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Current State of Energy Production in Cameroon and Projection for 2035

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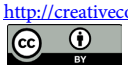

Abstract

The low electricity supply rate is a major cause of underdevelopment in Cameroon. To address this issue, Cameroon outlined a strategy in 2003 aiming for a production capacity of 3000 MW by 2020. However, by 2020, production had only reached 1040 MW, leading Cameroon to devise a new national energy sector development strategy targeting 5000 MW by 2035. This paper provides an overview of the current state of energy production and projects future output by 2035. Scientific articles and investigative reports on energy production in Cameroon have enabled an assessment of the current electrical energy production. The 2035 production estimate is based on the Energy Sector Development Projects (PDSEN) report in Cameroon. The current production is estimated at around 1600 MW. Considering the ongoing construction of power plants, future projects, and financing delays, achieving the 5000 MW goal by 2035 appears challenging. Nonetheless, diversifying energy production sources could bring Cameroon closer to this target.

Keywords

Energy Production, Cameroon Water Resources, Hydro Power, Electricity Supply, Energy Capacity

1. Introduction

According to the United Nations, nearly 640 million Africans lack access to electricity. With an estimated access rate of 40%, this contributes to underdevelopment, making Africa the least electrified continent [1]. Sub-Saharan Africa, including Cameroon, faces significant challenges in achieving the level of economic development necessary for the well-being of its population [2]. Access to electricity is crucial for economic and social development, as well as for improving quality of life [3]. Without it, building a solid and competitive industry is

challenging, as material processing, essential to a modern economy, relies on it [4]. Compared to other developing economies in North Africa, South Africa, Asia, and South America, sub-Saharan Africa ranks as the poorest region in terms of basic development infrastructure, including education, health, electrification, telecommunications, and transport [1].

Despite efforts to develop hydroelectric, thermal, and renewable energy sources, Cameroon's installed energy production remains well below demand due to its growing population and new industrialization. Before 2020, the energy production rate was only 0.76% [5]. Since 2004, Cameroon has been dedicated to addressing underdevelopment and poverty through initiatives like the Poverty Reduction Strategy Paper (PRSP) and, from 2009, the Growth and Employment Strategy Paper (GESP), part of the Vision 2035 plan. The goal was to reach an energy production capacity of 3000 MW by 2020, and later, 5000 MW by 2035, to overcome the energy deficit. This would meet the national economy and households' energy needs and potentially allow for surplus exports to neighboring countries. A stable energy supply allows the population to enhance their living conditions by engaging in income-generating activities such as agriculture and livestock farming. It also enables economic operators to expand their commercial and industrial activities. Guaranteed energy access supports efficient goods and services production, higher school enrollment rates, and quality healthcare centers, contributing to the country's emergence and sustainable development.

The aim of this work is to propose solutions to bridge the current energy deficit between supply and demand in Cameroon and to outline strategies to achieve an energy production target of 5000 MW by 2035. This will involve initially analyzing Cameroon's current energy landscape, focusing on all potential energy sources; specifically, it will update data on hydroelectric potential by evaluating existing infrastructure, its limitations, and current energy production capacity, as well as that of new power plants under construction and planned. The second part will examine the policies and strategies developed to boost installed energy capacity. The third part will clarify the causes of the observed shortcomings in the energy sector. The fourth part will highlight the scientific contribution of this work to addressing the current supply deficit, followed by a list of recommendations based on field observations. The article will conclude with a summary.

2. Methodology

The methodology is based on reviewing scientific articles and analyzing official documents and technical reports from local administrations and international institutions in the energy sector. This review focused on criteria like relevance, consistency, and the recurrence of information on energy potential, especially hydroelectricity in Cameroon. After preprocessing the documents, approximately fifty references were selected for their relevance to the same energy source and the information they provided (statistics, data), following the publi-

cation chronology. Visits to the Song Loulou, Edéa, Lom Pangar, Mekin, and Nachtigal hydroelectric sites in January-March 2021, February and December 2022, and June 2023 helped identify various realities in the hydroelectric sector. Data and figures related to the production capacity of future energy projects were sourced from various ministerial institutions (Minee, Minepat), project sponsors (investors, private partners), and based on their potential commissioning. Despite international organizations dedicated to hydropower issues worldwide striving to update available statistics, the absence of clear and reliable data on the potential and development of hydropower in Cameroon remains a significant barrier to fully leveraging the country's vast hydropower capacity to meet the energy access challenge across the sub-region [6]. The information collected from the selected documents was crucial in analyzing and evaluating the government's plans for the projected energy supply in 2020 and 2035. This research significantly contributes to the future development of hydroelectricity in the Central African sub-region, especially in Cameroon.

3. Current Energy Situation in Cameroon

3.1. Government Strategies for Energy Production

Cameroon's energy potential primarily comprises hydroelectricity (64%), thermal energy (30%), and other renewable energies (about 6%). The installed capacity increased from 933 MW to 1650 MW by 2020, falling short of the planned target of 3000 MW by a deficit of 1350 MW. Consequently, Cameroon has developed strategies like the Poverty Reduction Strategy Paper (PRSP) and the Growth and Employment Strategy Paper (GESP). The primary goal of these strategies is to significantly reduce poverty by fostering strong and sustainable economic growth. In December 1998, the first law on the electricity sector was enacted. Its aim was to modernize and improve the quality of electricity service by engaging the private sector to finance investments and manage the network, thus reducing the state budget's burden. However, these programs did not achieve the desired outcomes. Despite intentions, the country's growth rate decreased from 2.8% in 2005 to 3.3% in 2007, alongside inflation rising from 1.1% to 5.3% [7]. This was exacerbated by the low execution level of approved projects, inadequate construction of certain power stations, and an insufficient supply of nearly 900 MW of energy.

In 2020, the National Development Strategy (SND30) will be updated based on a revision of the DSCE. This update aims to align it with national socio-economic developments and the current international context, while also addressing the energy sector's shortcomings identified during the DSCE's implementation [6]. Among the reasons for these shortcomings in the sector are the mismatch between supply and demand, the deteriorated state of generation, transmission, and distribution infrastructure, and delays in constructing new generation dams as identified in the Electricity Sector Development Plan (PDSE 2030). For the period 2020-2030, the goal is to reach an installed production ca-

pacity of 5000 MW by 2035 to meet the energy needs of the national economy and households, and to consider exporting surplus to neighboring countries.

Many previous studies on energy in Cameroon have focused on demand and supply. Some authors suggest that Cameroon's energy policies should prioritize diversified energy production [8], with a greater emphasis on renewable energies, not only due to Cameroon's potential but also to ensure sustainable development. Despite efforts by international organizations responsible for hydropower issues to update statistics, the absence of clear and reliable data on the potential and development of hydropower in Cameroon remains a significant obstacle to optimally utilizing the country's vast hydropower capacity [1]. Although many studies have assessed the country's energy potential, very few have explored alternative solutions to hydropower for addressing the energy deficit [9].

3.2. Energy Supply

According to a literature review on energy production, the country's installed electricity generation capacity in 2018 was approximately 1402 MW, with 56.15% from hydroelectric sources, 43.84% from fossil fuels (17.55% natural gas and 26.29% oil), and the remainder from solar energy [9]. In 2020, the Energy of Cameroon (ENEO), the main energy supplier, reported electricity production of about 1529 MW, with 61.7% from hydroelectric power stations, 24.1% from thermal power stations, 14.1% from gas power stations, and 0.1% from solar energy. By 2021, Cameroon's energy supply decreased to an estimated 1047 MW, with an installed capacity of 822 MW from hydroelectric power stations by year-end—a roughly 30% decrease compared to the previous year—against an estimated energy demand of 1379 MW [10], a drop of around 30% compared with the previous year, against an estimated energy demand of 1379 MW. In its annual report, ENEO revealed that its electricity installations generated almost 807 MW. This shortfall was attributed to low water levels and challenges in delivering fuel to thermal power stations in the country's north. In 2022, generation supply figures were mixed. The Ministry of Water Resources and Energy (MINEE) reported a 1500 MW generation, marking an 87.34% increase in installed capacity from 822 MW in 2008. Meanwhile, another source cited a production of around 1990 MW [11]. As of 2022, Cameroon has not yet achieved its planned capacity of 3000 MW set for 2020, despite numerous programs implemented by the government in the electricity sector. The country still faces an energy deficit, with only 63.5% of its population having access to electricity in 2021, up from 49% in 2013, indicating a shortfall of around 330 MW. Demand for electricity is growing at an estimated 7.5% annually. ENEO is responsible for supplying 70% of the electricity consumed by households and businesses in Cameroon, with the remaining 30% provided by independent producers.

3.3. Financial Resources Invested

The Cameroonian government has allocated nearly 3500 billion CFA francs to address its financial deficit: 2000 billion for production, 1000 billion for upgrad-

ing the electricity transmission network (including the replacement of wooden poles with concrete ones and new transformers), and 500 billion for improving electricity distribution. Following a period of inactivity in the electricity sector from 1990 to 2006, Cameroon initiated several key projects. In 2008, the Energy Sector Development Project (PDSEN) was launched with the goal of increasing access to modern energy in rural areas and enhancing the planning and management of energy resources by specialized institutions, supported by a USD 50 million investment from the World Bank. According to recent statistics shared by the Minister of the Economy, Planning and Regional Development (MINEPAT) during a workshop in June 2023, Cameroon, which currently produces approximately 1682 MW of energy, aims to increase its production to 5000 MW by 2035 [12].

Since 1948, the country has constructed large hydroelectric schemes and thermal power stations to supply its population with electrical energy. Today, new hydroelectric dams and solar power stations are being built or are under construction, as illustrated in Figure 1.

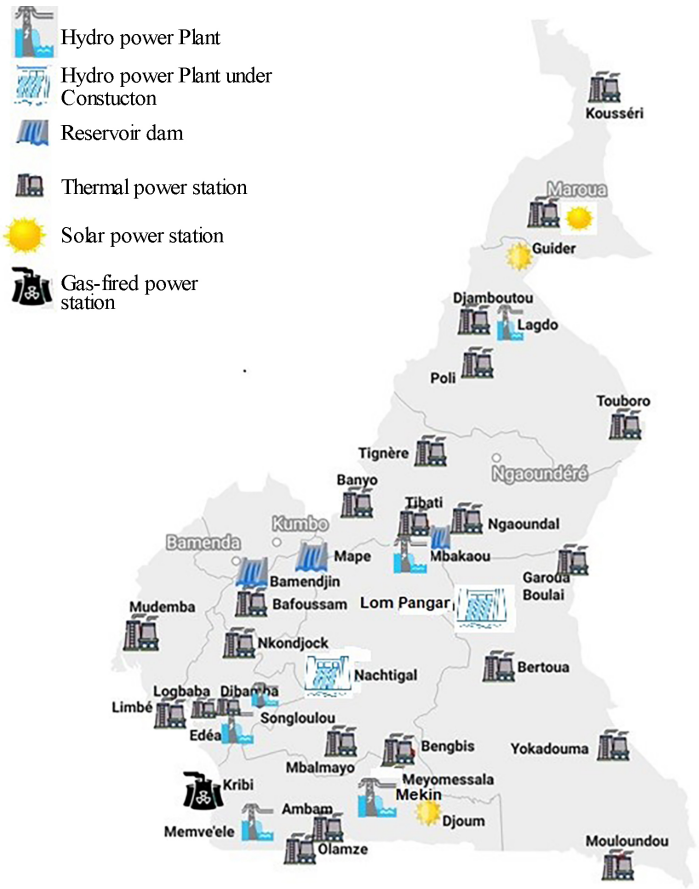

Figure 1. Power stations in Cameroon (Source: Authors' reconstruction) [13].

Table 1 shows statistics on the production capacity and installed power of various energy sources in Cameroon.

Table 1. Energy sources: Capacity and potential.

Energy source	Installed capacity	Production capacity	Potential capacity
Hydro power	1400 MW	989 MW	12,000 MW
Small hydro	9 MW	4 MW	158 MW
Thermal	605 MW	567 MW	-
Solar	55 MW	30 MW	113 MW
Wind	0 MW	0 MW	1067 MW
Biomass	37 MW	16 MW	420 MW

3.4. Hydroelectric Power Plants in Operation

The first hydroelectric power stations in Cameroon were inaugurated in 1929 to supply electricity to the Muyuka region [10] as a private operation. In 1948, the semi-public company Énergie Électrique du Cameroun (ENELCAM) was established to develop the Edéa I hydroelectric plant (22 MW) on the Sanaga River, providing electricity to Douala and Edéa. Since then, the installed energy capacity has increased with the construction of hydroelectric dams and thermal power stations. Recent data from 2019 estimates Cameroon's hydroelectric potential at 1367 MW against a demand of around 2000 MW, according to the World Bank. The country's current total hydroelectric generating capacity is approximately 947 MW, broken down as follows:

- **Song-Loulou hydroelectric power plant**

Song-Loulou is the power station with the largest installed electricity generation capacity in Cameroon, boasting 384 MW since 1981. Situated upstream of Edéa, it connects to the southern interconnected grid (RIS). Standing 39 meters high, it was constructed in two phases, each comprising 4 turbine-generator sets of 48 MW, between 1976 and 1985. However, production has been declining for two decades due to maintenance issues frequently causing turbine stoppages. Much of the production equipment is now obsolete.

- **Edéa hydroelectric power plant**

From 1948, ENELCAM began construction of the Edéa I hydroelectric power station on the Sanaga River, aimed at supplying Douala and Edéa. Initially inaugurated in 1954 with a capacity of 22 MW, the plant was expanded to 276 MW by 1976, featuring 14 generating units. Constructed in three phases, its primary purpose was to power Alucam, an aluminum production company founded in 1954. However, due to aging and obsolete equipment, the plant's current production capacity has decreased to 264 MW [6].

The Bamendjin, Mape, Mbakaou, and Lom-Pangar dams are the main reservoirs that supply water to the hydroelectric plants on the Sanaga River, as illustrated in Figure 2.

- **Memve'ele hydroelectric power plant**

It has an installed generating capacity of 211 MW/day, which feeds into the RIS. It is expected to supply electricity to six of Cameroon's ten regions, thereby

reducing the RIS's low energy supply. The current flow of the River Ntem is around 470 m^3/s, but over the past two years, this has drastically fallen to 80 m^3/s. In February 2023, a severe drought caused a period of low water levels, reducing its capacity to just 35 MW, or nearly 82%. With the return of the rains at the end of March 2023, the dam was once again operating at full capacity, producing almost 200 MW. After a 5-year delay, the Memve'ele dam began operating at full capacity in October 2022. A 225 kV transmission line has been carrying the energy produced by the dam from Nyabizan (Southern region) to Yaoundé (Central region) since September 2022. A few years ago, the government announced the Memve'ele 2 project, aimed at constructing a reservoir on the Ntem to definitively resolve the river's fluctuating hydrology. This project is still in the planning stages [14].

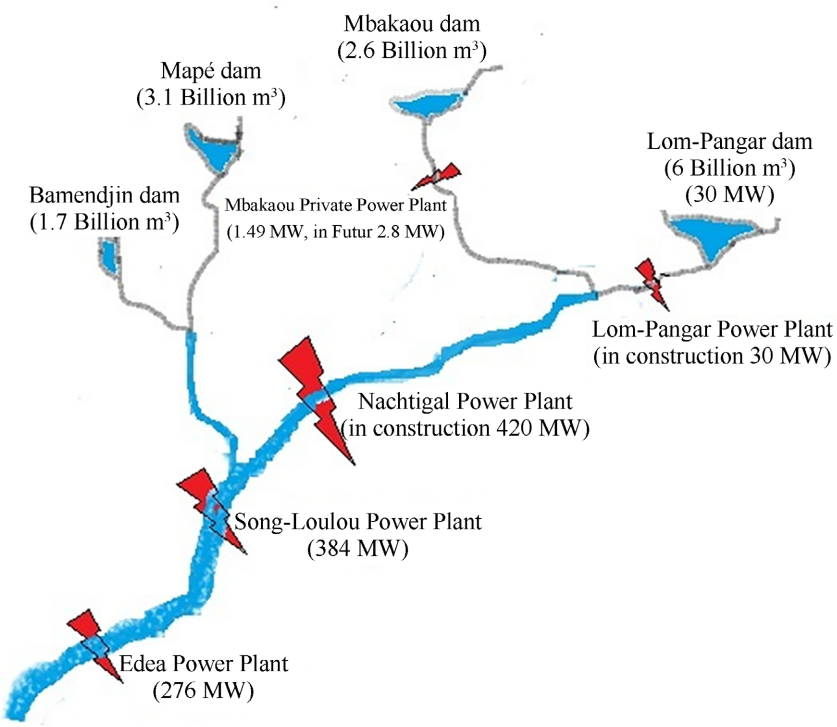

Figure 2. Hydroelectric power stations on the Sanaga River.

- **Mekin hydroelectric power plant**

The Mekin power station, located on the Dja River—a tributary of the Sangha that flows into the Congo River—has a capacity of 15 MW and stands 13 m tall. It is Cameroon's smallest hydroelectric dam based on installed capacity. Equipped with three horizontally arranged turbine-generator sets, each capable of producing 5 MW, the Mekin hydroelectric dam provides 75% of its electricity to the Southern Interconnected System (RIS). Additionally, it supplies power to three localities in the Centre and South regions.

- **Lagdo hydroelectric power station**

The Lagdo Dam, constructed in northern Cameroon from 1977 to 1982, was

the first dam in the region. Its reservoir can hold up to 7.7 billion cubic meters of water and powers a hydroelectric station with an original capacity of 72 MW. Serving as the primary electricity source for the Northern Interconnected Network (RIN), the dam has faced challenges due to silting and deteriorating infrastructure, reducing its output to as low as 30 MW and leading to load shedding. A rehabilitation project aimed at refurbishing the four turbines and other equipment is expected to increase the plant's capacity to 80 MW [15]. The refurbishment will cost the Cameroon government nearly 152.4 million euros.

- **Mbakaou small hydroelectric power station**

Mbakaou, Cameroon's first private hydroelectric dam, was commissioned in April 2022 in the Adamaoua region. It utilizes a flow of 13 m^3/s from the Djerem River and is equipped with two Kaplan turbines, generating a total rated power of 1.49 MW [16]. The power could be increased to 2.8 MW by 2026 to meet the growing needs of the population or if the RIN network expands to nearby towns like Ngaoundal and Banyo. The dam will significantly decrease load shedding and enhance living conditions in the area. It will also lead to the partial or complete closure of the Tibati, Ngaoundal, and Mbakaou thermal power stations, which were the primary power sources for these Adamaoua towns until December 2021. Environmentally, the Mbakaou mini power plant will allow Cameroon to reduce its CO_2 emissions by at least 4893 tonnes annually.

4. Other Energy Sources

4.1. Thermal Power Stations

Thermal power serves as the short-term solution implemented by the Cameroonian government to address the energy deficit not met by the operational hydroelectric power stations. National thermal production is estimated at 567.64 MW [17] [18], with the commissioning of new thermal power stations in Kribi (216 MW, 2013); Logbaba (150 MW, 2005); Dibamba (86 MW, 2009); Limbé (85 MW, 2004); Ahala (20 MW, 2015); and the old ones at Bertoua (13 MW, 2019); Oyomabang 1 and 2 (32 MW, 2002); Bamenda (20 MW); Bassa 2 and 3 (18 MW), Bafoussam (14 MW) [19] and others. There are also numerous isolated power stations with a total production capacity of 37,982 MW [18], electrifying surrounding localities. This brings the total national thermal generation capacity to 605,622 MW.

4.2. Hydrocarbons

Although Cameroon produces crude oil, it still heavily relies on importing liquefied petroleum products. Foreign trade statistics reveal a significant rise in imports from 1.026 million tons in 2018 to 1.62 million tons in 2020, marking a 59% increase. This surge in imports is due to growing demand and the disruption of SONARA's activities after the May 2019 incident [20]. Cameroon produces 81,000 b/d of crude oil and ranks 14th in Africa [21]. Production has decreased from 116,000 barrels per day in 2000 to 56,000 b/d, a 51.73% reduction.

Cameroon produces 2.68 billion m^3/year of natural gas and 1.2 million tonnes of liquefied natural gas (LNG) annually, with an estimated potential of 570 billion m^3 as of 2007 [8]. In 2022, gas production reached a volume of 2498.23 million m^3. The amount of natural gas sold to the Kribi thermal power plant for electricity production was 11.755 billion cubic feet. The Cameroon Oil Depots Company is facing significant challenges in supplying the domestic market due to rising demand. Consequently, the Cameroonian government is increasingly relying on international market imports [8]. Nearly two-thirds of the petroleum products consumed in the country are imported. This reliance on external sources, coupled with the prevailing economic conditions, has led to fuel price increases from 15.8% to 36.5%. The aim of this adjustment is to cut fuel subsidies by an average of less than 50% to alleviate the strain on public finances. The government reports a cumulative loss exceeding 1268 billion FCFA (2 billion euros) since 2020 [22]. Since February 2023, the price of a liter of super has been 730 FCFA, marking an increase of 100 FCFA. A liter of diesel now costs 720 FCFA, up by 175 FCFA. This has resulted in higher transportation costs, while only oil and domestic gas prices have remained stable.

In its 2016 Rural Electrification Development Plan (PDER), the government aimed to have renewable energies constitute 25% of the national electricity mix by 2035, totaling 1500 MW. This includes 650 MW (11%) from small hydroelectricity, 360 MW (6%) from photovoltaic solar, 420 MW (7%) from biomass, and 60 MW (1%) from wind power [14].

4.3. Small Hydropower

With its extensive network of rivers and streams, the country's potential for small hydroelectric power has been evaluated, identifying viable sites [11]. These sites are based on run-of-river systems with capacities ranging from 100 kW to 10,000 kW, such as Baré-Bakem at 110 kW and Nkam à Bexem at 9700 kW [5] [18]. Cameroon has initiated a comprehensive program to construct 50 mini hydroelectric power plants. This strategy, backed by a public-private partnership, aims to improve the quality of electrical service and reduce the production costs associated with diesel-fired thermal power plants, which significantly burden the public finances [14]. The estimated total mini-hydro capacity of the identified sites is around 158.241 MW [11], and this potential should be realized by 2035.

4.4. Solar Potential

Although the country has significant potential for solar energy, with average sunshine levels of around 5.8 kWh/m^2/day in the north and 4 kWh/m^2/day in the south, its development has been slow [23]. The Guider modular solar power plant in the north, with a capacity of 15 MW, is currently producing 1.5 MW, with plans to reach full capacity by the end of 2022. This should help reduce the deficit in the Northern Interconnected Grid (NIG). However, the challenges of storing and transporting solar energy prevent this solution from being optimal, despite its potential. ENEO, the concessionaire for the country's public electrici-

ty service, is planning to construct new solar power plants in northern Cameroon. The Maroua and Guider power plants, Cameroon's first public solar project with a combined capacity of 30 MW, were commissioned by MINEE in September 2023. Additionally, a 20 MW solar power plant is planned for the city of Garoua. These two solar plants will supply a total of 30 MW of clean energy to the RIN, enabling the shutdown of previously used thermal power plants in this region. This transition will result in budget savings for the State [24].

4.5. Biomass

Biomass in Cameroon, although still in its infancy, has been installed in several African countries. Private initiatives and projects have been underway since 2022, aiming at future exploitation. Biomass consists mainly of wood fuels, wood processing residues, agricultural residues, and food processing industry residues [8]. Its production capacity currently represents only 1% of Cameroon's energy mix. However, studies have shown that 37 identified sites across the country could produce up to 37 MW of electrical energy from biomass, according to the Rural Electrification Agency (AER). Biomass currently meets 70% of the country's energy demand [5]. Traditional biomass sources account for 74.22% of the country's primary energy consumption [7].

4.6. Wind Power

The potential of wind power is relatively modest and challenging to exploit due to low wind speeds, which rarely exceed 5 m/s [4] [8]. The Far North is an ideal location for wind power development, as its three regions have the highest wind speeds, between 3 and 5 m/s, offering a significant production capacity. There are vast areas where the average wind speed is well above 4 m/s at a height of 10 m above ground level [11]. In southern Cameroon, average wind speeds are 1.2 to 2.4 m/s lower than in the north. Some areas, like Bamenda, have wind power installations with average speeds of around 2.5 m/s in April. Plans to build a 42 MW wind farm in the Bamboutos mountains in the West, North-West, and South-West regions have been on hold since 2015 [25]. This project is expected to diversify Cameroon's energy mix, currently dominated by hydroelectricity, which accounts for 61.7% of national production, compared to 1% for biomass and 0% for wind power [26].

The need to introduce renewable energies into energy production arises from their ability to supply energy to remote areas through small-scale decentralized electrification. Increasing energy supply through renewable energies will enhance goods production and labor productivity by domesticating the technology derived from renewable energy deployment [27]. This is because working long hours, day and night, even in rural areas, will enable diversified economic growth.

5. Cameroon's Strategic Plan to 2035

During the first phase of the DSCE from 2010 to 2020, the plan aimed to double energy production and increase energy consumption per GDP unit by

27.7%, with specific targets of 33.5% in 2015, 40% in 2025, and 45% in 2035. Hydroelectricity and gas were prioritized as the primary sources of electrical power, targeting a capacity of 3000 MW by 2020. However, installed capacity increased from 933 MW to 1650 MW during this time, resulting in a shortfall of 1350 MW. Electricity access rates are 90% in urban areas but only 20% in rural areas [28]. However, it's important to note the discontinuity in electricity service for subscribers, due to frequent load shedding operations and a significant mismatch between supply and demand. This issue is worsened by outdated generation infrastructure and transmission and distribution networks, leading to approximately 40% energy loss. Additionally, delays in constructing new generation facilities, as outlined in the Electricity Sector Development Plan (PDSE 2030), contribute to the observed shortcomings in achieving the sector's goals.

5.1. Hydroelectric Power Stations under Construction

Electricity is recognized as a key driver of economic development [28] and the improvement of living conditions in any country. Over the past ten years, Cameroon has been constructing new second-generation hydroelectric dams, primarily in the Sanaga basin, to reduce the country's significant energy deficit. Table 2 displays the hydropower projects or dams currently under construction.

Table 2. Hydropower projects under construction.

Hydro power project	Start of construction	Drop height (m)	Flow rate (m^3/s)	Installed capacity (MW)
Nachtigal	2019	50	650	420 (7 × 60 MW)
Lom pangar	2011	36	1100	30 (4 × 7.5 MW)

5.2. Review of Work to Assess Cameroon's Future Hydropower Potential

To progressively reduce the country's current energy deficit by producing 5000 MW and avoid an imbalance between supply and demand by 2035, the State of Cameroon has identified several sites for future hydroelectric schemes [29] [30]. This energy production will not only satisfy local industrial and household demand but also allow for the export of surplus energy to neighboring countries facing difficulties, such as Chad, the Central African Republic, and especially Nigeria. In its National Development Strategy-SND 30, the Cameroon government is collaborating with financial partners on several future projects, as illustrated in Table 3.

All these projects, among the 17 priority hydroelectric projects in Cameroon, are part of the Electricity Sector Development Plan (PDSE) implementation. They aim to maintain the supply-demand balance for electricity in the Southern Interconnected System, according to MINEE.

Table 3. Planned hydropower projects in Cameroon.

Hydro power project	Expected capacity (MW)	Start of construction	Strategic partner	Start-up
Kikot	550	2025	EDF	2030
Minkouma	300	2026	Cam-Hydro USA	2030
Grand Eweng	1800	not yet known	Hydromine	
Chollet	600	not yet known	not yet known	2031
Song Mbengué	1080	not yet known	Fortescue future industries	
Song Dong	270	Technical studies in progress	Hydrochina International	
Noun Wouri	2000	Technical studies in progress	African Energy Company SA	
Makai	400	Technical studies in progress	Platinum Power	
Mouila Mogue	420	Technical studies in progress		

6. Discussions

Cameroon has immense hydroelectric potential yet fails to meet the electricity demands of its population and businesses. Despite an estimated annual demand increase of around 85,000 new customers, the country faces a significant energy shortfall for households and businesses [7]. Table 4 details energy consumption by sector. With an estimated energy potential of 25,000 MW, Cameroon could be entirely self-sufficient, as its total power generation output is eight billion kWh, or 128% of its needs.

Table 4. Energy consumption by sector since 2010 in percent (%).

Sectors/ Consumer	2022 [31]	2018 [9]	2010 [4]
Households	58.2	63.68	66.90
Transport	22.4	13.82	15.60
Industry	10.4	5.15	6.20
Commercial and public services	5.9	14.92	8.70
Other Sectors	3.1	2.43	2.60

Since 1980, electricity consumption in Cameroon has steadily increased, correlating with significant population growth [14]. This rise has been most notable in major cities, especially in terms of the population recorded over recent decades. To address medium and long-term energy demands, plans like the PDSE (Long-Term Development Plan for the Electricity Sector) and the PDER (Rural Electrification Development Plan) have been developed. These are implemented by the Ministry of Water and Energy (MINEE) and the Rural Electrification

Agency (AER) with the goal of achieving a 75% electrification rate by 2030 [32]. Therefore, it's encouraged to utilize alternative energies like solar, which is more practical for rural areas lacking access to interconnected networks, where extending or installing transmission lines is very costly for operators. Access to clean, inexpensive energy is crucial for eradicating poverty and reducing social inequalities [11]. Between 1982 and 2010, Cameroon did not need to construct new dams to increase installed generation capacity, as demonstrated in **Figure 3**, to meet rapidly increasing demand. Due to the country's grim economic situation, lack of funding led to the privatization of SONEL, Cameroon's sole national entity for electricity production, transmission, distribution, and usage. From this privatization emerged AES-Sonel and ENEO, which faced significant challenges in maintaining existing power plants' productivity. Efforts to extend the life of large dams and ensure a stable energy supply struggled. At this time, the installed hydroelectric production capacity was 732 MW, with the Song Loulou (384 MW) and Edéa (276 MW) dams on the Sanaga River contributing 91% of the nation's hydroelectric power, and the Lagdo dam (72 MW) on the Bénoué River.

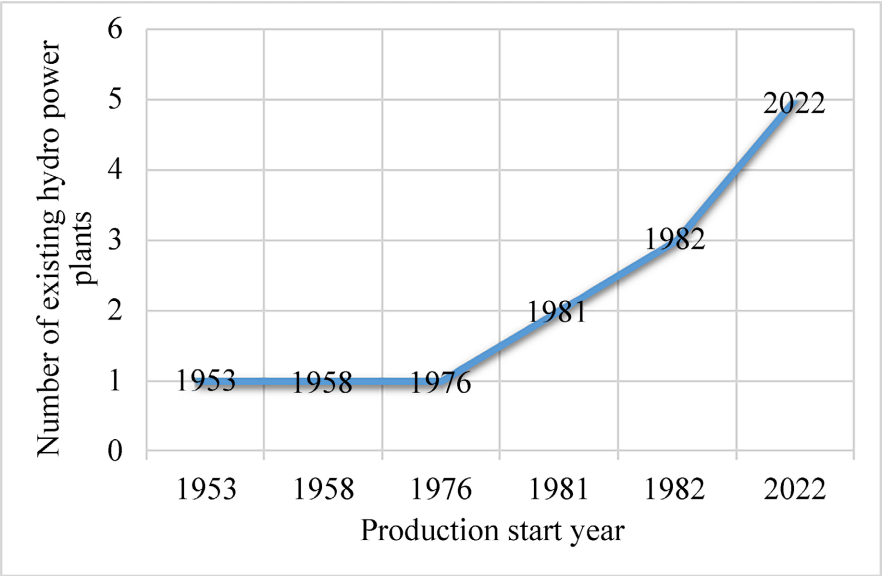

Figure 3. Number of existing hydropower plants 1953-2022.

Figure 4 illustrates the development of hydropower capacity in Cameroon from 1953, starting with the construction of the Edéa I hydropower plant (22 MW), up to 2022. Between 2010 and 2021, significant funding was secured for hydroelectric projects. It is only after 2022 that the new Memve'Ele, Mekin, and Mbakaou hydroelectric stations, with a combined capacity of 229 MW, will contribute to the national grid. Consequently, from 1982 to 2022, a span of nearly 40 years, the national hydroelectric production capacity stagnated at 732 MW, occasionally falling below the expected output during the dry season. This stagnation is a key factor behind the current energy imbalance, as energy demand has

been growing annually by approximately 5 to 7%.

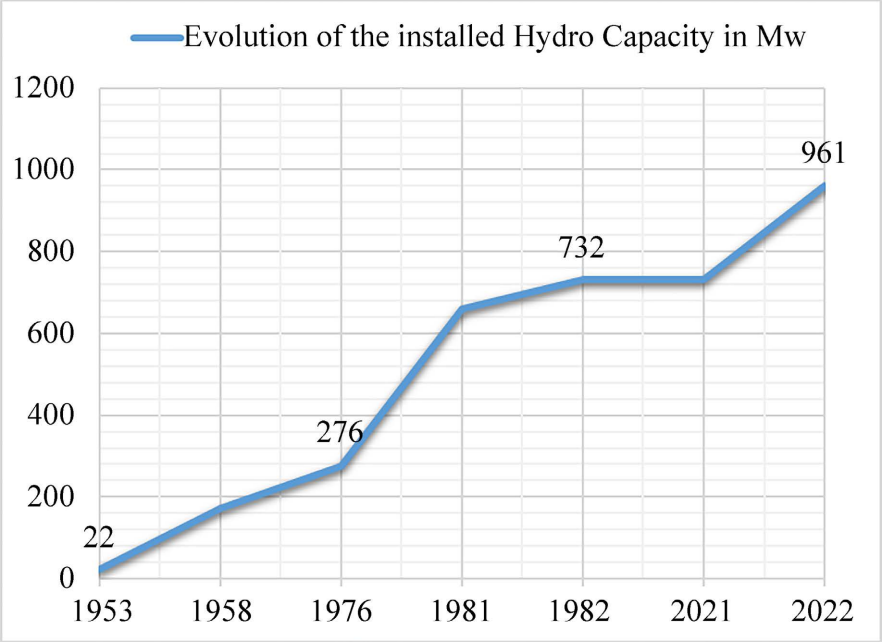

Figure 4. Evolution of installed hydroelectric capacity in Cameroon.

6.1. Causes of the Current Energy Crisis

The methodology for analyzing the causes of Cameroon's energy crisis involved visiting hydroelectric sites to examine the production systems of current power stations and the plans for new ones. This field trip, supplemented by official documents detailing Cameroon's strategies, revealed the country's electricity supply deficit and its vulnerability to load shedding. The crisis is largely attributed to the economic and financial downturn of the 1990s, which hindered the development of hydroelectric projects and the maintenance of existing facilities. Factors such as inadequate thermoelectric backup, slow development of other renewable energies, under-exploitation of available resources, and insufficient investment in rehabilitation and generation capacity [14], have been briefly described and are still relevant today. The main causes of the ongoing energy crisis in Cameroon since 2000 are listed in **Table 5**.

6.2. Financing Short-Term Energy Projects

According to government forecasts, production capacity will increase from 1540 MW in 2022 to 2000 MW in 2024, thanks to the commissioning of the Nachtigal hydroelectric power plant with an installed capacity of 420 MW, and the solar power plants under construction on the Northern Interconnected Network (RIN). The first two modular solar power plants in Maroua and Guider, with battery storage and a combined capacity of 30 MW, were commissioned in September 2023. The Cameroonian government states that Cameroon needs almost 2000 billion euros to finance its energy projects. These funds will support the

construction of the Limbé gas power plant (350 MW), the Grand Eweng, Chollet, Kikot, Katsina Ala (285 MW), and Menchum (72 MW) hydroelectric dams, among others. Due to a lack of funding and credible partners, some hydroelectric projects like the Bini Warack dam (75 MW) in the Adamaoua region have been put on hold. However, commissioning this dam, along with the Lagdo dam, could reduce the energy deficit in the northern regions.

Table 5. Main causes of the electricity supply crisis.

Different types of causes	Details
Technical aspects	Aging of production equipment Optimistic operation of the electricity sector Loss of production load Periodic forced shutdowns of power plants for safety reasons Blackouts in power plants and on transmission lines
In terms of industrial development	Lack of investment in production equipment Lack of clarity in the commissioning of projects; Delays in the completion of energy projects and the rehabilitation of power plants. There's a sharp increase in demand from industries during periods of intensive and massive production, such as in the cement and processing sectors. The Alucam plant is unable to manufacture MV and HV power cables.
Environmental and natural aspects	Impact of drought and siltation on hydroelectric dams Reduction and depletion of hydroelectric energy storage reservoirs Impact of heatwaves on thermoelectric power plants
On the economic front	Poorly prepared financing works Construction work deadlines missed Poorly evaluated and estimated construction costs Rapid growth in demand High cost and shortage of petroleum products (gas, diesel, oil).
On the social front	Land conflicts with neighboring communities Non-payment of compensation in full before work begins Long negotiations with local populations; Blockage of the start of work due to social demands

In 2006, the Cameroonian government developed the Electricity Sector Development Plan for 2030 (PDSE-2030) to address the growing demand for electricity, currently estimated at over 115 billion kWh/year [33]. Previously, the installed power generation capacity stood at 966 MW, with 75% coming from hydroelectric sources. However, the lack of maintenance and upkeep for production equipment made it challenging to satisfy the increasing demand [14].

Figure 5 illustrates that well before 2008, electricity demand consistently exceeded supply. The gap between supply and demand started to widen from the year 2000 onwards, driven by significant population and industrial growth.

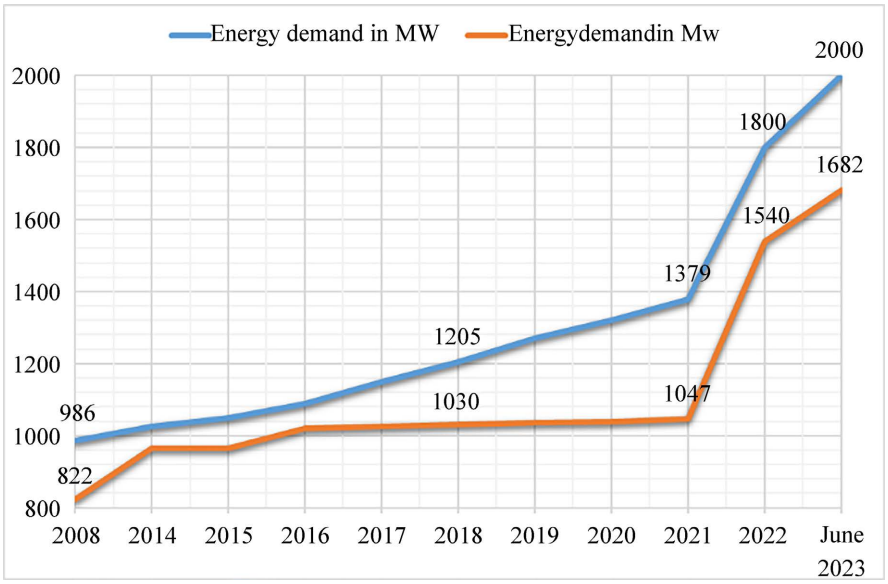

Figure 5. Trends in energy supply and demand in Cameroon over the past two decades.

Following the failure of the National Poverty Reduction Strategy initiated in 2004, including the preceding PDSE-2030 study, Cameroonian authorities in 2009 formulated a comprehensive development plan for the short, medium, and long term, named "Vision Cameroun 2035". This vision aimed to increase Cameroon's exports, particularly electricity exports to neighboring countries. Its primary goal was to modernize the economy, accelerate development, and achieve middle-income status in the medium term, ultimately transforming Cameroon into an industrialized or emerging country beyond 2030.

Despite all these initiatives, **Figure 6** shows that Cameroon's energy demand, compared with data for previous years (2010-2018) obtained by Laouan Marius et al. or Kidmo [4] [9], is increasing considerably in most sectors, especially in the

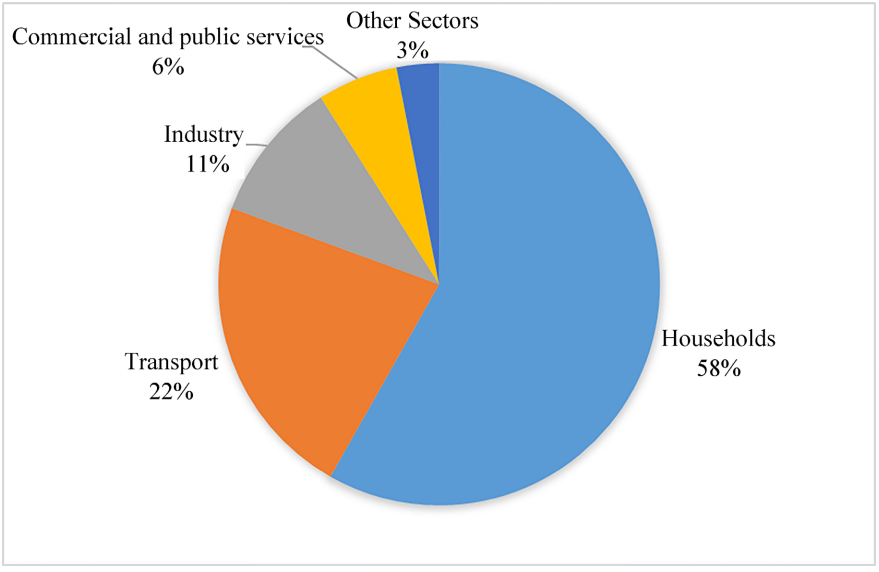

Figure 6. Energy demand by sector in 2022.

industrial sector, which frequently resorts to using generators. Given that energy is crucial for any country's development, it is imperative for Cameroon to address the 330 MW deficit in industrial energy needs by 2020. With an energy mix comprising 80% hydropower, 14% gas, and 6% solar, wind, and biomass, the country depends largely on hydropower to meet its energy needs. In 2016, the demand was estimated to grow by over 5% per year [34]. Despite efforts, the supply-demand gap is expected to widen by 7.5% annually from 2022 onwards.

Figures assessing the country's energy production potential and capacity in recent years vary across the literature, highlighting the problem of updating information. A review of the current literature on hydropower in Cameroon reveals unclear and divergent assessments of energy potential [6]. This discrepancy in assessing potential and the resulting outcomes has hindered accurate estimation of this source, as well as demand and supply in the country. The absence of precise information in scientific articles has often led us to rely on national or international publications and reports specializing in energy, particularly hydropower. The latter have had to publish more detailed information about our problem, specifically on the state of existing hydropower plants, their potential extension or renovation, new dam construction projects in their various stages of development, and the obstacles encountered.

In the push for industrialization and modernization, Cameroon encounters challenges such as a lack of funding and reliable technical partners. Hydroelectric projects demand significant capital and investment, despite the lower cost of electricity for consumers. Before 2013, the Cameroonian government announced plans to construct several hydroelectric dams, with a combined value of over 1389.4 billion francs, to be financed by both the state and private investors. **Figure 7** illustrates the development of hydropower projects from 2013 to 2023. Insufficient electricity production significantly hampers economic activity and private investment. This issue is particularly evident in the aluminum sector,

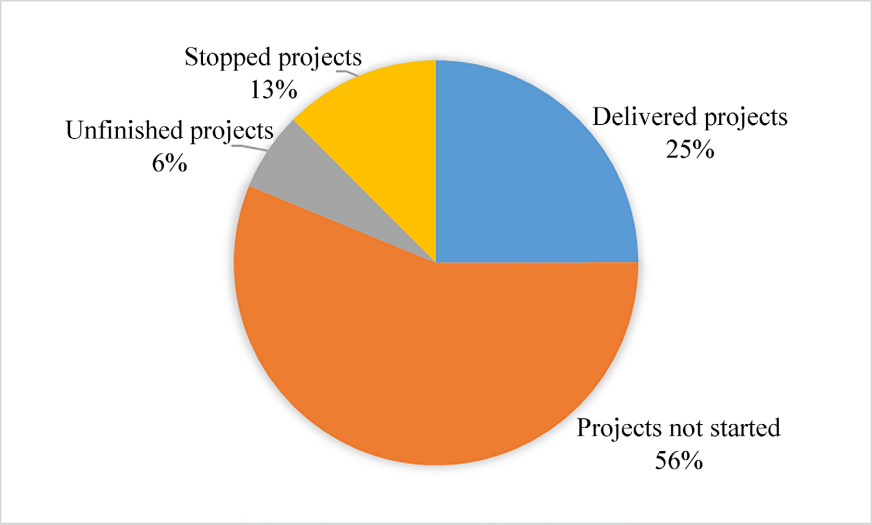

Figure 7. Development of hydroelectric projects between 2013 and 2023.

which relies on increased energy production capacity for development [35]. Several mining projects are currently pending government approval, as they are planned alongside power plants to mitigate the issue of long-distance energy transportation.

6.3. Possible Obstacles to Achieving Energy Production in 2035

➢ **Endogenous obstacles**

To achieve the targeted energy production of 5000 MW, it is advisable to take steps to avoid certain obstacles, similar to those encountered in Cameroon's initial programs. The potential obstacles impacting this objective are listed in Table 6 below:

Table 6. Possible obstacles.

Different types of obstacles	Details
Socio-economic plan	- Delaying work start due to social demands for unpaid compensation, - Releasing rights of way for mining, - Extended relocation of nearby residents to new housing areas, - Challenges in adaptation for locals in their new resettlement areas, - Insufficient support for local populations, - Limited local involvement in projects, - Lack of proper road infrastructure for site access.
Technical plan	- Insufficient skilled labor in certain sectors or professions and weak human capital, - Lack of clarity in project commissioning, - Missed deadlines for renewing existing equipment, - Neglect of scheduled maintenance, - Poorly prepared technical files, - Unmet work completion deadlines, - Inaccurately assessed and estimated construction costs, - Limited local technical skills in conducting feasibility studies, - Limited capacity of institutional actors.
Political front	- Administrative delays and red tape in issuing certificates of conformity - Poor governance characterized by corruption and favoritism - Procedural administration with limited resources - Low budget allocation for administrative operations - Lengthy tendering processes - Challenges in identifying specific institutional contacts - Delays in decision-making for selecting service providers - Difficulties in mobilizing credible partners or paying service providers - Inadequate tax legislation that fails to stimulate national private investment, featuring inconsistent texts - Absence of a clear framework for promoting investment in the energy sector - Delayed or nonexistent implementation of legislation - Complexity and multiplicity of reference texts - Lack of coordination among involved institutions - Security issues in certain project areas

➢ Exogenous obstacles

In addition to potential internal obstacles that could hinder reaching a 5000 MW capacity, there are external factors beyond Cameroon's control that might cause unexpected delays in energy production. Large-scale operations like these are typically financed through international loans. However, access to international funds for electricity projects is limited due to low load factors and the pricing policies in countries with low per capita incomes. These policies increase operational risks, as government-imposed tariffs often clash with the economic and financial goals of project owners. Ideally, a strategy should be developed to encourage as much self-financing of projects as possible. This can be achieved by enhancing their profitability through seeking public funds (both bilateral and multilateral loans), utilizing co-financing options with export credits, and implementing a tariff system that promotes better resource allocation and economic efficiency. This type of financing, subject to global economic fluctuations, will impact the acquisition of production equipment for these priority projects. Costs from intermediaries' margins and taxes could also increase the overall cost of each project, potentially hindering their construction. Additionally, climate changes affecting rainfall and, consequently, water storage in rivers and reservoirs, will impact hydroelectric dam production. It is important to note that delays in decision-making or agreements among parties involved in a project will likely increase its overall cost. This is due to factors such as technological advances in production equipment, financial costs, variations in economic growth rates, externalities, the effect of integration on the national economy, and changes in global energy markets. These factors could affect the realization of projects and prevent energy projections from becoming a reality.

7. Recommendations

To meet the 2030 objectives for developing power generation resources and meeting the growing demand for energy, the Cameroonian government [36] and various stakeholders, including financial partners, must undertake numerous studies, actions, and discussions to validate important aspects of the projects concerned, such as:

➢ ***Technical aspects***

✓ Rehabilitation and extension of existing power stations;
✓ Rehabilitation and extension of existing power stations;
✓ Completion of various hydroelectric projects already studied
✓ Acceleration of feasibility studies for projects still in the pipeline
✓ Utilization of gas deposits for electricity generation
✓ Improvement and expansion of the electricity transmission network
✓ Maintenance of distribution lines and replacement of electricity poles
✓ Enhancement of rural electrification in the least connected regions
✓ Feasibility study for the Alucam electric cable production project, including foundry capacity expansion and production doubling

- ✓ Rehabilitation study of the SONARA refinery for crude oil refining
- ✓ Development of a comprehensive energy plan with clear, quantifiable long-term goals
- ✓ Establishment of a multidisciplinary team to ensure synergy in energy planning, rather than independent initiatives by each ministerial department
- ✓ Capacity-building for managers of strategic institutions in charge of energy: MINEE, the Electricity Regulatory Agency (ARSEL), and the Rural Electrification Agency (AER).
- ✓ Interactive involvement of managers with proven skills, including economists, energy specialists, environmentalists, researchers, specialists in maintaining production and distribution infrastructures, planners, and technical network administrators.

➢ On the political and administrative front

- ✓ Quick transition from pilot to full operational phase for newly created project structures,
- ✓ Emphasis on seeking more beneficial funding partnerships,
- ✓ Implementation of a strategy for financing and managing energy projects,
- ✓ Preference for public-private partnership (PPP) and independent power production (IPP) models,
- ✓ Completion of a legal and institutional framework for the energy sector,
- ✓ Introduction of a law to stimulate energy liberalization.

8. Conclusions

The aim of this article was to present solutions to the current energy deficit between supply and demand in Cameroon and to propose ways to increase energy production to 5000 MW by 2035. We examined Cameroon's overall energy potential, focusing on existing and future sources, particularly hydroelectricity. Additionally, we assessed the current state of energy production in Cameroon, as outlined in various strategic plans (PRSP, DSCE, and, since 2020, the SND30) by the government, aiming to reduce the energy deficit and achieve a production target of 5000 MW by 2035. An exhaustive review of the literature presented data on the energy potential and its development through power plant construction. A critical examination of the current state and evolution of various energy sources, demand and supply, and the country's energy policy was conducted. Cameroon, aiming to become an emerging country by 2035, is heavily investing in hydroelectricity and developing other alternative electricity production sources to address the energy deficit. Despite significant government efforts in recent years to enhance the energy sector, the demand for energy continues to outpace supply improvements. Major industrial, administrative, commercial buildings, and households represent the primary sectors with essential energy needs. Consequently, there is a focus on producing clean, reliable renewable energies to ensure energy security and reduce greenhouse gas emissions.

Despite Cameroon's vast hydroelectric potential and a variety of renewable energy resources, the imbalance between supply and demand stems from aging

production equipment, insufficient funding and investment, slow project evaluation, and a lack of political will from state institutions to address concerns that hinder the country's energy development. A series of recommendations have been formulated for all policies related to the energy sector development plan, aiming to address the energy deficit in the medium and long term.

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Author Contribution Statement

All the researchers worked equally. Each of them helped in the writing of this paper.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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