolution of the CO<sub>2</sub> emission factor of electricity production as a function of the share of renewable energy

The presence of RE (14.25%) in the electricity generation mix in 2018 enabled the CO<sub>2</sub> EF of the electricity generation mix to fall from 0.663 kgCO<sub>2</sub>/kWh to 0.569 kgCO<sub>2</sub>/kWh, a reduction of 14.2% in 2018. As the share of renewables in the generation mix increases, the EF gradually decreases. With a RE penetration rate of 57%, the CO<sub>2</sub> content per kWh of the electricity generation mix will be half that of 2018. Thus, an increase of 43% in the share of renewable energies in the generation mix will result in a 50% reduction in the EF of the electricity generation mix in 2018. Burkina Faso can reduce the GHG content of its electricity if it invests more in renewable. The model proposed in this study (Figure 8) is an indicator that will enable decision-makers and public authorities to take measures to decarbonise Burkina Faso’s electricity sector. Burkina Faso will be able to reduce the GHG content of its electricity on the one hand, and meet the demand for electricity on the other, by investing more in RE. Solar energy is the most abundant RE source in Burkina Faso with an average sunshine rate of 5.5 kWh/m<sup>2</sup>/day and a sunshine duration of 3000 to 3500 hours/year (MEEVCC 2018). It is the preferred RE source in the Burkinabe electricity mix for low carbon electricity.

## Conclusion

The CO<sub>2</sub> emission factors of electricity generation in Burkina Faso and the contribution of RE to reduce CO<sub>2</sub> emissions from the Burkinabe power sector have been evaluated in this paper. It was found that the estimated CO<sub>2</sub> energy EF for HFO and DDO combustion are slightly lower than the IPCC default emission factors, but are within the 95% confidence interval given for the default EFs for residual fuel oils and diesel/gasoline respectively. The estimation of country-specific EFs took into account the characteristics of each fuel, notably the carbon content and the lower heating value. These emission factors are country-specific and are best suited to the national context for quantifying CO<sub>2</sub> emissions from power generation using the IPCC Tier 2 method, particularly for national GHG emission inventories under the UNFCCC. Burkina Faso’s power generation sector is a major contributor to CO<sub>2</sub> emissions in the energy sector. Increasing the share of renewable energies in the electricity production mix will, on the one hand, will solve the energy deficit and, on the other hand, significantly reduce the sector’s CO<sub>2</sub> emissions. As direct measurement of GHG emissions is a complex exercise, a tool for quantifying GHG emissions from the energy sector by means of emission factors could be developed in the short to medium term.

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