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Research Paper

Water-Energy Nexus: Evaluating the Effects of Climate Change on Energy and Water Sources Development in Liberia

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Abstract

The interactions between water and energy in Liberia under the water-energy nexus approach are considered in this study, focusing on the challenges and possibilities of these links. It assesses the climate-related issues concerning Liberian water systems including temperature, rainfalls, and available water amounts. It assesses the balance and the utilization of water in the climate change framework. Cross-sectional and meta-analysis model was used in this study. It addresses the vulnerability, particularly the damages to hydropower, energy production, and fisheries in Liberia. There are numerous water resources in Liberia however, there is a disconnect with regards to the availability of data and an effective water-energy monitoring. Additionally, also show coordination in water and energy projects. A sustainable use of water, an installation of eco-friendly electricity production sources and adaptation to climate changes is slowly being pursues as the country boast high renewable energy potential especially with regards to hydropower. The study finds high rainfall with projections that it may reduce and also limited access to water and electricity. The study also finds gradual increase in energy generation and a higher renewable energy generation. Finally, possible pathways for a multidimensional approach and technology including policing to continue sustaining Liberia under a complex climate-water-energy nexus are presented. These issues are questions of transformation within the relationships between energy systems, water resources, and climate transition.

Keywords

Water Sector, Energy, Sustainable Development, Climate Change

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1. INTRODUCTION

Water-Energy nexus is a term or approach to examine the interaction of energy and water resource. It involves multiple factors environmental governance, integrated water resource management, climate change and others that are concern with the concept (Jones-Crank et al., 2024). Water and energy are principal pillars of socioeconomic development. Water resource management needs energy; at the same time, energy development needs large amounts of water (Ijoma et al., 2022). Water and energy are the hallmarks of civilization and, more so, the growth of the human economy. Furthermore, it is frequently a case that these are handled separately, as a consequence they get inefficient and become a waste. Thus, the Water-energy nexus developed as a tool aimed at the water-energy systems relationship evaluation (Rasul, 2014). Water and Energy of the years have been interdependent and as such the generation of electricity requires water and transportation and water treatment requires electricity (Hamiche et al., 2016). The new perspective of water-energy nexus has been energy for water and water for energy highlighting the need for current and future ways to produce more energy with less water and vice-versa. Water and energy sustainability is also interwoven and is critical to human civilization (Shokri and Fard, 2023). The demand for water and energy continues to grow thereby putting pressure on these resources. This is majorly due to the growing population and climate change (Tudose et al., 2023). The impact of climate change on water-energy is a global secret as several studies have shown increase in temperature globally which is leading to river drying and increasing water stress levels thereby limiting hydro dams ability to effectively generate (Osman et al., 2023). Global shortages in water are an important challenge, due to it cross sectorial implications. The largest consumer of water is the energy sector thought there has been a 22% reduction in the energy sector in the USA from 2015-2020 due to renewable energy increase, a significant 47.5 trillion gallons of water is needed for cooling at fuel based power plants

(Licandeo et al., 2023). Liberia has many large-scale river basins, substantial amounts of rainfall on a yearly basis, and countless underground water reservoirs according to Gökçekus et al. (2022).

However, it is hard to control these resources as global warming, urbanization and economic difficulties occur. Besides, more than 50% of the citizens of Liberia also use non-renewable sources of energy such as wood and charcoal for cooking which leads to serious pollution that causes health problems to people (Jones, 2015). The country should also understand the importance of relying too much on burning traditional biomass for energy, which contributes significantly to environmental degradation and affects human health problems on a large scale. In the case of Liberia, what comes next is to harness and transform the plentiful water sources into safe green power. To accomplish this, it should ensure sufficient water to sustain them and other essential usages such as human consumption, irrigation, and environmental equilibrium. Changes in the climate will alter the water conditions, leading to severe implications for hydropower development in which the country is heavily investing in expanding the power generation sector (Wesseh Jr and Lin, 2015). Growing energy and water demands is majorly caused by the rapidly expanding population and urbanization which must be balanced against these competing problems. It is important to understand the impact of climate change on water and energy in achieving SDG 6 and SDG 7 (Liu et al., 2018; UN, 2018; Gao et al., 2024). This study aims to examine tradeoffs for synergies and how they relate to Liberia's growth of energy and management of water resources. The research established the following goals to fulfill the study's overall goal: examined climate change, using Liberian measures of temperature and precipitation, analyzing tradeoffs and synergies between the effects of climate change on Liberia's energy and water resources, examined how Liberia could adopt an adaptation and mitigation approach regarding its water and energy resources in the context of sustainable development and climate change, and measure water resources to facilitate sustainable economic expansion and electricity generation in Liberia.

2. EXPERIMENTAL SECTION

2.1 Materials

The primary material utilized during the conduct of this study were Maps, World Bank, aquastat data set as well as MODIS, and Terra Climate all of which to ensure accuracy and reliability in data collection, analysis and presentation.

2.2 Methods

The research methodology acts as the blueprint of the study. It entails outlining the study mode, subjects, data collection and analysis, results presentation, and conclusion. This study utilizes cross-sectional design to ascertain the current conflict and connection between water resource management and energy development in Liberia. The scope of this study is Liberia, a Republic. It consists of 15 counties and, on the West African coastline, a population of over five million. Hence, in this kind of study (cross-sectional) the phenomenon as it happens is captured, giving a total account. Further, journals, books, policies, and reports on the water and energy of Liberia will be the additional documents used to corroborate information. The present study involved data analysis from a meta-analysis. A meta-analysis is a review that combines data from multiple but complementary individual studies into one answer. Water resources management and hydroelectric development will be the better alternative of this paper in comparison with others. The study will give recommendations based on water and energy policy-making and practices that will be integrated into planning.

3. RESULT AND DISCUSSION

It is one of the wealthiest countries in terms of water resources; As shown in the Figure 1 Liberia has several rivers. It possesses fifteen large basins and twenty-three more minor coastline drainages that flow northeast to southwest into the Atlantic Ocean. The main rivers of Liberia are the Lofa, Cavalla, Mano, St. John, Cestos, and St. Paul Rivers, which flow from Guinea's Mounts Fouta Djallon. These rivers account for about 56% of drainage in Liberia, while the rest comprise 11 smaller tributaries and many shorter coastal rivers. The nation's largest hydropower station on St. Paul River is known as Mt. Coffee Power Plant, generating 88 Mw for the country's power. Simultaneously, the Firestone Hydroelectric Power Plant produces about 4.8 MW of energy for the Harbel region in addition to Firestone (Gökçekus et al., 2022).

3.1 Impact of Climate Change on Precipitation and Temperature

Climatologists determine the amount of warming at local and global scales through analysis of temperature changes. As shown in Figure 2(a), the average temperature for Liberia is approximately 27.00°C. Its range is 6.00°C within the year, with the middle of March as possibly the highest, with temperatures peaking at 31.20°C, and the middle of July as possibly the lowest, at around 25.80°C. It has been earlier noted that the climate of modern Liberia is characterized by all-year temperature highs. Average elevations lie between the 60°F and the 80°F, with an annual mean temperature of about 80°F. Monthly temperatures swing around 4°F, in which are have the highest 89.6°F for April and lowest of 79.7°F for August mean monthly temperature. Temperature changes are less impactful during the rest of the year except for the dry season when they seem most noticeable. The observed maximum temperature range inside each month does not surpass 6°F. Amongst the most noticeable characteristics of the climate of Liberia is the regular alternate

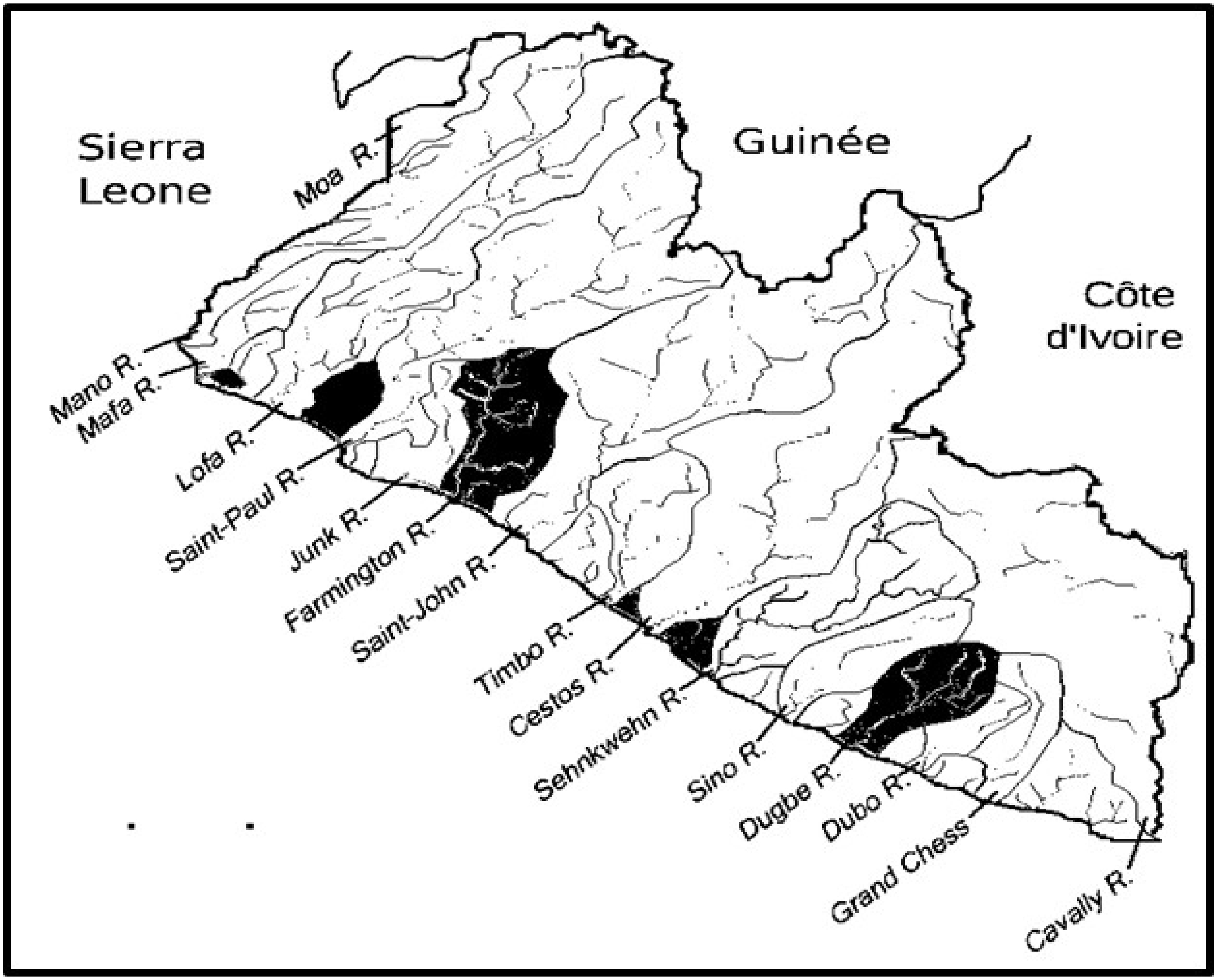
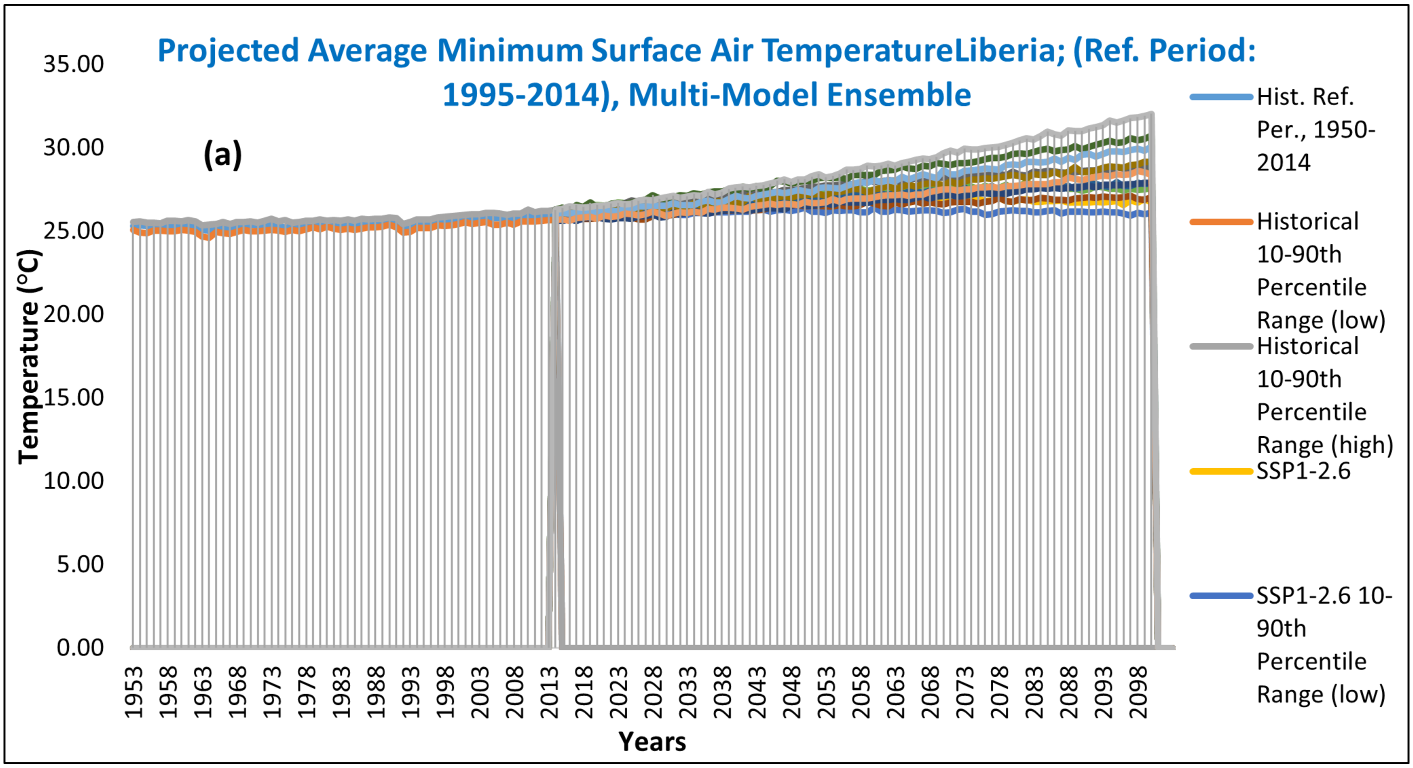


Figure 1. Liberia River Basins (Source: `https://i.imgur.com/C5nXLOr.jpg`)

switch between wet and dry seasons that takes place every year with related changes to the temperature. Between May and October are the Wet season months more or less, when the South-westerly winds day of the South Atlantic Ocean driven by the intertropical front blow over the country. Further, there are also the dry and rainy seasons and warm and cold seasons. The geography of the country together with its rainy seasons favor these changes. Areas on the coast display lower maximum temperatures and high humidity (Ross et al., 2023). The interiors are hotter during the dry and the hot seasons, in addition to this, harmattan reduces the temperatures and destroy the farmlands during the harmattan. Areas that fall within the highlands and the mountains get more rainfall, lower temperature, less humidity, less dust, and less susceptibility to floods. The inland area of Liberia is hotter and moister compared to its coastal locations. Normally, the maximum temperatures are highest within March-April, and the minimum temperatures at lowest during December-February.

The 21st century's first few decades are projected to bring warming of the mean temperature and higher precipitation in Liberia. In addition, temperature projections indicate that the expected temperature by 2100 should be lower. From 1990 to 2009 Liberia's temperature rose by 0.41°C. Moreover, the mean temperature in 2010–2029 will also be growing. From 2050 to 2099, the temperature is forecasted to drop. As for the temperature trends, the future projections are usually showing a general tendency toward warm conditions with mean annual temperatures likely to increase. GCMS agreements are strong such that the models foresee increase in temperatures throughout the year in the coastal zone and inland. In fact, the models predict well-rounded increases in



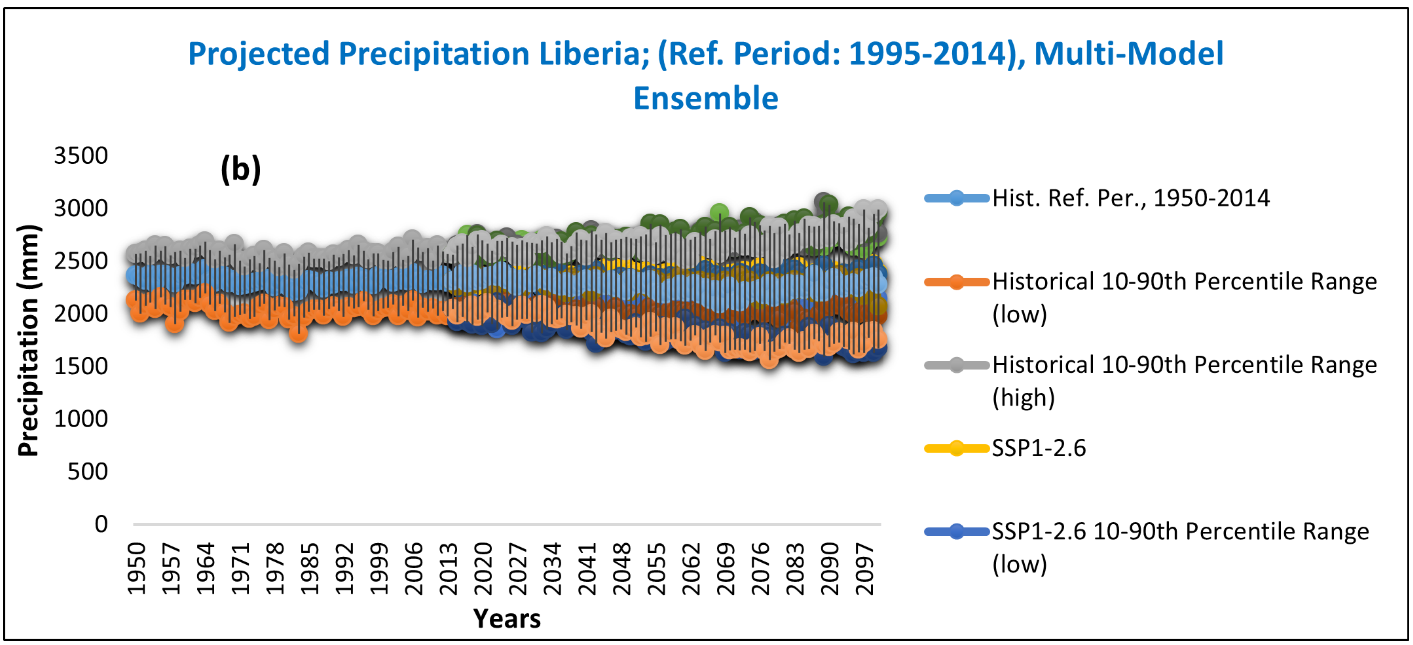


Figure 2. Liberia's Estimated Yearly Temperature (above) and Precipitation (below) (Source: https://climateknowledgeportal.worldbank.org/country/liberia/climate-data-projections)

both daytime high and nighttime low temperatures across the country as well. Based on the projection for the period 2061-2080, the minimum temperature warming is anticipated to be 1.5 to 1.7°C and the maximum temperature warming is about 1.5 to 2.2°C across the coastal region. The highest elevation areas will see even more severe warming in the future. Figure 2(b), also shows that the average annual rainfall in Liberia has ranged from the period to period and area to area. The annual precipitation in the capital city of Monrovia, according to historical data, appears to have an increasing trend from near 1900 until 1960. We must note that flooding occurred in some parts of the city in the years when the annual precipitation went above 5000 mm. Causation behind the oscillation or the landscape degradation due to the agriculture and emergence of the booming tourism sector should be taken into some prudence. Nonetheless, another adversity of climate change especially concerning precipitation trends in areas deemed to be barely arid is to the future of the country in the approaching years. The spatial pattern of rainfall variability will lead to seasonal rainfall shifts with periods of severe droughts particularly in the all-year-round wet, alternatively wet-dry, and dry seasonal regions. The inconstancy will be, besides, not only necessarily relevant with the seasonal changes but also with the intensity of the seasons (Wilson et al., 2019). Lessened rains during the rainy season will affect the forests and trees, water availability, and agricultural productivity, which would result in a change in livelihood. Due to increase of the rainfall in the dry season, more farming will be done on the already overused land of forest and wooded savannah regions. It should be noted that the characteristics of the future projected changes in precipitation trends heavily depend on the chosen emissions scenario and a specific model. The most common model projections feel that the total annual rainfall amounts are going to be around where they are now with a less event factor of wet and dry years. Consequently, future extreme weather events are anticipated to manifests and these include major floods that will become frequent for flat areas and coasts. This scenario leads to an expectation of an intensification of flash flood risk (Mulbah, 2013).

3.2 Liberia Water Resources Development

As shown in Table 1, Liberia's public supply and distribution systems are unable to meet nationwide access to safe drinking water. About 96% of urban part of Liberia and 70% from the rural part of Liberia now have access to safe drinking water. This gap in coverage leaves wide swathes of the Liberian population underserved by public utility systems or point-source protected wells, springs, or boreholes that are relatively costlier to operate and maintain. The share of the total urban population with access to safe drinking water dropped from 66% in 1994 to only 58% in 2001. Since then, there has been a slight improvement which reached 63% in 2005 as per the statistics obtained from WHO/UNICEF's Joint Monitoring Programme for Water Supply and Sanitation (Kumpel et al., 2016). In contrast to 1994 where at least 29 percent of the rural population had access to clean safe water, the cases of the people with such access are declining with the result that it is even possibly lower than 29 percent. In 2001, this figure was 28% and nothing changed in 2005. Rural sanitation coverage in Liberia still remains under five percent with Monrovia having only one-fourth of residents with improved sanitation. Although about 90 percent of the population knew about good hygiene practices, the percentage of those who practiced them was less than 67 percent. Liberia still has a lot to do as regards to community sanitation nationwide. Non-functional latrines in public spaces lead to many inequalities. Over 40 percent of the country's residents do not have latrines within a 1 km distance of their dwellings (Amoak et al., 2023). The 2015 deadline set for the Sustainable Development goals (SDGs), which aim at ensuring sustainable water and sanitation for all, have passed but little efforts have been put in Liberia to ensure better access to drinking water, improved sanitation and hygiene practices for all (Kanagasabai et al., 2021).

The drinking water supply in Liberia is still relatively weak although much attention has been paid to it. Drinking water supply systems have two basic components, source and supply. The sources of water can be classified into three groups. The first is the treated sources such as safeguarded springs, gravity feds schemes, mini piped schemes, and mini piped schemes; however, in a practical sense only two out of these tend to provide clean water; the other two also contributed to as much water contamination as the springs. Second are the untreated sources: rivers, streams, wells, swamps, ditches, lagoons, lakes, ponds, rainwater, and boreholes. Third, the uncovered springs are exposed to surface runoff or contamination from animals. Not all but some of these sources is eligible to undergo chemical treatment to meet the Drinking Water Quality Guidelines of WHO. Low treatment capacity of water treatment plants allows only to provide treated water to part of the country population, and most of the pipe-borne water systems were destroyed during the war. 4% of the households used water from the pure piped-borne facilities. Pipes are also in a dismal state resulted from the corrosion, the lack of rehabilitation, and the weak mechanical and operational maintenance systems. As regards sanitation, the type of sanitation describes what needs to be evaluated. The categories of sanitation can give numerous relevant outcomes. From open defecation to traditional pit latrine, facilities range by infrastructure diversity. This is indeed extremely applicable when making an analysis of the potential impact of the health-related issues arising from insufficient infrastructure (Abrampah et al., 2017). The second thing to think about is the possible level of dedication of the population to hygiene. It is the final one that determines correct maintenance of utility usage - which is apparent as public health is concerned. A case in point is the blanket lack of practice of carry behavior by the people who regularly have sanitation access but still live in communities with no sanitation access. In this context the risk of catching the disease is high. Thus, the infrastructure related provisions cannot be properly assessed without having performed a behavioural study because of the fact that such facilities are largely dependent on local demographic and cultural specifics (Mølbak et al., 1989). One of the major water woes in Liberia is diarrhea. This water disease is the first disease in Liberia which caused over 20% of deaths in the country. The main reason is unclean environment.

Table 1. Overview of Liberia Water Statistics

Variable	2001	2005	2014	2015	2020	2025
Rural Population with Access to Safe Drinking Water (%)	28%	28%	No Data	62.6	70.6	No Data
Urban Population with Access to Safe Drinking Water (%)	58%	63%	No Data	88.6	96.2	No Data
Total Internal Renewable Water Resources (Cubic Meter)	No Data	No Data	44,415	232,000 (MCM/Year)	No Data	No Data
Fresh Water Withdrawal as (%) of Renewable Water	0.0564	No Data	No Data	No Data	No Data	No Data
Groundwater Produced internally	No Data	No Data	45,000	No Data	No Data	No Data
Industrial Water Withdrawal (All Water Sources) (Million Cubic meters/year)	No Data	53.4	No Data	No Data	50	No Data
Municipal Water Withdrawal (All Water Sources) (Million Cubic meters/year)	No Data	80.2	No Data	No Data	80	No Data
Agricultural and Irrigation Water Withdrawal (All Water Sources) (Million Cubic meters/year)	24.6	No Data	No Data	No Data	10	No Data
Daily Water Demand (Cubic Meter) (MGD)	No Data	No Data	No Data	124,316 (32.80)	150,091 (39.60)	182,964 (48.27)

Moreover, prevalent are viruses including lymphatic filariasis and schistosomiasis, which have a prevalence rate of 2.5% and 0.9%, respectively. Malaria and typhoid fever are also highly prevalent in the region but not directly linked to water quality but rather to quantity. Malaria being the second leading cause of death, accounts for 17% of the deaths in the Liberian population. Typhoid fever too is accountable for a massive number of people with 3.6%. That is mainly due to the fact that there is not enough water for the people in the country (Runkle et al., 2013).

3.3 The Effects on the Energy Sector due to Climate Change

In 2004, almost everyone in Liberia, that is more than 95%, depended on biomass sources such as wood, charcoal, palm oil, and electricity. The proportion of areas with access to diesel-generated electricity was just at 2% in villages as well as in towns. Although biomass is the major source of energy, Liberia could develop its indigenous renewable energy sources, e.g., hydropower, biomass, and solar Liberia has rivers like Mano, Saint Paul and Lofa Rivers which has considerable hydropower potential. The effects of climate change on Liberia's power systems, for instance, damages to physical plants and line breaks as a result of natural disasters will be examined (Alfaro and Miller, 2014). Furthermore, biomass use can be affected by climate change as sea levels rise and floods occur, hence limiting access to areas where biomass is available. Higher temperatures have ensured economies in Liberia's high dependency on fossil fuels for development. The significant reliance on the fossil fuels normally as energy source is the biggest contributor to the national greenhouse gas emissions. In 2000, the energy sector in Liberia did not consider emissions from land-use change and forestry, which were 67.5% of the total emissions. According to the Liberian government, mitigation strategies lie largely in the energy and waste sectors. Too much biomass combustion for household purposes is responsible for indoor pollution which endangers health. This underlines the poor status of Liberia's energy sector and that sector significantly contributes to global warming. The energy subsector must devise policies and strategies for adaptation and mitigation of climate change concurrent with the overall national energy policy (Wesseh Jr and Zoumara, 2012).

Table 2 shows the nation's access to electricity and electricity production per source. Liberia is a post-war country whose infrastructure was badly damaged during the 14 years

Table 2. Liberia Population Access to Electricity and Share Electricity Production by Source

Population Access to Electricity (%)		Share Electricity Production by Source									
Year	Access %	Year	Coal %	Gas %	Hydro %	Solar - %	Wind - %	Oil - %	Nuclear - %	Other Renewables	Bioenergy - %
2007	3	2007	0	0	0	0	0	100	0	0	0
2008	1.28	2008	0	0	0	0	0	100	0	0	0
2009	1.90	2009	0	0	0	0	0	100	0	0	0
2010	5.16	2010	0	0	0	0	0	100	0	0	0
2011	4.10	2011	0	0	0	0	0	100	0	0	0
2012	9.11	2012	0	0	0	0	0	100	0	0	0
2013	9.80	2013	0	0	0	0	0	100	0	0	0
2014	9.40	2014	0	0	0	0	0	100	0	0	0
2015	15.16	2015	0	0	0	0	0	100	0	0	0
2016	17.70	2016	0	0	0	0	0	100	0	0	0
2017	24.20	2017	0	0	0	0	0	100	0	0	0
2018	22.88	2018	0	0	0	0	0	100	0	0	0
2019	23.10	2019	0	0	0	0	0	100	0	0	0
2020	27.53	2020	0	0	59.5505	0	0	40.4494	0	0	0
2021	29.80	2021	0	0	57.6087	0	0	42.3913	0	0	0

of civil war. As seen in the figure above in 2007 3% of the country's population had access to electricity. However, gradually electricity production continues to increase and currently, about 27.53% of the nation's population has access to population with 0.40% of said population having access to clean fuel or gas for cooking. Liberia has vast solar and biomass energy potential being near the equator. A handful of autonomous solar power companies are trying to change this as only a part of this potential is consumed commercially. 160-750 MW was expected to be electricity generation from biomass in the 2012 National power Workshop. However, the lack of delta sediment development, rather than the Carboniferous rocks, disposes of Liberia of coal, lignite, and peat, according to the 2021 National Energy Statistics Report. A little bit more than 4 billion tons of iron ore in Liberia. The renewable energy potential of Liberia is favorable. Example: sun, sea coasts, rain, flow of water into the ocean. However, majority of the nation's energy resources and capacity further remains unwarranted. Hydropower commands the renewable power in Liberia.

Undoubtedly, the 22MW energy equipment only serves the city. Many use kerosene and wood cook and light The rural energy and urban energy availability differed. 95% of the time cooking is done with wood, 5% charcoal (Milbrandt, 2009). The huge coal briquette consumption in the Monrovia hinterland doesn't address the country's energy demand. Table 2 also shows the sources of Liberia's energy or electricity generation or production per source. The above data shows that 57.61% of the country's energy generated comes from a renewable energy source (hydropower) while the remaining 42.39% comes from a non-renewable energy source (Fossil Fuel).

Table 3 shows the energy consumption and generation in terawatts/hour. According to the table above hydropower produces 0.53 TW of electricity per hour of the total 0.92 TWH while 0.39 TW per hour of said total electricity is produced from oil sources. The data shows a total of 0.92 TW is generated per hour. The table continues to show an increase in the nation's energy generation from the early 2000s to the present. The post-war Liberia and the prewar Liberia. The study which focuses on post-war Liberia starting from 2003 to date shows a gradual increase in the consumption of electricity in the country. As of the latest recorded year 2021, the table shows a primary energy consumption of 6 Terawatts Per hour. A similar dataset also indicates for this period that per capita energy consumption is 1,065 Kilowatts Per hour. In 2004, more than 95% of Liberians used wood, charcoal, palm oil, and electricity (Milbrandt, 2009).

Liberia is a water resource rich country with rivers like the Mano, Saint Paul, Lofa and others are some examples have a hydropower potential. Liberia could utilize its vast hydropower resources to generate electricity, strengthen resilience, and decrease emissions. The country derives energy from wood and charcoal. The infrastructural degradations and the natural disasters from climate change have jeopardized Liberia's electrical network. Floods and sea levels may hamper biomass removal. The recent fossil fuel consumption of the Liberian economy might have increased the temperatures (Ross et al., 2023). Average annual diesel and gasoline consumption increases by 14%. This research expected 10. 3% growth by 2020 and some less till 2028. Therefore, fossil fuel usage increases national GHG levels. LULUCF was not reported by the energy industry in 2000 as a whole. However, LULUCF emitted 5,414 Gg CO_2e, constituting 67.5% of the total. The Liberian government sees energy

Table 3. Energy Consumption and Generation Terawatts-Hour

Primary Energy Consumption - TWh		Electricity generation - TWh	
Years	TWh	Years	TWh
2000	1.8909329	2000	0.2
2001	2.0167847	2001	0.2
2002	1.989471	2002	0.2
2003	2.1787899	2003	0.2
2004	2.3634825	2004	0.2
2005	2.7665544	2005	0.2
2006	2.833771	2006	0.2
2007	2.6449285	2007	0.25
2008	2.3433158	2008	0.25
2009	2.1389852	2009	0.25
2010	3.367721	2010	0.25
2011	3.749771	2011	0.28
2012	4.1589627	2012	0.28
2013	3.6788895	2013	0.28
2014	4.844483	2014	0.28
2015	4.862246	2015	0.29
2016	5.590125	2016	0.38
2017	4.831436	2017	0.37
2018	5.4881964	2018	0.32
2019	5.4879627	2019	0.31
2020	5.240454	2020	0.89
2021	5.528998	2021	0.92

and waste as way of reducing destruction. Excessive use of biomass at home pollutes indoor air, exposing people to poor health. Emissions of CO_2 from charcoal and fuel-wood production are very high. The energy industry of Liberia is limited, contributing to global warming. For the economic and social development of Liberia, the energy sector needs to adopt a climate change adaptation and mitigation strategy to become climate-proof within a national comprehensive energy policy. Achieving carbon neutrality by 2050 implies the need for cost-effective, sustainable, modern, and clean energy services.

The energy sector is showing great promise in employing micro hydropower, solar, and biomass. Thus, job opportunities will be created with the assurance of energy resources, and the government's initiative to fight poverty will also be sufficed for. Hydropower, solar water heating and solar photovoltaic systems are the emerging technologies. This is because of power deficit in the country and high demand. The rich in society have opted for these technologies as an alternative and a substation for government-run power companies and generators. The cost of a solar water heating system is roughly $1,500 while that of a photovoltaic system is around $1,100 yet it has a payback period of 3-4 years. However, majority of customers are financially deprived and they buy economical diesel generator sets at $150 per piece with a daily cost of US$0.5. This is expensive for a family earning 200–300 per month (Wesseh Jr and Lin, 2015). The relationship between energy and its impact on the Water and Energy Nexus, climate change, existing energy sources, and the gap between energy demand and supply are the focus of analysis. From 150,000 MWh to 343,000 MWh there was a fourfold increase in energy consumption in Liberia from 2008 to 2012. The main reason for the market growth is the car industry. The energy is provided by hydroelectric power, diesel (internally sourced by the Liberian Electricity Corporation-LEC), and heavy fuel oil (HFO) by private sector independent power suppliers. There is a gap between demand and supply in the municipal energy market resulting from the fact that capacity cannot increase at the same pace as the growing demand. The current electrical infrastructure is underdeveloped to serve the anticipated needs. The nationwide load-shedding services are implemented owing to inadequate power supply. The lack of existing connections between Sierra Leone, Guinea, and Cote d'Ivoire prevents electricity importation across their boundaries. This implies that energy usage in Liberia is going to rise (Ijoma et al., 2022).

3.4 Water and Energy Policies

The growing demand for water and energy in Liberia, caused by the impact of population growth and economic activity increase, calls for new policies that could assist in more effective management of the country's- energy resources so that all citizens can access affordable, clean, and reliable

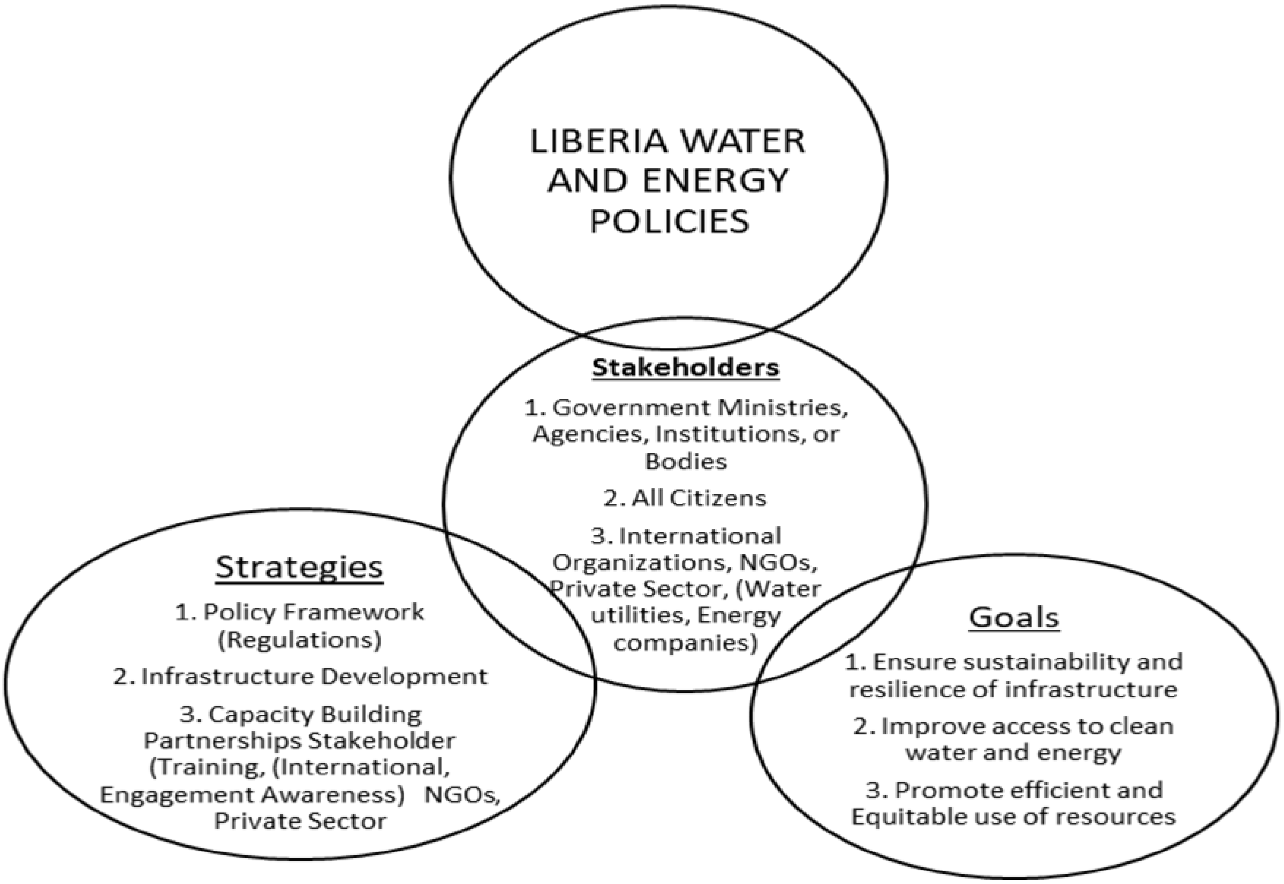


Figure 3. Integrated Water and Energy Policy Framework: Goals, Strategies, and Stakeholders Diagram

energy and adequate water (Figure 3). This one investigates policies and procedures to deal with the prevailing conditions. It suggests policy reform to guarantee the sustainable water and energy supply of the country. Long, short, and priority risk reduction measures for adaptation in water and energy sectors are classified respectively. Large-scale infrastructure such as Mount Coffee rehabilitation; small-hydro, run-of-the-river projects; extent of rain-fed water catchments; and groundwater recharge will be the long-term plan focus. In the short term, the emphasis is on gaining information and knowledge in general thus; making Water and Energy Systems Regulatory Commission, Coastal vulnerability mapping, and groundwater footprint mapping. Critical integrated water and energy management projects are the OFFSET responses for the adaptation strategy for the water and energy sectors and Liberia development strategy. For the water sector there is a given difference which operations aim at investing in forestry and agricultural practices that are inclined to achieve food security and water security while for the energy sector there is an offset. The integrated water-energy nexus management requires an integrated policy approach which provides the opportunity for synergistic and cumulative management systems. This is an integral part of the development and planning stage. The offices of the MLME, EPA and MPW, therefore, must cooperate in order to better coordinate infrastructure planning and execution. Nevertheless, as the energy and water sectors are traditionally operated by different governmental departments, coordination between those at this level will face many institutional obstacles. Therefore, it might require raising the coordination concept to an upper political level, the Executive Mansion. Although Liberia has apparently surplus of unmapped water and energy resources, the regulations on the relationship between these two fields are yet missing, which the government should be filling in. The water and energy resources bias is as a main mover of the economies have seen the policy and regulatory formation, improvement of people's living standards, and changes of the surrounding live styles. Notwithstanding, the currently being practices together with the public sector policies and laws sometimes contradict and misapply, thus leaving a way for political meddling and twists. Conflict-of-interest totally kills the sustainability of such resources and the "one-stop shopping" principle for investors. As such, the government does not exploit and harness the revenue potentials in the two sectors adequately consequently huge losses have been incurred in the millions. The jobs and poverty-reducing interventions are also temporarily shelved due to the mismatch in policies.

4. CONCLUSIONS

Liberia has so much water to exploit for the production of energy toward the mitigation of climate change. Yet, the linkage of water supply, energetic, and climatic variability is intricate. In that period, permanent accessibility, river catchment preservation, and wise water utilization should be continuous in line with Liberia's existing water resource management practice. Besides, the diversification using energy sources such as clean energy to hydropower is an important intent of green energy. It is a foundation to a sustainable green future. Therefore, they will remain basic Building Blocks in designing any new technology instrument developed for policy-making or citizen engagement. The implications of climate change in Liberia should be fully known and hence the introduction of quality water management and renewable energy sources in its negotiations should be implemented as well. At the same time, attention should be directed to the interdependence of climate change, water resources, and energy systems.

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