Open Access Library Journal
2023, Volume 10, e10481
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Assessment of Green House Gas Emissions from Thermal Technologies for Electricity Generation in Cameroon Using Life Cycle Analysis Method

Inoussah Moungnutou Mfetoum[1,2,3*], Max Keller Ndame Ngangue[1], Simon Koumi Ngoh[1,3], Francis Lénine Djanna Koffi[1], Jean Gaston Tamba[1,2], Louis Monkam[1]

[1]Technologies and Applied Sciences Laboratory, University Institute of Technology of Douala, University of Douala, Douala, Cameroon
[2]Transport and Applied Logistics Laboratory, University Institute of Technology of Douala, University of Douala, Douala, Cameroon
[3]Electrotechnical, Automatic and Energetic Laboratory, Higher Technical Teachers' Training College of Ebolowa, University of Ebolowa, Ebolowa, Cameroon
Email: *inoussah@gmail.com

How to cite this paper: Mfetoum, I.M., Ngangue, M.K.N., Ngoh, S.K., Koffi, F.L.D., Tamba, J.G. and Monkam, L. (2023) Assessment of Green House Gas Emissions from Thermal Technologies for Electricity Generation in Cameroon Using Life Cycle Analysis Method. *Open Access Library Journal*, **10**: e10481.
https://doi.org/10.4236/oalib.1110481

Received: July 6, 2023
Accepted: July 31, 2023
Published: August 3, 2023

Abstract

This research uses the Life Cycle Assessment methodology to assess the environmental impact of Cameroon's thermal power production technology. Thus, for Heavy Fuel Oil (HFO), Light Fuel Oil (LFO), and gas technologies, the Green House Gas equivalent emission factor values are 873 g/kWh, 944 g/kWh, and 577 g/kWh, respectively. These figures are much higher than the IEA-reported emission factor of the Cameroonian power mix, which is 207 g of CO_2-eq per MWh. On average, these technologies produce 1.7 million metric tons of CO_2 equivalent emissions every year.

Subject Areas

Energy, Environment and Sustainability

Keywords

Life Cycle Assessment, Cameron, Electricity, Green House Gas, Equivalent Emissions Factors

1. Introduction

Green House Gas (GHG) emission characteristics of diverse energy production systems need to be understood from an environmental perspective in light of rising concerns about anthropogenic climate change [1]. Numerous global Life Cycle Analysis (LCA) studies have been completed so far, with a focus on examining greenhouse gas emissions from power plants [2] [3]. Numerous studies [4] [5] [6] are now examining the nature of GHG emissions from energy-generating systems in Cameroon. There is now relatively little research being done on this topic for Cameroon, however, certain parts are being explored in this area. Most analyses of Cameroon utilize outdated information that does not accurately portray the state of the country's electricity grid. In Cameroon, life cycle analysis has been done before [7] [8] but not specifically for the generation of energy. This was done for biofuels. This calls for an in-depth analysis of the current power production systems in Cameroon.

Methods for predicting material/energy needs and computing GHG emissions have been developed thanks to prior work from throughout the globe, but are still immature and mature [9] [10] [11]. While there has been very little talk about developing a more compelling approach for predicting material/energy demands, there have been some efforts to enhance the process of calculating GHG emissions (for example, by making use of input-output tables) [12] [13]. In order to better understand the features of these systems from a global warming perspective, this study provides the findings of a life cycle assessment (LCA) of GHG emissions from power production systems. This research used cutting-edge methods to up-to-date data to create a model for calculating GHG emissions across the whole life cycle.

This model's strengths include the accuracy of its underlying assumptions about Cameroon's current economic and social conditions, the precision of its estimates of material and energy needs for systems of varying specifications, and the feasibility of simultaneously calculating GHG emissions via a cutting-edge method that combines process analysis and input-output analysis [14] [15]. This model was used to calculate the life-cycle greenhouse gas emissions per kilowatt-hour (kWh) for three different fuel types used in power generation: light fuel oil (LFO), heavy fuel oil (HFO), and natural gas (NG).

The separation between technology and society is impossible. That is to say, the features of technologies are largely determined by the features of the society in which they are used. Therefore, it is crucial to precisely describe the temporal and geographical range of any technical evaluation. The fundamental assumptions are the average level of production technologies currently exploited in Cameroon (energy, energy efficiency, load factor) and the current status reflecting Cameroon's socioeconomic situation (for instance, the share of production fuels, the technology used for production) in the second half of the 2000s [6].

Materials and building components may be evaluated for their environmental consequences in several ways. Although they serve their function, although, with certain limitations [16], they are not ideal. LCA, or life cycle assessment, is a technique used to assess the environmental impacts of processes and products across their entire lifespan [17] [18]. Extraction and processing of raw materials;

production; distribution; usage; reuse; maintenance; recycling; and ultimate disposal are all factors included in the evaluation [9]. Since LCA treats the framework, effect assessment, and data quality all at once, it has become a popular technique [19]. ISO 14040 provides the foundation for LCA methodologies, which are comprised of four separate analytic steps: establishing the objective and scope, developing the life-cycle inventory, evaluating the effect, and lastly interpreting the findings [20]. When used extensively, LCA analyzes the environmental impacts of a good or service across its entire life cycle, from the point of origination to the point of disposal. This includes the extraction of raw materials, the production phase, the use phase, and, if necessary, reprocessing.

ISO 14040 defines LCA as "a technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases". To aid with analytical decision-making, LCA is often used [10]. When contrasting well-established production and processing methods, such as recycling and incineration for waste management [21] it has found widespread use. More and more people are turning to LCA as a means of producing more environmentally friendly product cycles.

The environmental effects of the energy system as a whole may be evaluated by using a technique called life cycle analysis [16].

Life cycle assessment of the GHG emission factor as a benchmark for comparing the global warming impacts of various power production systems.

Greenhouse gas emissions including CO_2, CH_4, and N_2O are the main focus of this research. Carbon dioxide is released when fuel is burned. Leaks in the extraction of coal, oil, and natural gas are the primary sources of CH_4 emissions, which are then used in direct combustion power plants. When combustion occurs at high temperatures, the nitrogen dioxide (N2) in the fuel or combustion air is oxidized, releasing N_2O.

Life-cycle assessment has been used for environmental management since the 1960s, but it has gone by several names since then [21]. Some terminology that indicates distinct levels of and approaches to study sound quite similar, particularly in early 1990s writing. Life-cycle studies in the environment are now often referred to as life-cycle assessments. Life-cycle thinking is often believed to have originated in the United States military [22]. The cost of running and maintaining a system was previously taken into account. Life-Cycle Accounting or Life-Cycle Costing is the name given to this method of calculating expenses. LCA initially appeared in its present environmental understanding in a study conducted by Coca-Cola to assess the cradle-to-grave environmental consequences of their packaging [23]. At the time, we weren't as concerned with greenhouse gas emissions or electricity use as we were with cutting down on solid trash. Authorized by Boustead and Hancock [14], the first life-cycle perspective publication was a handbook on industrial energy analysis. Numerous life-cycle analyses had been published by that time, and there had been a subsequent surge in interest in the topic among the general populace [24].

In 1992, SETAC (the Society of Environmental Toxicology and Chemistry) hosted two life cycle assessment seminars. The first addressed data quality, while the second addressed life-cycle effect evaluation [10]. In 1993, a meeting was held in Portugal between the SETAC LCA advisory groups from North America and Europe. And they came up with the LCA Bible, also known as the Guidelines for Life-cycle Assessment: A Code of Practice [9]. In addition to SETAC's efforts, the Khasreen *et al.* [24] also saw the publishing of a number of LCA recommendations, such as the Dutch guidelines on LCA [18] [25]. Norwegian, Swedish, Finnish, and Danish authors collaborated to write the Nordic Guidelines on Life-cycle Assessment [11]. Life-cycle Assessment: What Is It and How Do You Do It? It was published by the United Nations Environment Programme, while Life-cycle Assessment: A Guide to Approaches, Experiences and Information Sources was published by the European Environment Agency [21].

Among the various efforts to standardize the life-cycle assessment technique was the 1994 publication of the first national LCA guideline, Z-760 Environmental Life-cycle Assessment, by the Canadian Standards Association [24]. The International Organization for Standardization (ISO) developed the most widely accepted standards [26]:

ISO 14040 Environmental management, LCA, Principles and framework (1997);

ISO 14041 Environmental management, LCA, Goal definition and inventory analysis (1998);

ISO 14042 Environmental management, LCA, Life-cycle impact assessment (2000);

ISO 14043 Environmental management, LCA, Life-cycle interpretation (2000).

At the end of this brief, non-exhaustive review of work on the assessment of greenhouse gas emissions linked to energy production, it emerges that very few use life cycle analysis. Elsewhere, these assessments are carried out on production systems that are very different from those encountered in Cameroon, where thermal power generation technologies are essentially made up of generator sets of more or less considerable power. The few studies carried out in Cameroon are not based on reliable data. To this end, this work aims to apply this life cycle assessment methodology to quantify these emissions and compare them with those from production systems in other (reference) countries, in order to provide decision-makers with information and indicators for better decision-making.

2. Methodology

2.1. Overview of the Cameroon Electrical System

Multiple power stations in Cameroon generate electricity from various resources. Both fossil fuels (HFO, LFO, NG), as well as biofuel, and hydraulic sources are used in production [6] [27] [28].

Electricity in Cameroon is transmitted through three separate linked systems. The electricity generated at the hydroelectric power stations of Song Loulou and Edéa and the thermal power plants of Oyomabang, Bassa, Logbaba, Limbé, and Bafoussam is transported to the consumption areas through the South integrated network (SIN). The SIN has 17 substations (4 interconnection stations and 13 source stations providing the distribution networks), 480 kilometers of 225 kilovolt (kV) lines, and 870 kilometers of 90 kilovolt (kV) lines. Central, Southern, Littoral, Western, Northwestern, and Southwestern are all part of the SIN's coverage area. The interior (Central and South Regions), the coast (Littoral Regions), and the western (West, Southwest, and Northwest Regions) parts make up its three primary divisions. The spatial arrangement of the SIN is shown in **Figure 1** [28] [29].

The power plants at Lagdo and Djamboutou use the North Interconnected Network (NIN) to provide their output to the many centers of demand in the region (Garoua, Maroua, Ngaoundéré, and Meiganga). Four source stations and a total of 600 kilometers of transmission lines (400 kilometers of 110 kV and 200 kilometers of 90 kV) make up the NIN. **Figure 2** presents the NIN's geographic reach into three northern areas [28] [29].

The Eastern Interconnected Network (EIN): There is no strictly speaking of an interconnected transport network. Only two 30 kV lines can evacuate energy to the consumption centers around the Bertoua power station [28] [29].

2.2. Production Infrastructures

In 2020, Cameroon's electricity generation infrastructure comprised three hydroelectric facilities, each equipped with three reservoir dams for the regulation of Sanaga River storage. The total storage capacity of these facilities was 7.6 billion cubic meters, with Mbakaou, Mapè, and Bamendjin accounting for 2.6 billion

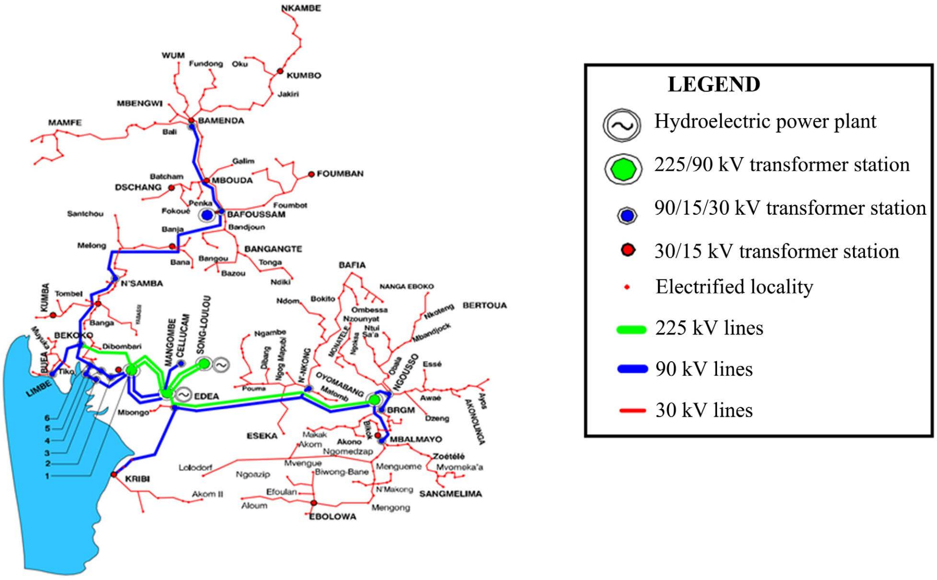

Figure 1. Southern interconnected network (SIN) of Cameroon.

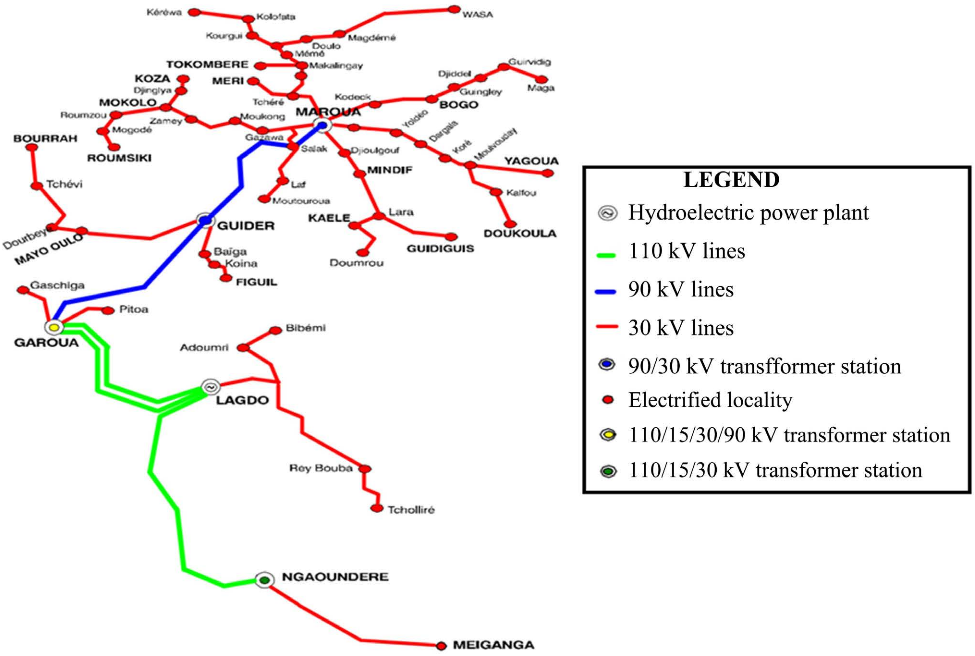

Figure 2. North interconnected network (NIN) of Cameroon.

cubic meters, 3.2 billion cubic meters, and 1.8 billion cubic meters, respectively. Additionally, the country had thermal power plants that utilized either light fuel oil (LFO) or heavy fuel oil (HFO), including natural gas. According to sources [5] and [27]. **Table 1** presents an overview of the primary power plants in Cameroon and their respective allocation across the interconnected networks.

It is noteworthy that in 2019, Cameroon possessed a generating capacity of 1529 MW, which was primarily derived from hydroelectric dams and thermal power plants. These sources were distributed in the following manner: The energy mix comprises 62.0% hydraulic sources, 17.4% gas thermal sources, 8.2% light fuel thermal sources, 11.2% heavy fuel thermal sources, and 1.2% renewable sources, primarily solar photovoltaic. The distribution of Cameroon's electricity generation in 2019 is depicted in **Figure 3**, as reported by sources [5] [6] [27], and [30].

The aforementioned capability encompasses that of ENEO, a prominent electricity distribution enterprise, along with autonomous producers such as the Dibamba Power Development Company (DPDC) and its Yassa-Dibamba power station (86 MW fueled by heavy fuel), and the Kribi Power Development Company (KPDC) and its Kribi facility (216 MW fueled by gas) [5] [6] [27], and [30].

The study analyzed three distinct electric power generation technologies, namely heavy fuel oil, light fuel oil, and natural gas. It has been posited that a mean level of production technology, encompassing energetic and exergetic efficiency, is prevalent in Cameroon. Furthermore, the current state of affairs is believed to be indicative of the socio-economic climate in Cameroon, with the proportion of imports being determined based on the extant quantity and quality of petroleum product production, spanning the time frame from 2006 to 2019.

Table 1. Major power plants in Cameroon (Sources: ENEO, DPDC, KPDC, MINEE).

Power plant	Fuel/Type	Installed Capacity (MW)	Commissioning	Network
Edéa	Hydro/Base	276	1950	SIN
Sonf-loulou	Hydro/Base	384	1981	SIN
Lagdo	Hydro/Base	72	1986	NIN
Limbé	HFO/Base	85	2004	SIN
Dibamba	HFO/Pointe	86	2009	SIN
Bassa 1 & 2	LFO/Base	18	-	SIN
Logbaba 1	LFO/Base	18	-	SIN
Bafoussam	LFO/Base	14	-	SIN
Oyomabang 1 & 2	LFO/Base	32	2004	SIN
26 Isolated power plants	LFO/Base	43	-	Isolated Sites
Logbaba 2	Gas/Base	50	2015	SIN
Kribi	Gas/Base	216	2013	SIN
Memvele'e	Hydro/Base	216	2019	SIN
Others Renewable	Renewable/Base	19	2019	SIN

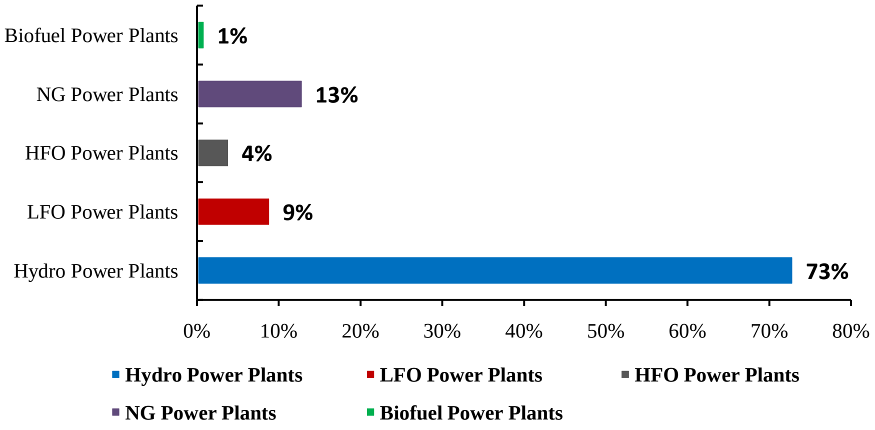

Figure 3. Share of electricity production by primary energy sources in Cameroon (2019).

The issue of methane emissions during the process of oil and natural gas extraction was examined. The calculated average energy and exergy yields have been taken into account for thermal power stations, as reported in references [5] [6], and [27].

Table 2 presents a summary of the operating parameters and estimated electrical energy output over the lifespan of various production systems.

The assumed source of crude oil for production is offshore fields located in the Gulf of Guinea, specifically Rio Del Rey. The Logbaba plant obtains its natural gas supply from either "Gaz du Cameroun" or the National Hydrocarbons Company's (NHC) field of operation in Kribi, which is situated in the broad Atlantic Ocean [5] [6], and [27].

Table 2. Operating parameters of power plants in Cameroon [6] [27].

Parameter	LFO power plant	HFO power plant	Natural Gaz power plant
Net power in 2019 (MW)	123	171	266
Energy efficiency (%)	31	33	37.4
Load factor (%)	70	70	70
Lifetime (Year)	50	50	50
Electricity produced during the lifetime (109 kWh)	28.478	7.653	17.416
Fuel consumed during the lifetime (106 GJ)	311.311	82.875	149.651

2.3. Methodology and Data Sources

In order to evaluate the energetic and exergetic performances of thermal power generation systems in Cameroon, we used data from the International Energy Agency (IEA) [27]. The reliability of these data was verified and validated on the basis of the reports of the national structures and more precisely the report of the Ministry of Water and Energy of Cameroon of 2014 (MINEE) [8], the operating data of the Kribi Power Development Company (KPDC) [28] and the Dibamba Power Development Company (DPDC) [29], the 2011 Cameroon Energy Information System (SIE-Cameroon) report, and the 2013 National Institute of Statistics Cameroon) [30]. The International Energy Agency provides data on primary energy consumption by source as well as electricity production data from each of these sources. It should be noted that the primary sources used in Cameroon are light fuel or diesel, fuel oil, natural gas for fossil sources and biofuels (agro-industrial residues, wood waste...) for renewable sources.

Table 3 shows the evolution of primary energy consumption by source. The assessment of all quantities (Embodied energy, GHG emission…) is based on these available data and the results obtained will be used to evaluate the evolution of the global emission factors for Cameroon.

2.4. Energetic-LCA Methodology for the Calculation of GHG Emissions

The concept of embodied energy pertains to the total amount of energy that is utilized in various activities required to facilitate a particular process. In the context of power generation systems, it is necessary to consider the energy expenditure associated with the complete production cycle. This encompasses the processes of raw material extraction and transportation, plant construction, energy generation, and eventual recycling or disposal following utilization. The diagram depicted in **Figure 4** illustrates the embodied energies pertaining to every stage of the life cycle of a power generation system, with a focus on the useful electrical output that serves as the intended end product [12].

The concept of embodied energy encompasses both direct and indirect forms

Table 3. Primary energy consumption for thermoelectricity generation in Cameroon from 2006 to 2014.

Primary energy consumption (GWh)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
LFO	445	680	680	1001	907	855	680	718	887	1634	889	938	794	651
HFO	126	184	192	282	256	241	192	203	250	461	251	258	224	183
Biofuel	643	76	77282	71	59	61	64	67	71	35	37	38	40	41
Natural Gas	0	482	500	413	417	467	492	921	1137	1486	1590	1767	2297	2168

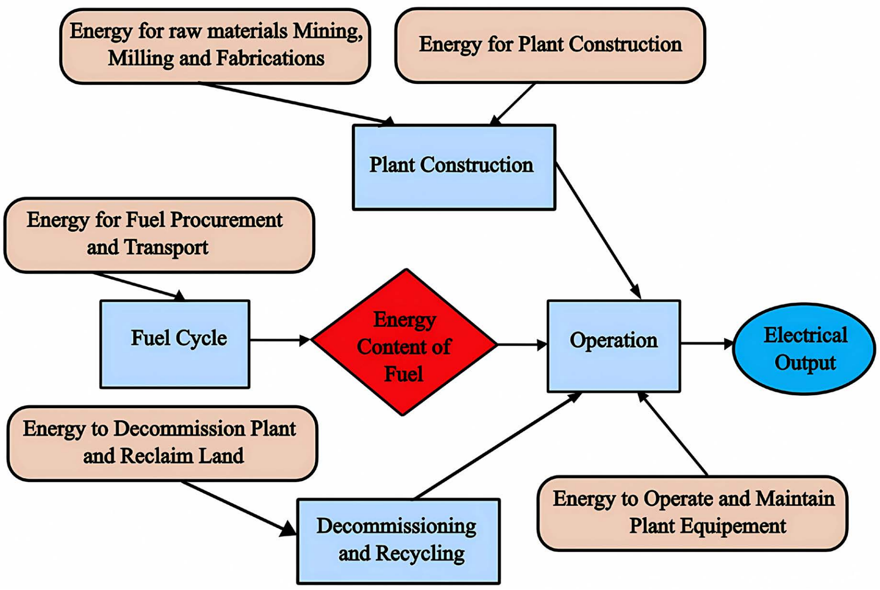

Figure 4. Embodied energy analysis of thermal technologies for the electricity generation [12].

of energy. According to scholarly sources, direct energy pertains to the energy utilized in primary processes, whereas indirect energy is necessary for the production of goods and services utilized in the primary processes [12].

In the context of power generation, the energy required for the production of electricity can be categorized into direct and indirect forms. Direct energy pertains to the actual generation of electricity, while indirect energy is associated with the extraction and transportation of raw materials, plant construction, decommissioning, and recycling of the power plant. This classification has been previously documented in literature sources [14] [31].

Equations (1) and (2) are utilized to assess energy indicators, namely life cycle energy payback (LCEPB) and life cycle energy cost (LCEC), in order to compare the efficacy of various power generation technologies [12] [24] [32] [33].

$$\text{LCEPB} = \frac{E_{\text{el}_{\text{CV}}}(\text{GJ})}{E_{\text{Inc}_{\text{CV}}}(\text{GJ})} \tag{1}$$

$$\text{LCEC} = \frac{E_{\text{Inc}_{\text{CV}}}(\text{MJ})}{E_{\text{el}_{\text{CV}}}(\text{kWh})} \tag{2}$$

$E_{\mathrm{el}_{\mathrm{CV}}}$ is the electrical energy produced by the system during its lifetime and $E_{\mathrm{Inc}_{\mathrm{CV}}}$ the embodied energy necessary for these productions.

2.5. Calculation of GHG Emissions

It is suggested that the embodied energies required for the worldwide production chain, with the exception of the energy directly consumed in power plants for electricity production, are derived from the combustion of coal or fuel oil, depending on the type of facility, namely LFO, HFO, or natural gas.

Table 4 presents the emission factors (EF) for various greenhouse gases, expressed in grams per gigajoule (g/GJ), as per the 1996 IPCC Guidelines [18]. These factors have been determined for each fuel type analyzed in the study. The computation of the comparable emission factor pertaining to a specific fuel involves the consideration of the global warming potential of each greenhouse gas over a period of 100 years. This entails assigning a value of 1 to CO_2, 21 to CH_4, and 310 to N_2O, as in Equation 3 (3).

$$\mathrm{EF}_{i_{comb}} = \sum_i \mathrm{GWP}_i \cdot \mathrm{EF}_{i_{comb}} \tag{3}$$

where GWP_i (in kg de CO_2eq/kg) is the global warming potential of the greenhouse gas *i*, $\mathrm{EF}_{i_{comb}}$ the emission factor GHG *i* with respect to the fuel.

Equation (4) has been utilized to determine the quantity of greenhouse gas emissions released during a specific stage of the electricity generation process.

$$E_{m_{jk}} = \mathrm{EF}_{\mathrm{eq}_{comb}} \cdot E_{nr_{jk}} \tag{4}$$

where $E_{m_{jk}}$ is the total quantity of CO_2-eq issued (in g/kWh) corresponding to the consumption of a quantity of energy $E_{nr_{jk}}$ (GJ/kWh) during phase *j* of the type of fuel *k*.

The calculation of the GHG emission factor denoted as $\mathrm{LCE}_{\mathrm{eq}_k}$ for the thermal generation system in Cameroon involves the summation of emissions from various phases, as per Equation (5). The resulting value is expressed in grams per kilowatt-hour.

$$\mathrm{LCE}_{\mathrm{eq}_k} = \sum_j E_{m_{jk}} \tag{5}$$

Equation (6) is used to determine the quantity $M_{\mathrm{CO_2\text{-}eq}_k}$ of CO_2-eq emitted during the production of an electric quantity E_{el_k} by the technology *k*.

$$M_{\mathrm{CO_2\text{-}eq}_k} = \mathrm{LCE}_k \cdot E_{el_k} \tag{6}$$

3. Results and Discussions

3.1. Energy Cost of Thermal Technologies of Power Generation in Cameroon

By conducting a material balance analysis, we were able to determine the embodied energies required for the production of each kilowatt-hour of net electricity in each respective system throughout the electricity production chain. The findings have been succinctly presented in Table 5.

Table 4. Emission factors EF (g/GJ) of different GHGs by type of fossil fuel [18].

GHG	Coal	Heavy fuel	Natural gas
CO_2	92,708	77,319	56,549
CH_4	15	3	4
N_2O	3	1.75	2.5
CO_2-eq	93,953	77,925	57,408

Table 5. Embodied energy in the different phases of the electricity generation life cycle in Cameroon.

Description of phases		Embodied energy (105 GJ/kWhe)		
		LFO Power Plant	HFO Power Plant	Gaz Power Plant
Fuel Cycle	Exploration	5.75	5.91	4.92
	Production	12.57	73.13	60.90
	Transport	1.27	7.36	6.13
Plant construction	Raw material of construction	0.01	0.04	0..3
	Establishment of the power plant	0.07	0.43	0.36
	Plant equipment	0.05	0.27	0.22
Operation of the plant	Maintenance	7.09	41.25	34.35
	Combustion	1093.15	1082.87	859.24
Dismantling of the plant	Dismantling	0.005	0.028	0.023
	Recycling of the site	0.001	0.005	0.004
Total direct energy		1093.15	1082.87	859.27
Total indirect energy		26.82	128.42	106.94
Total		1119.97	1211.29	966.18

The allocation of shares for direct and indirect energies can be derived from the data presented in this table. The data indicates that the LFO, HFO, and Gas plants have direct fuel usage rates of 97.6%, 89.4%, and 88.9%, respectively, throughout their life cycles. Additionally, the indirect fuel usage rates for these plants are 2.4%, 10.6%, and 11.1%. A notable amount of energy is consumed by gas plants, primarily for the processing of fuel.

Table 6 displays the energy performance of the three technologies in terms of Life Cycle Energy Pay Back and Life Cycle Energy Cost. Based on the findings, it can be concluded that gas technologies exhibit superior performance compared to alternative options. The primary energy conversion efficiency of gas technologies is higher, which is reflected in the E (effect) indicator, similar to performance. The second metric pertains to the amount of energy required to generate a single kilowatt-hour of electricity.

Table 6. Performance indicators for thermal technologies of power generation in Cameroon.

Performance indicator	LFO Power Plant	HFO Power Plant	Gaz Power Plant
LCEPB	0.321	0.297	0.373
LCEC (MJ/kWh)	11.20	12.11	9.66

3.2. GHG Emission Factor from the Energetic-LCA of Thermal Power Plants in Cameroon

Our calculations are based on the hypothesis that the energy required for certain indirect phases of the production cycle can be sourced from either coal or heavy-fuel oil combustion. Table 7 shows the results of the above calculations.

The data presented in the table indicates that gas power plants exhibit a relatively high percentage of indirect emissions (14.5%) and a correspondingly low percentage of direct emissions (85.5%). The share of indirect emissions from natural gas-fired power plants is relatively higher for the following three reasons. Firstly, the liquefaction of natural gas requires a considerable amount of energy, as natural gas is generally transported in the form of liquefied natural gas (LNG). Secondly, the CO_2 produced when raw natural gas (NG) is extracted is released into the air during refining. For example, raw natural gas extracted from some gas wells can contain a considerable amount of CO_2, up to almost 11% molar. Thirdly, the CO_2 emissions linked to the maritime transport of NG are greater than those linked to the transport of coal and oil. This is because ships carrying NG travel faster than those carrying coal or oil, which requires significant energy consumption.

Based on our analysis of the life cycle of thermal energy generation technologies in Cameroon, we have determined the emission factors for each type. The LFO plants have an emission factor of 872.74 g/kWh, the HFO plants have an emission factor of 943.94 g/kWh, and the gas plants have an emission factor of 576.65 g/kWh.

The values presented in Table 8 indicate that they are relatively high when compared to those reported in the literature. It is worth noting that the thermal power generation technologies in Cameroon produce emissions that exceed the average mix of Cameroonian electricity, which is estimated to be 207 g of CO_2-eq by the International Energy Agency (IEA). High emission rates can be attributed to various factors such as the obsolescence of production equipment, inadequate maintenance practices, and low yields.

This comparison is further illustrated by the graph in Figure 5.

It is clear that the emission factors of thermal power plants in Cameroon are higher than those of industrialized countries such as France and Japan, and almost on a par with those of a developing country like Singapore. This high level of emissions is further exacerbated by the aging nature of the production facilities, combined with the fact that maintenance programs are not adhered to, resulting in poor combustion and therefore very high emissions.

Table 7. Emission factor of LFO, HFO and Natural Gas plants for electricity generation in Cameroon.

Description of phases		Emissions of CO_2-eq (g/kWh)		
		LFO Power Plant	HFO Power Plant	Gaz Power Plant
Fuel Cycle	Exploration	4.48	4.60	3.83
	Production	9.80	56.99	47.46
	Transport	0.99	5.74	4.78
Plant construction	Raw material of construction	0.0067	0.039	0.032
	Establishment of the power plant	0.058	0.34	0.28
	Plant equipment	0.043	0.25	0.21
Operation of the plant	Maintenance	5.53	32.14	26.77
	Combustion	851.84	843.82	493.27
Dismantling of the plant	Dismantling	0.0037	0.022	0.018
	Recycling of the site	0.0007	0.004	0.003
Total		872.74	943.94	576.65

Table 8. Comparison of emission factors calculated for Cameroon with those of other countries.

Emission factor (g/kWh)	Cameroon	Japan	Deviation (%)	Singapore	Deviation (%)	France	Deviation (%)
LFO power plant	872.74	780	11.9%	889	1.8%	704	24.0%
HFO power plant	943.94	742	27.2%	1014	6.9%	704	34.1%
Gaz power plant	576.65	607.6	5.1%	493	17.0%	406	42.0%

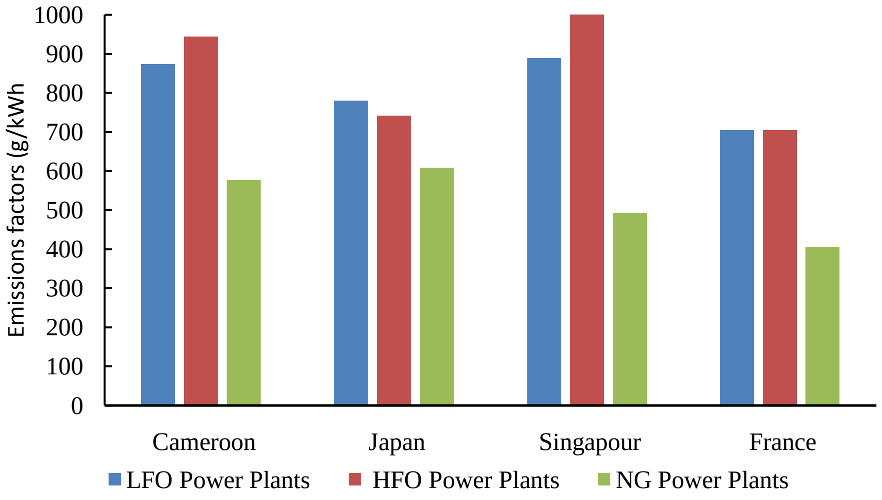

Figure 5. Mean emissions factors of some countries.

3.3. Evolution of GHG Emissions Linked to Electricity Production by Thermal Sources in Cameroon

Based on our analysis of energy cycles, we have computed the CO_2-eq emissions

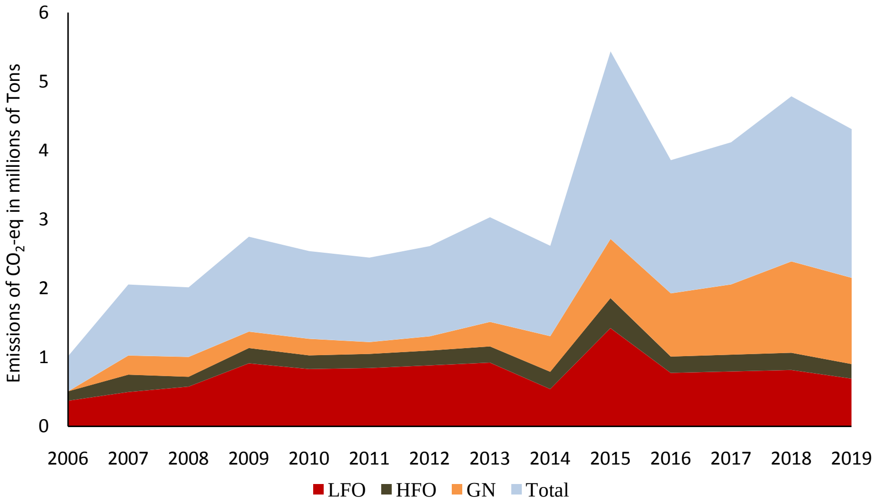

Figure 6. Evolution of GHG emissions by electricity generation technology and total emission.

of various electricity generation technologies using data spanning from 2006 to 2019. Calculation of the aforementioned can be facilitated by employing Equation (6).

The graphical representation in **Figure 6** depicts the progression of greenhouse gas (GHG) emissions for individual technologies over a span of 14 years, commencing in 2006 and concluding in 2019. Based on our analysis, it has been determined that the annual CO_2-eq emissions from the power plants utilizing fossil fuels (LFO, HFO, and Natural Gas) have an average of 1.17 million tons. The LFO plants contribute an average of 61.12%, while the HFO plants contribute 18.36%, and the gas plants contribute 23.09%.

4. Conclusions

This study analyzes the embodied energies associated with various stages of electricity generation in Cameroon, specifically focusing on three thermal technologies. The analysis is based on a material balance approach. The application of these energy sources in the production process resulted in two distinct assessments. Initially, it is crucial to assess the performance indicators, including the energy payback ratio (EPBR) and energy cost (EC), to enable a comparative analysis of diverse technologies. The emission factors for greenhouse gases in CO_2 equivalent were calculated for various technologies, enabling the tracking of annual CO_2-eq emissions over a 14-year period.

Based on the study, it can be inferred that gas power plants exhibit superior performance in natural resource conservation, as compared to LFO and HFO thermal power plants. This is due to their high-energy return time and low energy cost. Additionally, gas power plants have a lower GHG emission factor, thereby resulting in a lower environmental impact.

A comprehensive analysis that considers all electricity production sources in Cameroon, including hydroelectricity, bioelectricity, solar, and wind energy, can yield global indicators for the country. This will enable a thorough examination of the effects of integrating renewable energies on the electricity mix and its impact on the identified indicators.

Acknowledgements

We would like to thank the Cameroonian Ministry of Water and Energy (MINEE) and the Cameroonian National Institute of Statistics (INS) and the International Energy Agency (IEA) for providing relevant information and data, which make this study possible.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Hondo, H. (2005) Life Cycle GHG Emission Analysis of Power Generation Systems: Japanese Case. *Energy*, **30**, 2042-2056. https://doi.org/10.1016/j.energy.2004.07.020

[2] Khan, U., Zevenhoven, C.A.P., Stougie, L. and Tveit, T.M. (2023) Life Cycle Cost Analysis (LCCA) of Stirling-Cycle-Based Heat Pumps vs. Conventional Boilers. *Cleaner Environmental Systems*, **8**, Article ID: 100105. https://doi.org/10.1016/j.cesys.2022.100105

[3] Liu, H., Zhou, S., Peng, T. and Ou, X. (2017) Life Cycle Energy Consumption and Greenhouse Gas Emissions Analysis of Natural Gas-Based Distributed Generation Projects in China. *Energies*, **10**, Article 1515. https://doi.org/10.3390/en10101515

[4] Chen, L., *et al.* (2022) Strategies to Achieve a Carbon Neutral Society: A Review. *Environmental Chemistry Letters*, **20**, 2277-2310. https://doi.org/10.1007/s10311-022-01435-8

[5] Dountio, E.G., Meukam, P., Tchaptchet, D.L.P., Ango, L.E.O. and Simo, A. (2016) Electricity Generation Technology Options under the Greenhouse Gases Mitigation Scenario: Case Study of Cameroon. *Energy Strategy Reviews*, **13-14**, 191-211. https://doi.org/10.1016/j.esr.2016.10.003

[6] Inoussah, M.M., Adolphe, M.I. and Daniel, L. (2017) Assessment of Sustainability Indicators of Thermoelectric Power Generation in Cameroon Using Exergetic Analysis Tools. *Energy and Power Engineering*, **9**, 22-39. https://doi.org/10.4236/epe.2017.91003

[7] Bot, B.V., Axaopoulos, P.J., Sakellariou, E.I., Sosso, O.T. and Tamba, J.G. (2022) Energetic and Economic Analysis of Biomass Briquettes Production from Agricultural Residues. *Applied Energy*, **321**, Article ID: 119430. https://doi.org/10.1016/j.apenergy.2022.119430

[8] Tagne, R.F.T., *et al.* (2022) Environmental Impact of Second-Generation Biofuels Production from Agricultural Residues in Cameroon: A Life-Cycle Assessment Study. *Journal of Cleaner Production*, **378**, Article ID: 134630. https://doi.org/10.1016/j.jclepro.2022.134630

[9] Consoli, F., *et al.* (1993) Guidelines for Life-Cycle Assessment: A “Code of Practice”. *The SETAC Workshop*, Sesimbra, 31 March-3 April 1993, 1-85.

[10] Fava, J.A. (1993) A Conceptual Framework for Life-Cycle Impact Assessment. So-

ciety of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Pensacola.

[11] Lindfors, L.G., *et al.* (1995) Nord 1995: 20: Nordic Guidelines on Life-Cycle Assessment. NMR. https://scholar.google.com/scholar_lookup?title=Nord+1995%3A20%3A+Nordic+guide-lines+on+life-cycle+assessment&author=Lindfors%2C+L.-G.&publication_year=1995

[12] Fernando, A.T.D. (2010) Embodied Energy Analysis of New Zealand Power Generation Systems. Master's Thesis, University of Canterbury, Canterbury. https://doi.org/10.2316/P.2010.699-031

[13] Stamford, L. (2012) Life Cycle Sustainability Assessment of Electricity Generation: A Methodology and an Application in the UK Context. https://www.semanticscholar.org/paper/Life-cycle-sustainability-assessment-of-electricity-Stamford/4468cc3dacd396fee23a5129f17ff93b19c8f52d

[14] Boustead, I. (1979) Handbook of Industrial Energy Analysis. Ellis Horwood and Halsted Press, Chichester and New York. http://archive.org/details/handbookofindust0000bous

[15] Treloar, G.J. (1994) Energy Analysis of the Construction of Office Buildings. Deakin University, Geelong.

[16] Zbicinski, I., Stavenuiter, J. and Kozlowska, B. (2006) Product Design and Life Cycle Assessment. Baltic University Press, Uppsala.

[17] Klöpffer, W. (2006) The Role of SETAC in the Development of LCA. *The International Journal of Life Cycle Assessment*, **11**, 116-122. https://doi.org/10.1065/lca2006.04.019

[18] Mosier, A., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S. and van Cleemput, O. (1999) An Overview of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventory Methodology for Nitrous Oxide from Agriculture. *Environmental Science & Policy*, **2**, 325-333. https://doi.org/10.1016/S1462-9011(99)00022-2

[19] Selmes, D.G. (2005) Towards Sustainability : Direction for Life Cycle Assessment. Master's Thesis, Heriot-Watt University, Edinburgh. https://www.ros.hw.ac.uk/handle/10399/1136

[20] LaGrega, M.D., Buckingham, P.L. and Evans, J.C. (2001) Hazardous Waste Management. 2nd edition, McGraw-Hill, Boston. http://catdir.loc.gov/catdir/toc/mh021/00059453.html

[21] Hunt, R.G., Franklin, W.E. and Hunt, R.G. (1996) LCA—How It Came About: Personal Reflections on the Origin and the Development of LCA in the USA. *The International Journal of Life Cycle Assessment*, **1**, 4-7. https://doi.org/10.1007/BF02978624

[22] Jensen, A.A., *et al.* (1998) Life Cycle Assessment (LCA)—A Guide to Approaches, Experiences and Information Sources. European Environment Agency, Copenhagen.

[23] Heijungs, R., *et al.* (1992) Environmental Life Cycle Assessment of Products: Guide and Backgrounds (Part 1). https://hdl.handle.net/1887/8061

[24] Khasreen, M.M., Banfill, P.F.G. and Menzies, G.F. (2009) Life-Cycle Assessment and the Environmental Impact of Buildings: A Review. *Sustainability*, **1**, 674-701. https://doi.org/10.3390/su1030674

[25] Broekema, R. and Kramer, G. (2014) LCA of Dutch Semi-Skimmed Milk and Semi-Mature Cheese. Comparative LCA of Dutch Dairy Products and Plant-Based Alternatives.

[26] DeMendonça, M. and Baxter, T.E. (2001) Design for the Environment (DFE)—An Approach to Achieve the ISO 14000 International Standardization. *Environmental Management and Health*, **12**, 51-56. https://doi.org/10.1108/09566160110381922

[27] Rapport MINEE (2021) Statistical Yearbook of Cameroon's Water and Energy. Collection of Series of Water and Energy Sub-Sector Statistical Information up to 2019. Ministère de l'Eau et de l'Energie, Yaoundé.

[28] PDSE (2006) Document Stratégique de la Croissance et de l'Emploi, horizon à 2030, Cameroun.

[29] SIE-Cameroun (2011) Situation Energétique au Cameroun: Rapport 2011. Ministère de l'Eau et de l'Energie, Cameroun.

[30] Institut National de la Statistique (2020) Annuaire 2019 Statistique du Cameroun. Cameroun. https://ins-cameroun.cm/en/statistique/annuaire-statistique-du-cameroun-edition-2019-2/

[31] World Energy Council (2004) Comparison of Energy Systems Using Life Cycle Assessment: A Special Report of the World Energy Council. London.

[32] Lenzen, M. and Munksgaard, J. (2002) Energy and CO_2 Life-Cycle Analyses of wInd Turbines—Review and Applications. *Renewable Energy*, **26**, 339-362. https://doi.org/10.1016/S0960-1481(01)00145-8

[33] Norton, B., Eames, P.C. and Lo, S.N. (1998) Full-Energy-Chain Analysis of Greenhouse Gas Emissions for Solar Thermal Electric Power Generation Systems. *Renewable Energy*, **15**, 131-136. https://doi.org/10.1016/S0960-1481(98)00158-X