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Hydropower generation potential and prospective scenarios for sustainable electricity supply for the period 2022–2042: A case study of the NIN zone of Cameroon

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Abstract

Hydropower is the sole renewable energy source on the grid in Cameroon, accounting for approximately 62% of this supply as of 2019. So far, hydropower is the most attractive source of grid electricity in the country, with a technically exploitable capability of around 115 TWh per year. However, the actual hydropower output (943 kW) is quite low, corresponding to about 7% of the country's technically exploitable potential. The South Interconnected Network (SIN) zone, home to a technically exploitable potential of 83 TWh per year, produces 98.00% of the country's hydroelectricity, while the North Interconnected Network (NIN) zone generates the remainder. Nevertheless, with its technically exploitable capability of around 7.5 TWh per year, the NIN zone has the potential to alleviate the energy poverty of its population and forecast sustainable energy-consuming projects (SECP), including electricity export (EE) to neighboring Chad and Nigeria. The present study is aimed at exploring short, median and high scenarios based on projected Average Annual Growth Rate (AAGR) of the national real Gross Domestic Product (GDP), which are translated into electricity demand (ED) expected over a 20-year period (2022–2042). High scenario is an optimistic status that displays an AAGR of the GDP projected at 6.40%, equivalent to projected ED (PED) of 6.61%, while median scenario is a more conservative status, with realistic assumptions aligned with an AAGR of the GDP anticipated at 5.0%, corresponding to PED of 5.79%. Low scenario, more likely in the aftermath of COVID-19 pandemic, is the most pessimistic status, with an AAGR of 3.60% matching a PED of 3.60%. To achieve the objective of this study, a comprehensive review on economically exploitable hydropower potential (EEHP) sites in the NIN zone is performed, while under construction hydroelectric plants and projected ones are highlighted. Finally, the intended special contribution of this research is to shed light on hydrologic and energetic parameters of prioritized hydropower sites which match PED, under the best-case scenario of SECP expected by the end of the 20-year period in the zone.
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Keywords: Hydrologic data; Hydropower; Flow rate; Power; Hydroelectricity; Cameroon

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Nomenclature

H_N	Operating head (m)
F_N	Nominal flow rate (m^3/s)
F_{max}	Maximum flow rate (m^3/s)
T_U	Annual utilization factor (%)
E_A	Energy supplied annually (MWh or GWh)
P_I	Installed power (kW)
P_N	Nominal power (kW)

Abbreviations

AAGR	Average Annual Growth Rate
GDP	Gross Domestic Product
SECP	Sustainable Energy-Consuming Project
EE	Electricity Export
ED	Electricity demand
PED	Projected Electricity Demand
SIN	South Interconnected Network
NIN	North Interconnected Network
EN	East Network
TWh	Tera-watt-hour
kV	Kilo Volts
MW	Mega Watt
P_1	A 50 MW agro-food industries in Garoua in the North Region
P_2	A 20 MW cotton processing industry in the North Region
P_3	A 50 MW tin Mayo Darle mine + tin foundry in the Adamawa Region
P_4	30.5 MW alumina - bauxite of Minim Martap and Ngaoundal in the Adamawa Region

1. Introduction

Interest in developing renewable energy as the backbone of a secure and sustainable energy supply has never been as high as rising international concern over climate change problems and global warming [1]. Mounting criticisms over global climate change are observed as well as increased apprehension and doubt over fossil fuel based energy supplies [2]. Complementary to these trends, the increasing global energy demand coupled with the need to develop and promote renewable energy sources to mitigate energy crisis, has shifted focus towards promising renewable sources, including solar, biomass, wind, hydropower and geothermal energy [3]. It is acknowledged that hydropower as a clean energy can be used in the mitigation of climate change impacts in addition to unlock sustainable economic growth and be a pillar for achieving the Paris Agreement [4–6]. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) notes, in the third and final installment of their sixth assessment report on climate change published in 2022 that hydropower has one of the lowest lifecycle greenhouse gases (GHGs) emissions per kWh among all energy sources [7]. As a cost-effective path to net zero, hydropower is a privileged means to mitigate the worst impacts of climate change [8].

As of 2020, hydropower generated around 4297 TWh, corresponding to more than 16% of the world's electricity and approximately 58% of the world's renewable electricity, which represents far more than the contribution from any other renewable resources worldwide. As such, hydropower is a key renewable energy resource and for hundreds of countries across the globe, it is the sole renewable energy that represents opportunities to expand access to electricity to large populations, especially in Sub-Saharan Africa (SSA) [9]. In SSA, where access to electricity is extremely low and three-quarters of the global population without access to electricity lives in [10], hydropower accounts for over 70% of the renewable electricity share and approximately 16% of the total electricity [9]. In 2021,

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hydropower was the most prevailing technology in SSA in terms of new installed capacity [11,12]. This trend is similar to that of Cameroon whose hydropower capacity is expected to drastically rise over the next decades.

The core source of electricity in Cameroon is hydropower and the ratio of the electric power produced via usage of hydroelectricity displays about 62% of the total power generation in the country. Despites its attractive technically exploitable potential of around 115 TWh per year [3], so far, only 7% of the country's technically exploitable potential has been developed. Hydropower potential across the country is unevenly distributed across the three independent networks, namely, the North Interconnected Network (NIN), the East Network (EN) and the South Interconnected Network (SIN). The national grid is composed of these three independent networks, with no possibility of electricity transfer between them for the time being. Therefore, each network grid has its own transmission network lines, with different voltage levels, 90 and 110 kV for the NIN, 30 kV for the EN, and 90 and 225 kV for the SIN [3]. The SIN zone is home to a technically exploitable hydropower potential of 83 TWh per year, with less than 10% of its estimated technical potential utilized. Currently, the SIN zone generates 881 MW, corresponding to 98% of the annual hydropower production of the country, while the NIN zone produces the remainder, 18 MW representing 2% of the total hydropower production of Cameroon. The EN zone, despite its economically exploitable hydropower potential (EEHP) of 6.3 TWh, has not yet commissioned its first hydropower dam of 30 MW installed capacity in Lom pangar [13]. The NIN zone, with its technically exploitable potential of around 7.5 TWh per year, of which barely 8% is harnessed, has the potential to alleviate energy poverty of its population in addition to export electricity to neighboring Chad and Nigeria. As such, the use of hydropower to improve clean energy access in the NIN zone where the electricity consumption level averages 43 kWh/capita/year, is highly required to win the fight against energy poverty as well as to promote sustainable development [3].

Cameroon has a GDP growth rate of 3.40% as of 2021. The country has forecasted a GDP growth of 4.40% for 2022, under the condition of bringing under control the current Coronavirus disease (COVID-19) crisis. This represents a rise of 1.00% compared with the 3.40% growth achieved in 2021 after the 0.70% recorded in 2020 due to the impact of the COVID-19 world crisis which showed one of the lowest GPD growth. The optimistic scenario suggests that, depending on global economic growth by the end of the 20-year period, electricity demand could reach up to 5000 MW in the country [3]. The pessimistic scenario, more likely due to the COVID-19 pandemic, limits the growth by 3.60% (6.40% for the optimistic scenario) depending on the GDP volume decrease.

The country needs more energy as it strives to grow towards its main target to become a middle-income country and to reduce poverty levels below its target, 10% by the end of the 20-year period. The current situation of electricity access in Cameroon is very unenthusiastic to eradicate poverty because rural areas still have a low rate of electrification of 27%, in comparison with its target to reduce poverty levels. The rate of electrification in urban areas in the NIN zone is about 67%, while the electrification rate is 40%.

It is well recognized also that there is an unambiguous relationship between economic growth and energy consumption: the growth of economic activity drives energy consumption [14]. Along the lines of its steady Gross Domestic Product (GDP) increment, the growth in electricity demand in Cameroon has revealed a similar trend of annual increase. Electricity demand in Cameroon is growing in tandem with its GDP increase.

The present study aims at exploring short, median and high scenarios based on projected Average Annual Growth Rate (AAGR) of the national real GDP, which are translated into electricity demand (ED) expected over a 20-year period (2022–2042) of sustainable energy-consuming projects (SECP), including electricity export (EE) to neighboring Chad (N'Djamena and the 17 border communities) and Nigeria (Yola). Accordingly, this paper focuses on the study of EEHP in the NIN zone, which has triggered prospective scenarios for ED correlated to AAGR of the national real GDP. Finally, the intended special contribution of this research is to shed light on hydrologic and energetic parameters of prioritized hydropower sites which match PED, under the best-case scenario of SECP expected by the end of the 20-year period in the NIN zone.

1.1. Spatial delimitation of the NIN zone

The NIN zone which is the area of study is located between Latitudes 6°N and 12°N and Longitudes 11°E and 15°E. Chad neighbors it to the north and north-east, the Central African Republic to the east, Nigeria to the west and four regions (North West, West, Centre and East) of Cameroon to the south (Fig. 1). The NIN zone has a total surface area of about 164,054 km^2 shared between three regions: Far North (34,263 km^2), North (66,090 km^2) and Adamawa (63,701 km^2) [15]. The climate in the NIN zone ranges from semi-dry sub-tropical in Far North and

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North regions to moist tropical in the Adamawa region. Two seasons exist in the NIN zone. The first season is observed in Far North and North regions, with a long dry season (Mid-October–Mid-May) and a short rainy season (Mid-May–Mid-October) [16]. During an average rainy season, approximately 600–900 mm of rainfall occurs in the Far North Region, while the average rainfall in the North Region is in the range 900–1500 mm [17]. The Adamawa Region, home to all EEHP sites, experiences between 1500 and 2500 mm of rainfall per year.

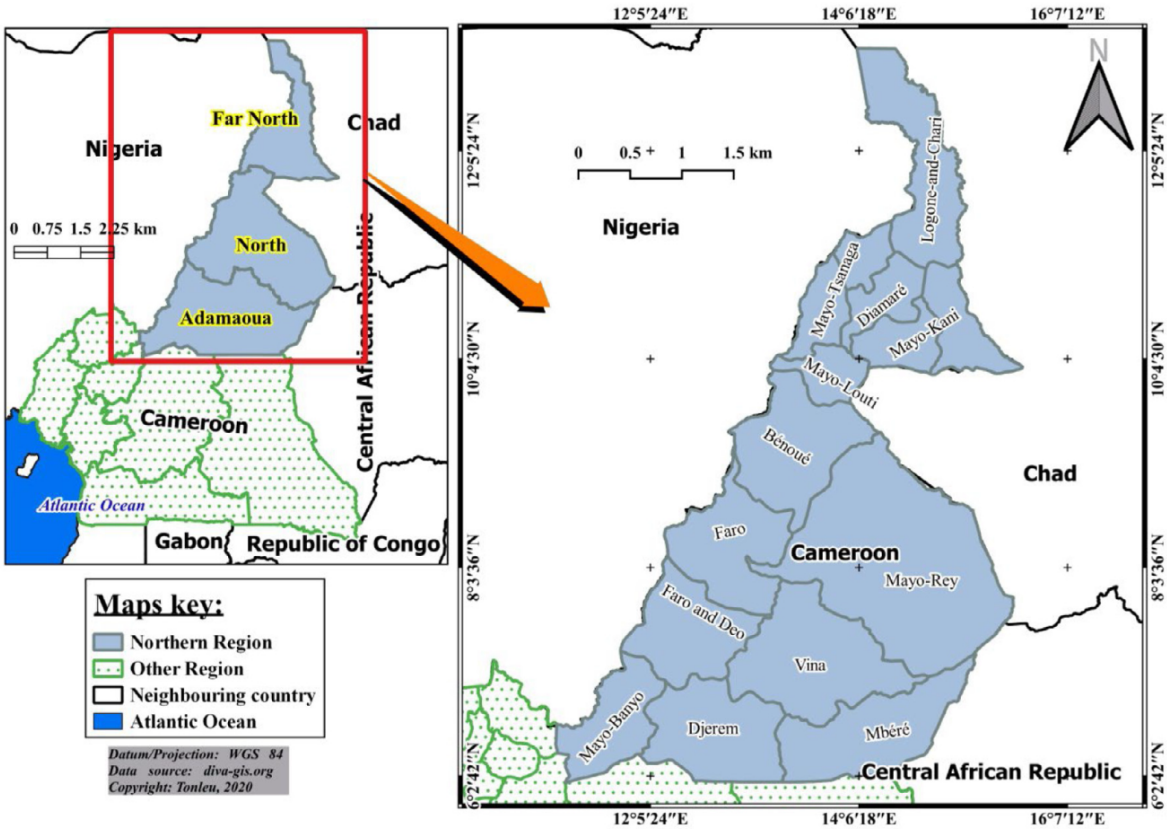

Fig. 1. Geographical location of the study area.

1.2. Rainfall and temperature

The historical records of rainfall (Fig. 2(a)) based on hydrological data of hydrometric stations show that the NIN zone is characterized by low monthly rainfall volumes (MRV) in the range 0–10 mm in November, December and January, followed by MRV between 30 and 59 mm in February and March. MRV in the range 60–100 mm, corresponding to a minimum of 7 rainy days per month are observed from April to September. In May, MRW exceed 100 mm, with more than 16 rainy days. Temperature variations in the NIN zone range between 23 °C (November) and 31 °C (April). Overall, mean annual temperature variations are provided by Fig. 2(b).

2. Research methodology

An outline of the current economic situation of Cameroon is vital for a full understanding of prospective scenarios for ED in the NIN zone. The lack of scientific literature research directly devoted to this topic could constitute a considerable drawback.

This study scrutinizes the national GDP growth rate, particularly in the aftermath of the COVID-19 crisis, which may influence SECP translate into median and high scenarios. For the general picture of projected sustainable electricity supply (PSES), EEHP sites in the NIN zone is highlighted as well as existing, under construction, projected hydroelectric plants, hydrologic and energetic parameters of hydropower candidates' sites (prioritized

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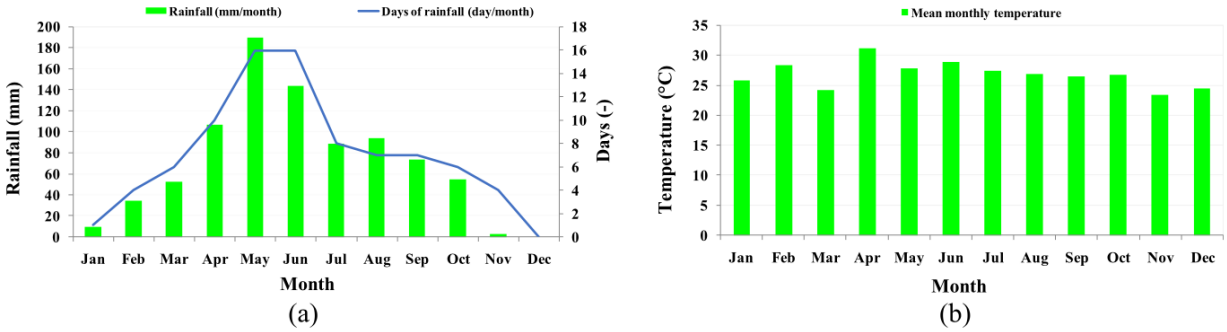

Fig. 2. (a) Rainfall and monthly number of rain days and (b) Mean monthly temperature.

sites). In conclusion, to reach the study objective, the research methodology adopted which illustrates how electricity demand (ED) grows in tandem with its GDP increase, is depicted in a flow chart as shown in Fig. 3.

3. Hydropower site ranking and prioritization

3.1. EEHP sites

Hydropower site ranking is based on technical, economic, social and environmental criteria. Technical criteria include power, capacity factor, fall and rainfall, while economic criteria consider the cost of the dam, the proximity of high energy consumers and the eligibility to electricity export. Social criteria incorporate regional electrification of population and its relocation. Environmental criteria include impact on rare and endangered species and loss of livelihood. The ranking of the most suitable hydropower sites is based on elimination and choice translating reality (ELECTRE III), which eliminate any unacceptable alternatives. ELECTRE III combines geographic information systems in conjunction with a multi-criteria decision making (MCDM) based system to help policies makers selecting the most reasonable solution [18]. The ranking process is not considered in this study, however the seventeen ranked EEHP sites in the NIN zone have been mapped as illustrated on Fig. 4. Table 1 provides the ranking of the seventeen EEHP sites including projected power (MW), falls (m), cumulative power (MW), input water volume (hm^3/annum), catchment area (km^2), river basin and geographical coordinates. These seventeen EEHP sites display a projected cumulative power of 792 MW.

Table 1. Ranking of EEHP sites in the NIN zone.

Ranking	Site	Power (MW)	Cumulative power (MW)	Fall (m)	Input volume (hm^3/annum)	Catchment area (km^2)	River basin
1st	Upstream of Mbam	148	148	165	3 780	5 800	Mbam
2nd	Mbinjal	94	242	89	4 250	7 110	Faro
3rd	Fo	56	298	90	3 900	6 510	Faro
4th	Mayo Taram	40	338	175	710	825	Mbam
5th	Mayo Darle	19	357	100	670	780	Mbam
6th	Mandourou	86	443	115	2 450	3 920	Faro
7th	Mayo Djinga	12	455	100	480	610	Mbam
8th	Warak Falls	69	524	223	880	1390	North Vina
9th	Von	32	556	140	2800	4670	Faro
10th	Vogzom	54	610	63	3430	6380	North Vina
11th	Djohong	34	644	90	1300	2170	Mbere–Ngou
12th	Bakari Bata	34	678	85	1360	2270	Mbere–Ngou
13th	Djam Tari	11	689	40	1060	1690	Mayo Nolti
14th	Gbabiri	56	745	401	470	1060	Mbere–Ngou
15th	Lancrenon	31	776	320	1200	2150	Mbere–Ngou
16th	Djalingo	5	781	49	950	1400	South Vina
17th	Ngai	11	792	97	360	885	South Vina

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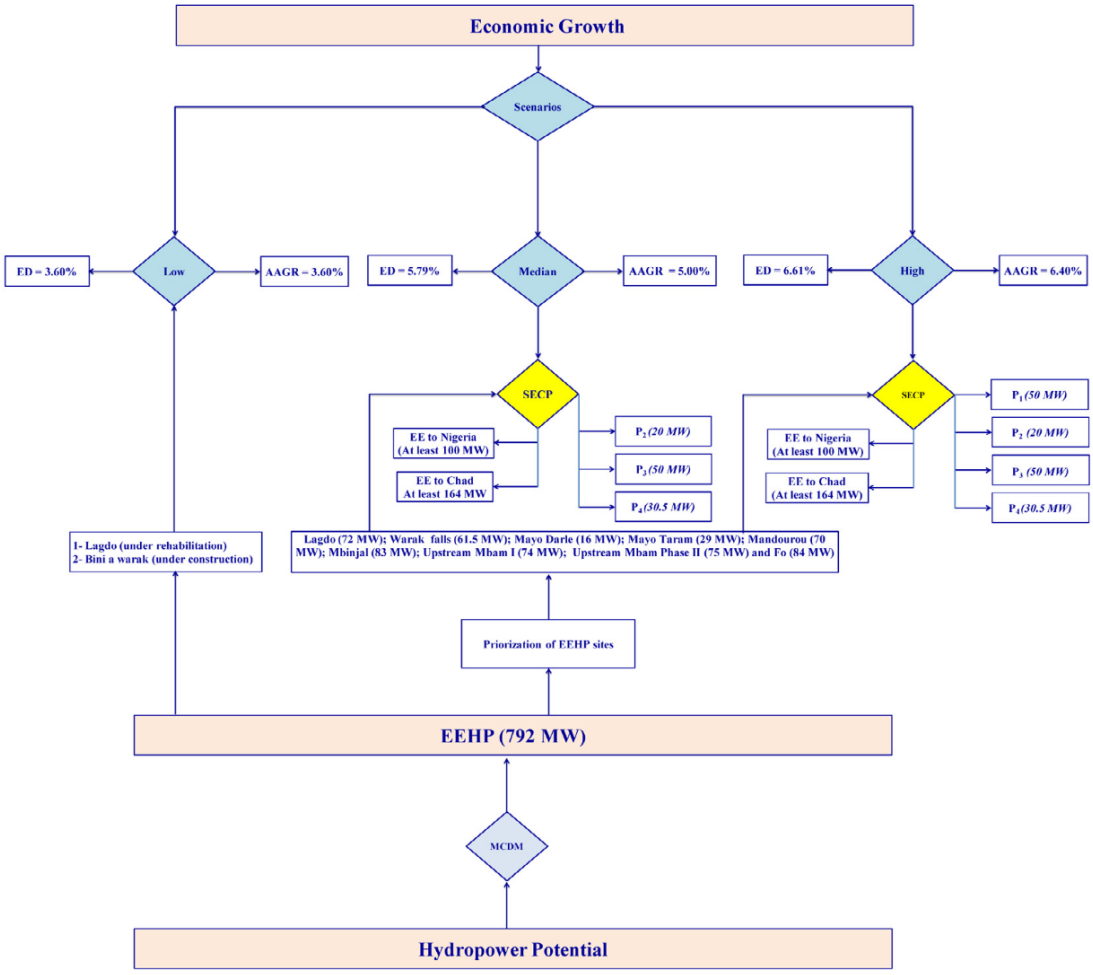

Fig. 3. Research methodology flow chart.

Table 2. Prioritized EEHP sites.

Order of priority	Site	Projected capacity (MW)	Projected cumulative capacity (MW)	Cost (BF CFA/MW)	Cost (Euro/kW)
1st	Warak Falls	61.50	61.50	1.14	1 735.08
2nd	Mbinjal	83.00	144.50	2.12	3 232.44
3rd	Mandourou	70.00	214.50	1.87	2 852.79
4th	Upstream of Mbam Phase 1	74.50	289.00	1.97	2 997.63
4th	Upstream of Mbam Phase 2	74.50	363.50	1.97	2 997.63
5th	Fo	84.00	447.50	2.96	4 518.73
6th	Mayo Darle	16.00	463.50	1.94	2 953.51
7th	Mayo Taram	29.00	492.50	1.97	2 996.22

3.2. Prioritized EEHP sites

The ranking of hydropower sites, with respect to the seventeen ranked EEHP sites provided in Table 1, led policies makers and other stakeholders of hydroelectric projects in Cameroon, to prioritize seven EEHP sites for the PSES that match PED expected over the 20-year period (2022–2042). Fig. 4 maps the seven prioritized EEHP sites scheduled for the period 2022–2042, while Table 2 provides their order of priority, projected capacity, cumulative capacity and cost per MW. It can be noticed that investment costs vary from 1,735.08 to 4,518.73 Euro per kilowatt.

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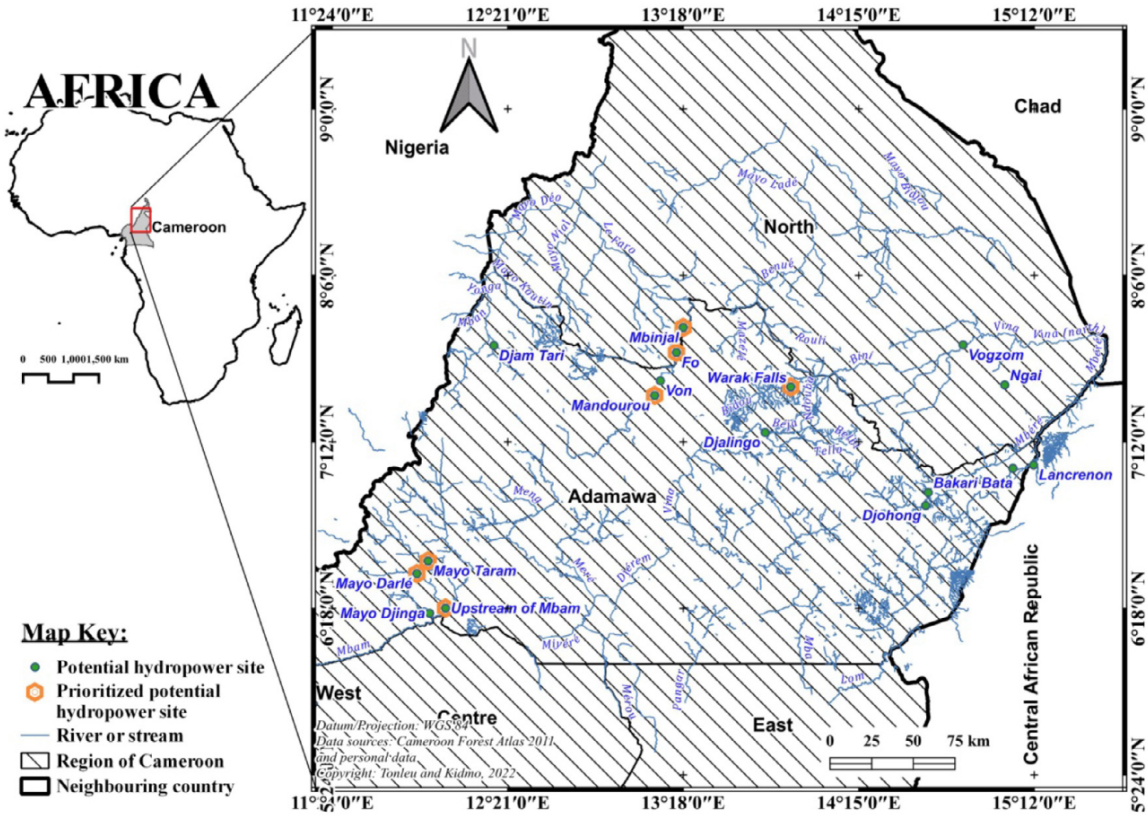

Fig. 4. Map of seventeen ranked and seven prioritized EEHP sites in the NIN zone.

3.3. Hydrologic and energetic parameters of prioritized sites

Table 3 presents average and nominal flow rates, days and percentages of days observed as well as nominal flow regulated to volume. Monthly volumes of each of the seven selected sites were provided by the main stakeholder of hydroelectric projects in Cameroon. Hydrological regulation is required to level the curve of the hydrological regime, and guarantee hydropower generation over the twelve months of the year. Fig. 5 depicts monthly volumes contribution of each of the seven prioritized sites. It can be observed that monthly volume contribution is the lowest between November and December, and from January to June. From July to October, these volumes contribution are higher, with September being the highest.

Table 4 recapitulates projected hydrologic and energetic useful parameters for the seven Prioritized EEHP sites scheduled for the indicated period. Hydrologic data include, annual inputs, useful and mobilized volumes, while energetic parameters consist of operating head (m), nominal flow rate (m^3/s), maximum flow rate (m^3/s), energy supplied annually (MWh or GWh), nominal power (kW) and available power (kW).

The analysis of hydrologic and energy parameters for the seven prioritized EEHP sites, allows to verify the annual producible energy of 3.5 TWh, including the energy produced by existing Lagdo power plant.

The utilization factor (T_U) related to the installed power varies from 0.65 (Warak falls) to 0.8 (Mbinjal), while these values range between 0.75 (Warak falls) and to 0.92 (Mbinjal) when related to the rated power plant. The utilization factor (T_U) in equivalent hours, associated with the installed or nominal power, is defined as the maximum amount of energy delivered during a time period divided by the amount of energy that would have been generated if the plant was running at the installed or nominal power output throughout that time period. The development of a

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Table 3. Nominal flow rate selection.

Sites	Flow rate (m^3/s)	Nominal Flow rate (m^3/s)	Days observed (%)	Days observed	Nominal flow regulated to volume
Warak falls	22	26	35	127	Daily
Mbinjal	106	98	40	146	Daily
Mandourou	62	65	39	142	Daily
Upstream Mbam	99	96	46	168	Daily
Fo	99	98	39	143	Daily
Mayo Darle	17	17	47	169	Daily
Mayo Taram	18	18	46	166	Daily

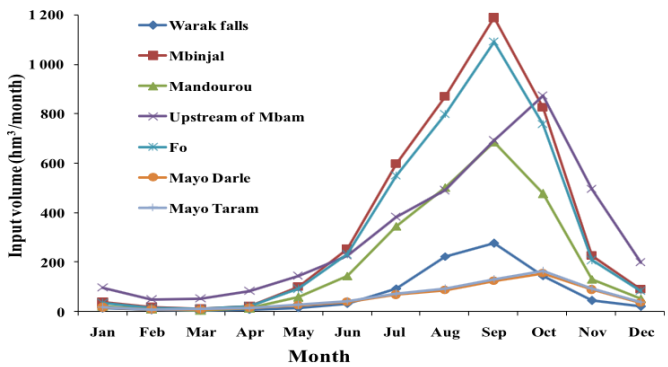

Fig. 5. Monthly contributions of the seven selected sites.

Table 4. Recap of projected hydropower plants useful parameters, with flow regulation.

Sites candidates	Warak falls	Mbinjal	Mandourou	Upstream Mbam	Fo	Mayo Darle	Mayo Taram
Annual input (hm^3)	882	4 246	2 442	3 785	3 887	672	712
Annual useful volume (hm^3)	702	3 354	1 954	3 142	3 110	538	570
Annual regulated volume (hm^3)	600	2 851	1 661	2 670	2 643	457	484
Mobilized volume (hm^3)	270	1 480	792	1 010	1 300	167	176
H_N (m)	232	90	115	165	90	100	175
F_N (m^3/s)	26	98	65	96	99	17	18
P_N (MW)	48	71	60	127	71	14	25
F_{max} (m^3/s)	31	115	76	113	115	20	21
P_I (MW)	56	82	70	148	83	16	29
E_A (GWh)	330	599	449	1 046	557	101	199
E_A (GWh) 4% unavailability	317	575	431	1 004	535	97	191
T_U related to P_I (%)	65	80	70	77	74	69	75
T_U in equivalent hours related to P_I	5 657	7 013	6 158	6 785	6 442	6 060	6 588
T_U related to P_N (%)	75	92	82	90	86	79	87
T_U in equivalent hours related to P_N	6 600	8 099	7 184	7 907	7 531	6 926	7 642

regulation dam in Mandourou can contribute to the optimization of Fo and Mbinjal hydropower plants on the Faro river, by increasing approximately 254 GWh in the producible energy, compared to the run-of-river hydropower plant variant in which they could be carried out.

4. GDP trends and prospective scenarios

Research studies have recognized the unambiguous relationship between economic growth (measured mainly by the GDP) and energy consumption [14]. As in most SSA countries, it is widely acknowledged in Cameroon that both structural and technical deficits in energy remain a key blockage that hinders economic and development [19].

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Research studies [20,21] have shown that economic policy meant to improve energy supply will inevitably have a positive effect on economic growth: the growth of economic activity drives energy consumption.

4.1. GDP trends

The GDP in Cameroon from 1994 and 2019 displayed a positive trend. Between 2000 and 2019, the country experienced a sustained AAGR of the national real GDP, with 2.23% (2005) corresponding to the lowest recorded so far. Between 2011 and 2019, AAGR showed values above 3.38%. In 2020, the novel coronavirus pandemic, also termed as COVID-19, classified as one of the major global threats, has shut down and paralyzed economies worldwide [22]. COVID-19 badly impacted Cameroon's economy through the government enforcement of lockdown in the effort to contain the spread of the virus. The pandemic has resulted in a significant decrease in the AAGR of the national real GDP, from 3.38% in 2019 to 0.70% in 2020. Fig. 6 illustrates AAGR values of the national real GDP between 2000 and 2021. In 2021, the economy of the country took back a positive growth trend, with an AAGR value of 3.40%. Notwithstanding this, the aftermath of the pandemic in Cameroon is projected with a positive GDP growth trends (scenarios) so as to drive energy consumption.

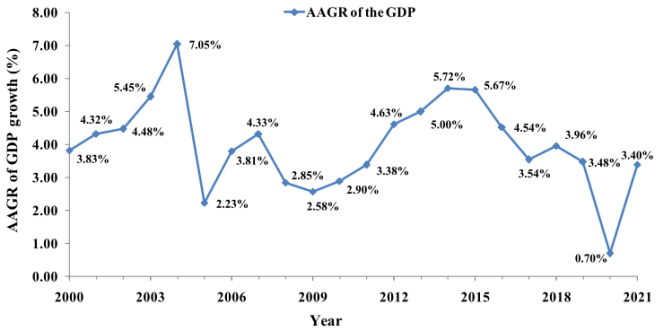

Fig. 6. AAGR graph of the national real GDP from 2000 to 2021.

4.2. Prospective scenarios

Three prospective scenarios namely: high, median and low scenarios based on projected AAGR of the national real GDP were identified in tandem with electricity demands. High scenario suggests that, the country will experience a sustained value of 6.40% for the AAGR of the national real GDP (equivalent to PED of 6.61%), while median scenario proposes a sustained value of 5.00% (corresponding to PED of 5.79%), for the next 20-year. Low scenario, with an AAGR of the national real GDP of 3.60% (matching a PED of 3.60%) is more likely due to the pandemic aftermath which will be an uncharted territory for economies.

5. High scenario

It is an optimistic scenario aligning, in terms of economic growth, aimed at making Cameroon to become a middle-income country by the end of the 20-year period (2022–2042), while adopting, however, more conservative and realistic assumptions. This is ultimately translated into an annual economic growth of 6.40% on average (equivalent to PED of 6.61%) over the considered period. This scenario assumes, in accordance with the strategic guidelines of the State of Cameroon, the realization of SECP. The following summarizes high scenario SECP:

- 4 energy consuming projects:
  - A 50 MW agro-food industries in Garoua in the North Region (P_1);
  - A 20 MW cotton processing industry in the North Region (P_2);
  - A 50 MW tin Mayo Darle mine + tin foundry in the Adamawa Region (P_3);
  - 30.5 MW alumina - bauxite of Minim Martap and Ngaoundal in the Adamawa Region (P_4).

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- Electricity export (EE) projects to:
  - Nigeria ; (Ngaoundere–Yola);
  - Chad (N'Djamena and 17 border communities outside Kousseri).

5.1. Sustainable energy-consuming projects (SECP)

For high scenario, a total of 150.5 MW is required for SECP, corresponding to 70 MW in the North Region (P_1 and P_2) and 80.5 MW in the Adamawa Region (P_3 and P_4). Table 5 provides the schedule of prioritized EEHP sites as well as SECP between 2022 and 2042. It can be observed that Ladgo hydropower plant has a limited output of 18 MW at best, one-quarter of its capacity due to silting of the dam and the obsolescence of the installations. EDC, a state-owned company in charge of construction and development of all hydroelectric projects in Cameroon, has received bids for the rehabilitation and extension of the hydroelectric infrastructure. The hydropower dam has an estimated installed capacity of 72 MW (4 Francis turbine generator units of 18 MW each). It is expected that by 2024, the 72-MW capacity will be fully restored. P_1 and P_4 projects are expected to commence in 2026, while P_3 project is scheduled for 2027. P_2 project as well as Mbinjal and Upstream Mbam I plants are programmed to be online by 2030. Between 2025 and 2035, six hydropower plants are projected to be fully operational.

Table 5. Demand of the major projects and their power schedule.

Year	Installed capacity (MW)	P_1	P_2	P_3	P_4
2022	Lagdo (18 MW)	–	–	–	–
2023		–	–	–	–
2024	Lagdo (fully rehabilitated) (72 MW)	–	–	–	–
2025	Warak falls (61.5 MW) + Mayo Darle (16 MW)	–	–	–	–
2026	Mayo Taram (29 MW)	6.0	–	–	30.5
2027	Mandourou (70 MW)	8.0	–	50.0	30.5
2028		12.0	–	50.0	30.5
2029		16.0	–	50.0	30.5
2030	Mbinjal (83 MW) + Upstream Mbam I (74.5 MW)	20.0	20.0	50.0	30.5
2031		24.0	20.0	50.0	30.5
2032		28.0	20.0	50.0	30.5
2033		32.0	20.0	50.0	30.5
2034		36.0	20.0	50.0	30.5
2035	Upstream Mbam Phase II (74.5 MW)	40.0	20.0	50.0	30.5
2036		44.0	20.0	50.0	30.5
2037		48.0	20.0	50.0	30.5
2038		50.0	20.0	50.0	30.5
2039		50.0	20.0	50.0	30.5
2040	Fo (84 MW)	50.0	20.0	50.0	30.5
2041		50.0	20.0	50.0	30.5
2042		50.0	20.0	50.0	30.5

5.2. EE to Chad Interconnection (N'djamena & the 17 border Localities)

Table 6 provides median and high scenarios of electricity export to Chad. The start date of the electricity interconnection is 2025, once hydropower plants on Warak falls (61.5 MW) and Mayo Darle (16 MW) are operational. This electricity interconnection is intended to satisfy a significant portion of the demand of the Chadian capital, N'Djamena, and the border communities in Chad, according to the Cameroon/Chad MoU for the realization of the electrical interconnection Cameroon — Chad and electrification of border communities. The protocol also provides for an interconnection line to supply N'Djamena city. Moreover, 17 Chadian border localities are planned to be electrified under the subject convention, namely: Lere, Pala, Bongor Datcheka, Fianga Bridge Karoual, Mbaibokoum, Laramanaye, Tikem, Gounougoya, Binder, Bidzar, Dana, Kabe Hileaufa, Ooukoula, Bosoya, Manay and Mindjivin.

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Table 6. Median and high scenarios of electricity export to Chad and Nigeria.

Year	Installed capacity (MW)	Cumulative capacity (MW)	Export to Chad (MW)	Export to Nigeria (MW)
2022	Lagdo (18 MW)	18.0	–	–
2023		18.0	–	–
2024	Lagdo (fully rehabilitated) (72 MW)	72.0	–	–
2025	Warak falls (61.5 MW) + Mayo Darle (16 MW)	149.5	60	10
2026	Mayo Taram (29 MW)	178.5	60	10
2027	Mandourou (70 MW)	248.5	60	10
2028		248.5	60	10
2029		248.5	60	10
2030	Mbinjal (83 MW) + Upstream Mbam I (74 MW)	405.5	77	100
2031		405.5	77	100
2032		405.5	77	100
2033		405.5	77	100
2034		405.5	77	100
2035	Upstream Mbam Phase II (75 MW)	480.5	99	100
2036		480.5	99	100
2037		480.5	99	100
2038		480.5	99	100
2039		480.5	99	100
2040	Fo (84 MW)	564.5	164	100
2041		564.5	164	100
2042		564.5	164	100

5.3. EE to Nigeria (Yola)

An interconnection between the NIN zone and Yola (Nigeria) is provided by the framework agreement between Cameroon and Nigeria (dated on February 2011) and other available materials. As the long-term needs of Nigeria through the interconnection with Yola is not known, it was recognized that eventually, the guaranteed export to Yola will be stabilized at 100 MW. The power plants of Lagdo, Warak falls, Mayo Darle, Mayo Taram, Mandourou and Mbinjal will strengthen the available power of the NIN zone, including electricity export to Nigeria. The schedule for the provision of generation capacities for export of the 4 pre-indicated hydropower plants was considered, as shown in the Table 6, presuming that the minimum guaranteed power for electricity export to Nigeria will evolve depending on the commissioning of new power plants, while taking into account the specific needs of the NIN zone.

5.4. Dwellers electricity demand

Fig. 7 depicts projected dwellers electricity demands for low (3.60%), median (5.79%) and high (6.61%) scenarios over the 20-year period (2022–2042). The current electricity demand is estimated at 56.30 MW. At the end of the 20-year period, projected dwellers electricity demands correspond to 114.21, 120.82 and 121.76 MW, respectively for low, median and high scenarios. It is observed that, the gap between low and median scenarios reaches 6.61 MW, while it is 0.94 MW between median and high scenarios at the end of the projected 20-year period.

5.5. Overall power demand versus projected hydropower capacity

Fig. 8 illustrates projected overall electricity demands for median and high scenarios versus projected installed hydropower capacity over the 20-year period (2022–2042). The overall electricity demand includes demands for SECP and interconnection projects with Nigeria and Chad which are forecasted only for median and high scenarios, and dwellers electricity demand applicable to the three scenarios. It is observed that the projected installed hydropower capacity shows an excess supply of power starting from 2024 when the Lagdo hydropower dam is fully

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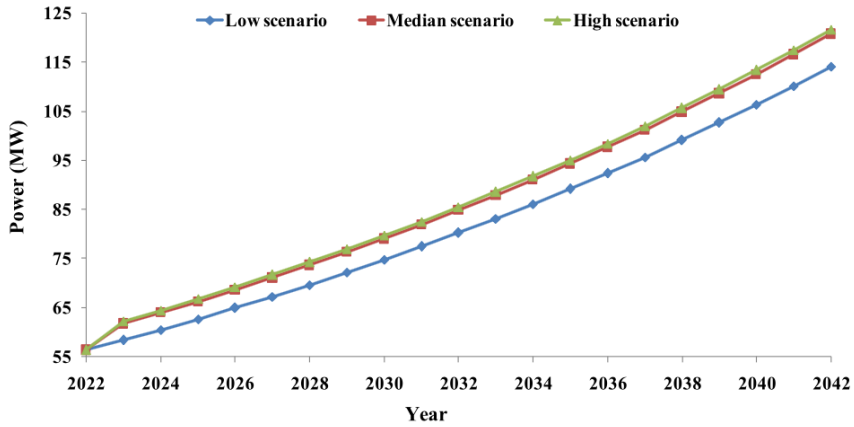

Fig. 7. Projected dwellers electricity demands for low, median and high scenarios.

rehabilitated until the end of the 20-year period. This situation means that the excess supply of power will feed the interconnection with Nigeria as the minimum guaranteed electricity export to Yola is stabilized at 100 MW.

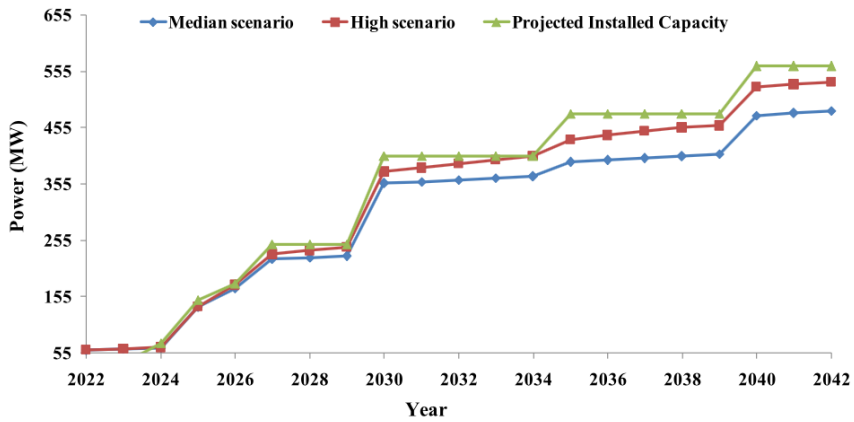

Fig. 8. Projected overall power demand for median and high scenarios versus projected installed hydropower capacity.

6. Median scenario

For median scenario, a total of 100.5 MW is required for SECP, corresponding to 20 MW in the North Region (P_2) and 80.5 MW in the Adamawa Region (P_3 and P_4). This scenario corresponds to an AAGR of the national real GDP estimated at 5.0% on average over the period 2022–2042. Table 6 provides median and high scenarios of electricity export to Chad and Nigeria. The interconnection demand with Chad for median and high scenarios are identical. Fig. 7 depicts the projected dwellers electricity demand for median scenario over the 20-year period (2022–2042). The current electricity demand is estimated at 56.30 MW. At the end of the 20-year period, the projected dwellers electricity demand corresponds to 120.82 MW. Fig. 8 illustrates the projected overall electricity demand for median scenario versus the projected installed hydropower capacity over the 20-year period (2022–2042). The overall electricity demand includes demands for major projects, interconnection projects with Nigeria and Chad and dwellers power.

7. Low scenario

This is the most pessimistic scenario assuming in the future, less stimulation of the Cameroonian economy and the business climate in the country, which should result in the non-realization of all the future major projects and

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none of the interconnection, as described in high and median scenarios. Low scenario is based on the underlying assumptions, admitting a continuation of the growth rate of the national real GDP, with a slow and weak trend of improvement that will fade in the long run. The AAGR of the GDP is thus estimated at 3.60% per annum on average throughout the period 2022–2042. The per capita income is expected to grow gradually, but in a closer way to the recent recorded data. This scenario also assumes that Cameroon will look exclusively to meet dwellers power demand. The annual growth of dwellers' power demand is estimated at 3.60% based on data provided by the national public electricity utility. Fig. 7 depicts the projected dwellers electricity demand for low scenario over the 20-year period. The current electricity demand is estimated at 56.3 MW. At the end of the 20-year period, the projected dwellers' electricity demand corresponds to 114.21 MW. Table 7 provides hydropower generation scheduled for low scenario. First, the Lagdo hydropower dam is to be rehabilitated to its full capacity of 72 MW. The rehabilitation is expected over the next two years and no export of electricity is allowed in accordance with the trade memorandum of understanding (MoU) signed by China International Water and Electric Corporation (CWE) and the government of Cameroon. Warak falls hydropower development is under construction for a projected capacity of 61.5 MW. The hydropower generation capacity in the 20-year period is forecasted to 133.5 MW.

Table 7. Hydropower generation schedule for low scenario.

Candidates' sites	Status	Projected capacity (MW)	Projected cumulative capacity (MW)
Lagdo	Existing	18	18
Lagdo	After rehabilitation	72	72
Warak falls	Under construction	61.5	133.5

8. Conclusion

An overview of prospective scenarios for sustainable electricity supply in the NIN zone of Cameroon for the 20-year (2022–2042) period has been comprehensively studied in this paper. This research seeks to contribute to collect relevant information on hydropower generation potential in addition to shedding light on energetic parameters of suitable hydropower sites for sustainable electricity supply in this zone. Median and high scenarios, which match two different electricity demands, are correlated to prospective major projects in the NIN zone. These two scenarios suggest that the country will implement sustainable energy-consuming projects and electricity export to Chad and Nigeria, while low scenario, more likely in the aftermath of COVID-19 pandemic and in the wake of an unprecedented global economy crisis triggered by Russia's invasion of Ukraine, assumes that the country will look exclusively to meet dwellers power demand. As electricity demand in the country is established to grow in tandem with its GDP increase, it is acknowledged that the growth of economic activity drives energy consumption.

Declaration of competing 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.

Data availability

Data will be made available on request.

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