LARRY T. WOYEA

WIND AND SOLAR PRODUCTION BENEFITS FOR
SOLVING LIBERIA’S ELECTRICITY AND WATER CRISIS

MASTER THESIS

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NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF ENVIRONMENTAL SCIENCES AND ENGINEERING

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Approval

We certify that we have read the thesis submitted by Larry T, Woyea titled **"WIND AND SOLAR PRODUCTION BENEFITS FOR SOLVING LIBERIA'S ELECTRICITY AND WATER CRISIS"** and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Environmental Sciences and Engineering.

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Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

LARRY T. WOYEA

10/06/2023

Dedication

First of all, God our heavenly Father is thanked for His power, wisdom, inspiration, and guidance throughout this effort. I also wish to dedicate this work to my late parents, Mr. Woyea Forkpa, Mrs. Molee Yamah Kaso Woyea, and Uncle Zubah Yanquoi, as well as to my lovely and devoted wife, Mrs. Cecelia Howard Woyea, my children, and her.

And now to my uncles, nephews, brothers, sisters, and aunts. Your all's prayers, encouragement, and support were vital to my success.

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LARRY T. WOYEA

Abstract

Wind and Solar Production Benefits For
Solving Liberia's Electricity and Water Crisis

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The act of burning fossil fuels results in an increased production of greenhouse gases, which contribute to the warming of the Earth. Scientists need to find ways to create energy that is clean, affordable, and can be used without causing harm to the environment. They want to use wind and sunlight to reduce the amount of harmful gases that are released into the air. Wind and sunlight power systems have been utilized by numerous countries to fulfill their electricity needs.. To solve the electricity and water crisis, this research intends to investigate the financial strength and long-term feasibility of wind and solar power systems as a source of clean, reasonably priced, and sustainable electricity in Liberia, which has an estimated population of 4.5 million.

Due to a lack of accurate metrological data on wind pressure and solar radiation in Liberia, a review of previous studies (2012-2022) on the country's renewable energy and water resources was conducted to identify any research gaps. NASA data were used for 39 years (1982–2021) during this review. The RETScreen (8,0) application was employed to measure the monetary viability and ecological sustainability of solar energy plants, and the results presented using the map from the sun radiation and the present study, the potential for sun energy in Liberia is enormous, and installing power plants there is both practical and affordable. From 1754.029-kilowatt hour/m^2 to 2292.678-kilowatt hour/m^2, the expected energy output capacity, the findings demonstrate that compared to wind potential, the solar potential is significantly more variable. This would make it so we don't need to use as much fossil fuels to make energy anymore, which is better for the environment. The use of photo Voltaic technology enables cost-effective access to both electricity and water, compared to the rates applied for grid connections

Keywords: RET screen, solar potential, two axis, wind potential, weibull distribution.

Özet

Rüzgar ve Güneş Enerjisi Üretiminin Faydaları İçin Liberya'nın Elektrik ve Su Krizini Çözmek

LARRY T.WOYEA

M.Sc. Çevre Bilimleri ve Mühendisliği Bölümü

10 Haziran, 2023, 94 Sayfa

Bir enerji kaynağı olarak fosil yakıtların yakılması, atmosfere salınan ve küresel ısınmaya katkıda bulunan sera gazı (GHG) miktarını artırmaya devam etmiştir. Bilim adamlarının, sera gazı emisyonlarındaki artışı azaltmak için rüzgar basıncını ve güneş radyasyonunu kullanarak temiz, makul fiyatlı ve sürdürülebilir enerji üretmenin yollarını acilen geliştirmeleri gerekiyor. Birçok ülke elektrik ihtiyaçlarını karşılamak için rüzgar ve güneş enerjisi sistemlerini kullanmıştır. Elektrik ve su krizini çözmek için bu çalışma, tahmini nüfusu 4,5 milyon olan Liberya'da temiz, makul fiyatlı ve sürdürülebilir elektrik kaynağı olarak rüzgar ve PV sistemlerinin ekonomik uygulanabilirliğini ve çevresel sürdürülebilirliğini değerlendirmeye çalışıyor.

Liberya'da rüzgar basıncı ve güneş radyasyonu ile ilgili doğru metrolojik verilerin bulunmaması nedeniyle, herhangi bir araştırma açığını belirlemek için ülkenin yenilenebilir enerji ve su kaynaklarına ilişkin önceki çalışmaların (2012-2022) bir incelemesi yapılmıştır. Bu inceleme sırasında NASA verileri 39 yıllık bir süre (1982–2021) için kullanıldı. RETScreen (8,0) modeli, PV sisteminin ekonomik uygulanabilirliğini ve çevresel sürdürülebilirliğini değerlendirmek için kullanıldı ve güneş atlas haritasına ve mevcut çalışmaya dayalı olarak sunulan sonuçlar, Liberya'nın güneş enerjisi potansiyeli çok önemli ve enerji santralleri tüm bölgelerde ekonomik olarak uygulanabilir. Sonuçlar, güneş enerjisi potansiyelinin, 1754.029 kWh/m2 ila 2292.678 kWh/m2 tahmini enerji çıkış aralığı ile rüzgar potansiyelinden önemli ölçüde daha değişken olduğunu göstermektedir. Bu miktarda enerji üretimi, ülkenin fosil yakıtlara olan bağımlılığını ve Karbon yoğunluğunu büyük ölçüde azaltacaktır. Son olarak, küçük ölçekli şebekeye bağlı PV sistemi, şebekeye bağlı kullanıcıların elektrik için ödeyeceğinden daha düşük bir enerji üretim maliyetiyle elektrik ve su krizlerini ele alabilir.

Anahtar Kelimeler: Güneş potansiyeli, iki eksen, RETS ekranı, rüzgar potansiyeli, weibull dağılımı.

Table of Contents

CHAPTER IV

CHAPTER V

List of Tables

Page

List of Figures

Page

List of Abbreviations

ALCS:	Annual Life Cycle Saving
CBL:	Central Bank of Liberia
CF:	Capacity Factor
ECOWAS:	Economic Community of West African States
EP:	Equity Payback
EU:	European Union
FAO:	Food Agriculture Organization
FDA:	Forestry Development Authority
GEF:	Global Environment Facility
GEG:	Green Economic Growth
GHG:	Greenhouse Gas
GHI:	Global Horizontal Index
GSR:	Global Solar Radiation
GW:	Groundwater
GWh:	Gaga Witt Per Hour
IWRM:	Integrated Water Resource Management
LCOE:	Levelized Cost of Energy
LEAP:	Liberia Energy Assistance Program
LEC:	Liberia Electricity Cooperation
MW:	Maga Witt

NACUL:	National Charcoal Union of Liberia
NASA:	National Aeronautics and Space Administration
NGOS:	Non-Governmental Organizations
NPV:	Net Present Value
PGE:	Power Generating Factor
PV:	Photovoltaic
R&D:	Research and Development
REEEP:	Renewable Energy and Energy Efficiency Partnership
SP:	Simple Payback
SSE:	Surface Meteorology and Solar Energy Service
TRWR:	Total Renewable Water Resources
UNDP:	United Nations Development Program
USAID:	United Stata Agency for International Development
USD:	United State Dollar
VMP:	Probable Windspeed
WPD:	Wind Power Density

CHAPTER I

Introduction

Changing weather is currently the greatest pressing ecological problem because of the rise in greenhouse gas (GHG) pollutants caused by burning coal and oil (Burton et al.,2019). Therefore, scientists have promoted the quest for alternative energy sources that could produce energy and preserve the environment (Vijayavenkataraman et al., 2012, Arreyudip et al., 2018 & Gouraet al., 2013). Renewable, clean, and capable of producing electricity at a reasonable price are wind and solar energy. Using a wind turbine or a photovoltaic (PV) module, you can turn wind or solar energy into electricity. In many nations, the electricity demand has been satisfied through the use of wind and PV systems.

Several scientists have investigated utilizing winds as well as sun power for the creation of electricity. For example, Zhou et al. (2011) used climatic Examining the possibilities of wind energy from the shore in China using data from 1979 to 2008. Researchers discovered that the nearby nearshore wind turbines have a capacity of roughly 146,336 Gigawatts. The 300-megawatt aggregate performance of two developed wind turbines in Egypt in terms of techno-economic performance was assessed by Ahmed et al. in 2019. These outcomes showed that it constructed wind turbines generated around 1130 gigawatt-hours, so it was expected that electricity prices might decrease to between €1.96-2.09/cents per kilowatt hour. In 2019, GaliMa-aba, Ghoubbet, and Bada Wein in the Republic of Djibouti were explored by Dabar and colleagues for their potential as windy power sources. Based on this research, it was determined that 1073 GWh of energy would be produced annually, with expenses averaging between 7.03 and 9.67 US cents per kWh. Chadee et al. evaluated the price of wind-generated power in Trinidad and Tobago islands in 2018. The researchers found that the price of energy was lower than the existing home support rate on the islands. Using various solar panels, Parikh et al. 2019 studied the possibilities of renewable radiation. Research outcomes demonstrated that the suggested solar PV project could produce 173.6 Megawatts of power at its full capacity. Additionally, Rehman et al. 2017 looked into the viability of the Grid-connected Photovoltaic system 10 Megawatt at 44 locations in Saudi Arabia. They discovered that Bisha was the ideal site for the eventual placement of Photovoltaic plants. In evaluating a techno-economic analysis of a solar power plant in Jos, Nigeria, Adaramola et al. (2014) used the Homer software. The projected plant's capacity factor was found to be 40.4% with a 331.536 GWh yearly power production.

Liberia Energy Situation

There are currently about 4.6 million people living in Liberia. An estimated 38% are those who make less than $1.90 a day in the United States. Rural areas experience significantly more poverty than urban areas (World Bank 2014). Biomass accounts for well over 80 percent of the primary power sources used in Liberia, which is where most use the nation's energy. The use of woody biomass for residential heating and cooking is the most significant. Over 95% of the population, according to an estimate from 2004, relies on palm oil for lighting and warmth and cooking, using wood and coal. By the most recent Census (2008 numbers, published in 2009), 91% of rural households use firewood for cooking, compared to 21% and 70percent of urban dwellers who use charcoal. Monrovia has a far higher percentage of dwellings that use charcoal, at 85%. Only 2 percent of people have access to clean cooking technologies and energy sources (World Bank 2014).

Nowadays, transportation and economic production are the main uses of electricity and petroleum-based energy services. Kerosene, electricity, and liquefied petroleum gas are the main sources of modern energy services used in homes for lighting, cooking, and entertainment. Urban households with greater incomes use them. Historically, Monrovia, the nation's capital, served the majority of the country's 35,000 clients, or over 13 percent of the total population. 191 MW of power was installed altogether. The hydropower from the Mt. Coffee plant, which has a production output of 63 Megawatts in the rainy period and 5 Megawatts in the hot period, together with 31percentage HFO and 21percentage petroleum, made up the generation mix. 10 small isolated power systems totaling 13-megawatt generation capacity were managed by the utility Liberia Electricity Cooperation to supply electricity to rural communities outside of Monrovia.

As per data from the authorities and the World Bank, below 2 percent of people in rural areas and 16.8 percent of urban residents currently have access to electricity, the majority of which is produced locally using petrol or diesel generators and high-priced fuels. Public power is accessible to about 1% of the population. Around 2,500 people out of an estimated 210,000 homes were served by LEC's 5,600 connections in Monrovia in March 2012. LEC was already providing service to 11,000 subscribers by August 2012. According to a baseline evaluation carried out by Norad, about ninety thousand homes and enterprises in Monrovia might be supplied with affordable gasoline and diesel sources. At Nimba, Grand Gedeh, Maryland county, 36,000 people have access to imported power from Ivory Coast.

Energy Potentials of Liberia (Solar)

Liberia experiences a humid, tropical climate with year-round average temperatures of roughly 27° C (81° F), barely ever going beyond or below the temperature range of 20–36° C (68–97° F). Monthly solar irradiance on a horizontal surface peaks during the summer months in February and March, averaging roughly 4 kilowatt hours/m2/day. in June, July, and August during the rainy season to 6 kWh/m2/day in Liberia. At 1,712 kWh/m2/year, which may provide 1,400 to 1,500 kWh/kWp, the nation as a whole has a substantial and continuous potential for solar radiation. (USAID Factsheet Liberia 2017 & Power Africa 2018)

Biomass

There are plenty of trees in Liberia because they cover 43% of the country's area (41,790 km^2, according to the World Bank 2015). There are two legally protected areas, East Nimba (about 149,000 hectares) and Sapo National Park (11 declared National Forests, with limited protection), in the nation (about 15,000 ha). Forest resource management is the sole responsibility of the FDA, Forest Development Authority, which concentrates on extensive timber concessions production. To determine how Liberia's biomass resources (other than forestry) could be exploited for energy, the US National Renewable Energy Laboratory (NREL) researched them. NREL estimates that once logging processes resume, the 20 million m3 (162,645 TJ/year) yearly amount of trash from such activities might be very substantial of which 1.09 million cubic meters will be produced on the sawn timber and will be produced on logging operation; the majority of this unused will be lost. 100 million bags of charcoal could be produced each year from the waste from wood goods, which is much more than what the country currently uses.

According to NREL's estimates, only 6% of Liberia's 37% of its total acreage is now under cultivation. About 3 million hectares of cropland remain, which suggests that in adding to the capital now available, there is a good chance for crop varieties, such as plant farms that might yield materials appropriate for the making of charcoal. Big rubber farms (>800 ha) presently span 58,000 hectares in Liberia, which are around Monrovia. NREL believes that a total of 100,000 ha was formerly covered by rubber trees. According to Buchanan Renewables, the total area covered by rubber trees in plantations today is closer to 250,000 hectares, of which perhaps a third has to be replanted soon. There are other smaller (5–800 ha) rubber plantations, however, these are typically thought to have estates with more recent trees. There are also many small household plantations, each less than 5 acres.

Charcoal makers are known to utilize the significant amounts of wood residue that an active rubber plantation produces each year as a result of pruning and replanting processes. Trees need to be replaced after 25 to 30 years when they stop producing; an old tree's hectare can yield roughly 81 dried tons of timber (branches and trunks) (180 cubic meters approximately of green wood). Many oil-palm trees can be found in the wild, on deserted farms, on private land, and on shoreline locations (30,000 ha). The majority of trees have outlived their usefulness. We don't know if old plants are used to make coal.

The typical home plantation is 1.2 hectares, and 32% of the 353,000 plantations contain cocoa trees, 13 percent have oil palms, and 6% use coconut plants as a source of income. Although the contribution of these trees to the manufacture of charcoal is unknown, it cannot be disregarded.

As stated by the Liberian Central Bank (CBL), 255 tons of merchant charcoal were utilized overall in 1999). According to the National Charcoal Union of Liberia (NACUL), 960,000 trees are cut down each year in Monrovia and Liberia's annual consumption of charcoal increased to 36,500 tons in 2005. Production and consumption both grew more and at least 100,000 tons were produced and consumed. According to some sources, production/consumption for the year 2010 has already surpassed between 235 000 and 285 000 tons, with a manufacture/feasting rate of 59 kg per person annually. Private businesses and neighborhood-based organizations manage the entire charcoal production and commercialization process. Although there are no reliable statistics on firewood usage in Liberia, the results of a survey carried out by CSET in 2004 suggest that a severe firewood shortage could develop in some areas of the country, particularly in Montserrado County. According to estimates, each person uses 1 m3 of firewood annually. It can reach up to 18m3 per home in some rural locations. Forecasts for the nation predict a rise in demand of roughly 0.6 m3 per home year. According to other projections, demand will rise by around 0.43 m3 per individual annually. As opposed to that, the majority of the firewood used in rural households is typically made out of dead wood, branches, etc., and is taken from the area nearby.

The availability of trees and the low population density make it plausible to expect If there are no immediate or long-term issues with harvesting firewood, the manufacturing of charcoal poses a greater risk of significant environmental harm to timber resources.

Improved Cook Stoves

Only a 2parcent of the population can access clean cooking methods and fuels (World Bank, 2014). Buying and utilizing stoves that run on gas or electricity is primarily done in Monrovia. GIZ/EnDev created upgraded charcoal cookstoves (referred to as "Red Fire Pots"), which are made locally and marketed mostly in Monrovia. Improved cookstoves are also imported by one retailer.

Hydropower

There are numerous rivers, a vast sea coast, and a rainy season in Liberia that lasts from April to November. Around 510 centimeters (200 in) of rain falls annually along the shore and 80 inches (200 centimeters) offshore. During the wet seasons, the coastline region's moisture content fluctuates from 78 percent to 50 percent, with an average of roughly 82% (Ministry of Land, Mines, and Energy, Liberia). The Rural Energy Strategy and Blueprint states that Liberia has a 2,300 MW hydropower potential. The biggest potential is found in large rivers with low heads and a higher yearly average discharge. Many places are ideal for above 5-megawatt hydro projects because they have heads and flows exceeding 50 m3/s. The likelihood varies during the dry and wet seasons.

Wind

According to estimates, Liberia's wind energy potential is not very high. Although coastal and mountainous areas may have some promise, only a few regions may have the requisite wind velocity of 7 m/s required for wind-generating facilities, which is probably insufficient for commercial use. By 2025, 0.47 GWh of wind energy will be produced in Liberia, according to the SE4All Action Agenda Report from 2015. Wind energy is neither evaluated nor suggested for use in the Liberia Rural Energy Plan and Long-term plan.

Fossil Fuel

In Liberia, all fossil fuels are imported. Certain oil exploration blocks in Liberia reach depths of between 2,500 and 4,500 meters from the coastal waters. Oil discovery in the Liberian basins will be extremely challenging and expensive because of its distinctive geology. Multinational oil corporations have been granted permission to conduct exploration since 2011. With the Liberian government, production-sharing contracts were signed by Anadarko Petroleum, African Petroleum, Chevron, and ExxonMobil (PSCs). Ten wells have already been drilled as part of exploratory drilling by several of these businesses. In two zones in Liberia, According to African Petroleum, it discovered a cumulative 32m (105ft) of net oil payout. Eventually, ExxonMobil started drilling on November 22, 2016. ExxonMobil claimed that there was not enough oil in the well to produce more oil than would be required to cover the cost of drilling and extracting it on December 19, 2016, after failing to detect any oil. Exxon chose to continue exploring other parts of the block rather than drilling, which might cost up to $1 million per day, as there was adequate support in the rock samples taken from the ocean below. Oil corporations as well as Anadarko, Repsol, Tullow, and most newly African Petroleum have all given up oil blocks. Due to a history of no commercial oil finds in the basin, the Liberian oil basin is facing market hurdles and a lack of interest.

Key Problems of the Energy Sectors

The greatest problems and bottlenecks in Liberia's electricity sector, according to Power Africa, are as follows:

- Insufficiently strong and established enabling environment
- Unprofitable public utility with high tariffs and significant profitable losses
- anticipated the delivery and distribution network expansion to replace the current generation range
- emerging off-grid market.

Electricity Supply

The Bushrod Island 36magawatt fuel plant and the 88MW hydroelectric Mount Coffee facility supply the principal Greater Monrovia's plan, which is managed by Liberia Electricity Cooperation. Only 5- megawatts of the 22- megawatt of fast petrol engines. at the Bushrod Island facility was still in use, with 2.5 MW of that being available. Hence, LEC has 131 MW in total, which is made up of 88 MW of hydro, 38 HFO, and 5 MW of LHO. There is a problem with the enlarged but inadequate Facilities for transmission and distribution already in place.

Electricity from Ivory Coast is imported into the counties of Maryland, Grand Gedeh, and Nimba reaching 36,000 people as of the end of July 2017 and continuing to grow. The EU has provided support for this international undertaking. Through USAID, the EU, the UNDP, and some NGOs, Backup modest hydroelectric, biomass, or generator and rooftop solar installations have been made available to several state agencies, local administrations, and private industry firms in rural parts of various counties. Although the number of residences in Liberia with solar PV systems is unknown, it is still a tiny amount. In Monrovia, only one tiny wind turbine has been spotted. There is no information available at this time regarding the nation's stand-alone diesel plant usage. The Liberia Electricity Corporation has irregular statistics on home access to power in the county capitals. Due in part to its pricey diesel generation, In October 2012, the public tariffs in Liberia were $0.52/kilowatt hour, making it one of the costliest in the world. The tariff has decreased since the hydropower project went into operation (from $0.39 to $0.45 per kilowatt hour in 2017). Personal production is predicted to cost at least USD 0.75/kWh. The potential for hydroelectricity in Liberia is enormous. Before the civil war began, Liberia had operating hydroelectric power facilities including Harbel (Firestone), a 4MW facility; Mount Coffee, a 64magawtt facility; and Yandahun, a 30kilowatt community micro hydro in Lofa County. The war-devastated Mount Coffee and Yandahun businesses have just finished reconstruction with improved capabilities.

Water Resources of Liberia

Water is abundantly available across Liberia. At 49,028 m3, water availability per person in Sub-Saharan Africa ranks third highest and is much greater than the

Falkenmarki water stress threshold. Water absorption is also very little. Less than 1% of the water supply comes from renewable sources. Although there is a lot of During the summer months, the surface river flows often be minimal. The Mount Coffee Dam, which is the principal source of municipality energy and a sizable generator of electricity for Monrovia, suffers greatly from low flows on the St. Paul River.

The main causes of water contamination and ecosystem deterioration are artisanal and industrial-scale mining operations, as well as rubber plantations. Settlements with insufficient waste disposal and unsanitary conditions have damaged wetlands, biodiversity, and public health. Both rural and urban regions get their drinking water primarily from underground because of raised water tables, which make it accessible. Nevertheless, the significant incidence of unguarded pit toilets and boreholes that are easily contaminated by wastewater, particularly in rainy periodic floods, poses a threat to groundwater quality. Communities that rely on shallow groundwater as a source of drinking water may face major health hazards as a result of contamination. Water-borne disease illness occurrences in urban areas, particularly in urban slums, will become more likely as a result of increased rainfall intensity and flood danger brought on by climate change. Seasonal storms and tidal surges will become more disruptive as sea levels rise, endangering bodies of water and mangroves, structures, and human habitation.

Data on the quantity, quality, and use of surface and groundwater in metropolitan areas, as well as knowledge of the groundwater balance, are scarce. This worsens management systems and raises ambiguity regarding future dangers to the public's health and water supply. Although the sector lacks a ministry devoted solely to water resources, management of water resources is divided among different managerial agencies. The inability of these organizations to coordinate hinders water management initiatives. The Integrated Water Resources Management (IWRM) Policy of Liberia is hindered by a lack of funds and technical expertise.

Surface Water

Liberia has 23 minor coastline drainage channel zones that flow into the Atlantic Ocean along with 15 sizable drains that flow from the northeast to the southwest. The Fouta Djallon Mountains of Guinea are home to the Mano, Lofa, St. Paul, St. John, Cestos, and Cavalla Rivers' source areas.

Those rivers flood Liberia in 56 percent with the other 46% being drained by 11 medium-sized tributaries and numerous short coastal rivers. 2-4 The coastal plains of Liberia contain three of the country's five Ramsar areas, 55,000 hectares of coastal mangroves, and more than 600,000 hectares of floodplains. 5,6 The two largest lakes are Lake Shepherd and Lake Piso, and both lakes are brackish. The largest Ramsar site in the nation is Lake Piso. 7 The sole notable reservoir in Liberia is the Mount Coffee Dam, which holds 239 MCM of water from the St. Paul River. The dam serves as a major source of sources of water for Monrovia and is utilized to produce city electricity. Waterfalls, rocks, sandbanks, and waterfalls occur primarily in upriver regions of most rivers in Liberia, preventing river traffic and limiting inland transportation to a 30- to the 40-kilometer range. The two biggest lakes in the nation are Lake Piso and Lake Shepherd.

Coastal locations are prone to flooding during the rainy season (UNICEF 2006). Liberia's freshwater wetland (swamps) is believed to be over 600,000 hectares, adjacent to the shoreline of several kilometers of tidal riverbanks (3092 km) and other smaller tributaries totaling more than 1000 km, and covered with mangroves reaching 30 meters in height. Wetlands—Mangroves that can reach 30 meters in height cover along the coast, there are several smaller rivers (>1,000 kilometers), rivulets (645 km), and flood riverbanks (3,092 kilometers) (DAI 2008). Much is unknown about the exact worth of Liberia's freshwater wetlands, which provide water for medicinal plants and other products, as well as key fishing grounds, flood management, and improved water quality are just a few examples of ecological services. The relevance of saline and brackish wetlands to artisanal and commercial marine fishing is also poorly understood. Wetlands, which make up roughly 12% of Liberia's surface water, cover around 12% of the country.

The basin's major tributaries include River names like the Mano, Lofa, St. Paul, Cestos, Cavalla, and St. John. Between Sierra Leone and Côte d'Ivoire, the Lofa and Mano watersheds, St. Paul, and St. John basins between Guinea and Liberia, and the Lofa, St. Paul, and St. John basins between Liberia and Guinea, respectively, are the seven international river basins that Liberia shares with its neighbors. Many rivers merge. The Boundary Mountains were used to gather information. While the Lofa

River begins in Wologizi, the rivers St. John, Cestos, and Cavalla have their origins in the Nimba Mountains. From Mount Mano and Mount Putu, respectively, the rivers Mano and Nuhn pour into the Mano, Cestos, St. John, and Lofa rivers' mouths. It possesses diamond deposits that have been washed away from the mountains that they pass over.

Table 1.1

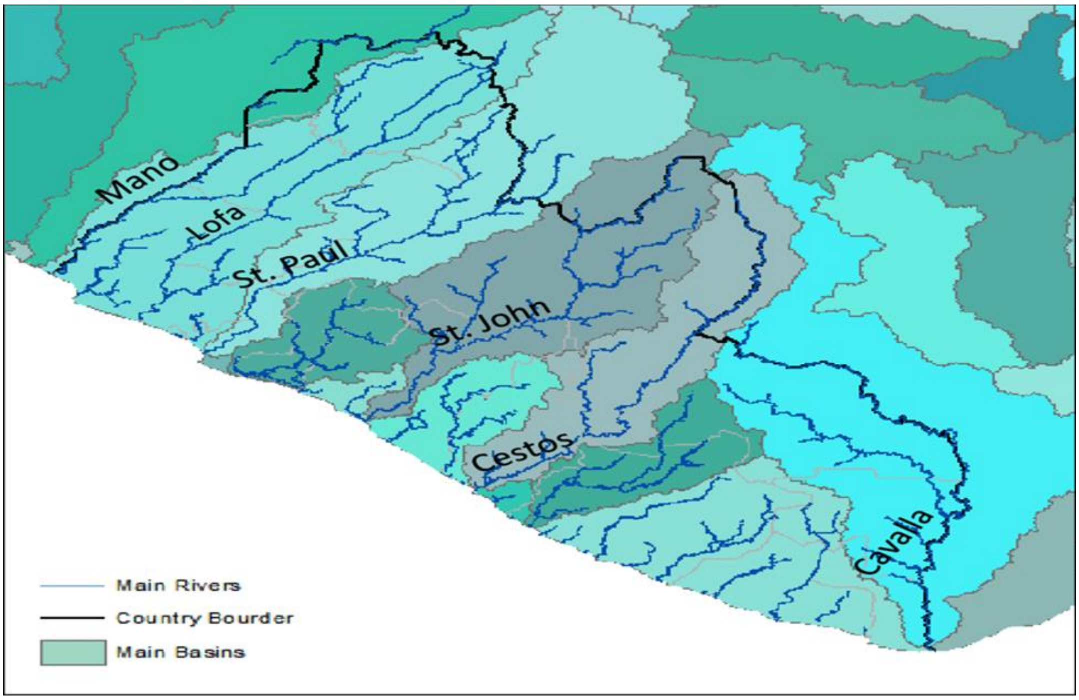
Liberia's data on water resources

Description	**Year**	**Liberia**	**Sub-Saharan Africa (median)**
Long-term average precipitation (mm/year)	2017	2,391	1,032
Total renewable freshwater resources (TRWR) (mcm/year)	2017	232,000	38,385
Falkenmark Index-TRWR per capita (m^3/year)	2017	49,028	2,519
Total renewable surface water (mcm/year)	2017	232,000	36,970
Total renewable groundwater (mcm/year)	2017	45,000	7,470
Total freshwater withdrawal (mcm/year)	2002	130.8	658
Total dam capacity (mcm/year)	2015	238.6	7,085
Dependency ratio (%)	2017	13.79	23
Interannual variability	2013	0.8	1.55
Seasonal variability	2013	2.8	3.15
Environmental flow requirement(mcm/year)	2017	176,800	18,570
SDG 6.4.2 water stress (%)	2002	0.26	5.7

Source: FAO Aquasat

Figure 1.1

Map of six major rivers



Source: Rachel A Neugarten, Assessing the Contribution of Biodiversity and Ecosystem Services to Liberia's Sustainable Development through Natural Capital Mapping and Accounting

Table 1.2

Main river basins of Liberia

Basin	Area (km2)	Annual flow (m3 /sec)
Mano	6,604	251
St. Paul	12,820	512.3
St. John	14,762	N/A
Cavalla	13,726	380
Cestos	10,000	60.3
Lofa	9,194	N/A

Source: Liberia environmental profile

The water looks to be plentiful in Liberia, Nonetheless, it seems to be in short supply in crowded cities and emerging ones like Monrovia, where rubbish is dumped in bodies of water. Open toilets have been constructed along the riverside, polluting the water for people who reside downstream. The distribution and supply of water are essential parts of a nation's socioeconomic growth. A sufficient and secure supply of water is required due to the rapid growth of the population, the expanding of agriculture, and industrialization.

Groundwater

Except for a small area of unconsolidated sedimentary aquifers near Monrovia on the northwest coast of Liberia, almost all of the country's groundwater is found in hard rock aquifers. In both groundwater systems, aquifer productivity varies, but knowledge of aquifer features is inadequate. Even though the majority of Wells are brief (5m to 25m deep), they frequently have modest recharge. Although deeper, more productive strata may also contain groundwater, Due to the large variations in groundwater supply, digging water wells can be expensive and dangerous. Although unconsolidated coastal sedimentary aquifers are more productive, freshwater is usually impacted by the saline intrusion. Liberia Hydrological Services, Liberia River Basin 2016, and Esther D., et al., A Study of the Basement Complex Aquifer System in Lofa County 2021.

In African towns, groundwater is an essential supply of drinking water; nevertheless, the combined use of aquifers as a repository for sources of human waste pollution such as sewage ponds, latrines, and gutters has harmed this resource. It's unclear how much climate change has already had an impact on groundwater abstractions (Cisneros et al., 2014). Despite extensive research and execution of water supply projects in Liberia over the past 20 years, particularly in remote settings, the ratio of people without access to sanitary facilities and safe drinking water is large and growing.

The subject underlines the necessity for the urban poor to have access to sanitary facilities and secure water to consume (Karanja, 2003). It can be discovered in water-containing aquifers and have hydraulic qualities that enable significant amounts of water to be pumped through boreholes and excavated wells. Protected hand-dug wells provide water to about 64% of the city's populace and 65% of local inhabitants (GoL, 2014). The usage of freshwater sources such as groundwater resources has grown increasingly significant as a result of population growth and rising water demand.

Human activities such as agriculture, urbanization, and industry, on the other hand, are degrading groundwater quality (Kazakis and Voudouris2015). Groundwater is a generally safe and reliable source of water when compared to surface water. Groundwater (GW) is a critical resource for home use, agricultural and industrial operations, and ecosystem services [CHEN et al. Groundwater has traditionally been thought to be more resistant to contamination than surface water and to be less influenced by drought and climate change [HOWARD 2014]. Margaret (1968) coined the term "groundwater vulnerability" to describe the possibility for surface contamination to migrate to groundwater and, as a result, to take the required precautions to conserve resources. Groundwater is one of Liberia's greatest important drinking water supplies, consisting of minerals that contain water and have hydrodynamic characteristics that enable considerable amounts of water to be recovered through boreholes and dug wells. In Liberia, groundwater development began in the 1800s when people began digging wells for domestic use in both remote and city areas.

Since then, non-governmental organizations (international) and other groups have joined the endeavor to provide water from wells to rural populations. It's unclear how much climate change has already had an impact on groundwater abstractions (Cisneros et al., 2014). Despite extensive research and execution of water supply projects in Liberia during the last two decades, the ratio of people without access to facilities for sewerage and secure water to consume is large and increasing., particularly in rural areas. The subject underlines the necessity for the urban poor to have access to safe drinking water and sanitation (Karanja, 2003). Liberia's groundwater is of good quality, but it isn't being used to its full potential. Protected hand-dug wells provide water to about 64% of the urban population and 65% of the rural population (GoL, 2014).

The usage of freshwater sources such as groundwater resources has grown increasingly significant as a result of population growth and rising water demand. Groundwater is a generally safe and reliable source of water when compared to surface water. Groundwater (GW) is a critical resource for home use, agricultural and industrial operations, and ecosystem services [CHEN et al. Groundwater has traditionally been thought to be more resistant to contamination than surface water and to be less influenced by drought and climate change [HOWARD 2014]. Groundwater is one of Liberia`s most important water resources, containing rocks that can hold water and have hydraulic properties that make it possible to recover a large amount of water using wells and boreholes. In Liberia, groundwater development began in the 1800s when people began digging wells for domestic use in both rural and urban areas.

Despite being a major source of drinking water, groundwater resources are little known. This is particularly true of hand-dug wells. There are few aquifer assessments and hydrogeological characteristic assessments. In both rural and urban areas, more than 70% of the population relies on groundwater as their primary supply of drinking water. Yet, there aren't many statistics available on groundwater usage by industry. As the civil wars damaged the majority of municipal water systems, the vast majority of individuals were compelled to depend on small, hand-dug wells to obtain their water.

Studies on drinking water quality are scarce, but they show that microbial contamination poses broad concerns. In a 2011 state of groundwater survey in Monrovia, E. coli was found in every unsupervised well, 44 percent of boreholes, and 52 percent of hand-dug-covered wells. 45 Comparable research showed high levels of nitrates in Monrovia, which were most likely brought on by the city's inadequate sewage system. Significant amounts of lead (46.47 percent) have also been connected to poor solid waste management and industry pollution in Monrovia, Robertsport, Voinjama, and Sanniquellie. An increase in sea levels, beach erosion, and inland storm surges that raise the saline of essential water supplies are additional threats to coastline groundwater.

Rainfall

Before the internal conflict, the Ministry of Land Mines and Energy's Liberia Hydrological Service ran a network of 28 hydrologic and hydro-geological sites in 11 major rivers basin across the nation, collecting simple hydrologic information was gathered. The majority of Liberia experiences the two seasons of the West African monsoon, except for the southernmost part of the nation, where it rains always. While other projections indicate that total rainfall will gradually increase toward the interior in the long term, with the western coast in 2050 expected to get the maximum average yearly rainfall (5,000 mm), there is a spatial pattern of average annual precipitation when comparing current to 2050 projections. Rainfall near the coast is anticipated Rainfall near the coast will continue to rise during the rainy season, while the dryness will significantly move the first month of July, to the east of the mid-dry season. Between December and February, the summer wind crosses the planet and sweeps into

Liberia, bringing with it a lot of fog, dust, and cool nighttime temperatures. Even during the rainiest months, bright days are frequent although the severe torrential rains, fog, and dust do not continuously fall. Although it's unknown how climate change will affect overall rainfall, it will aggravate floods and promote the transmission of infectious diseases. The rainy period in Liberia lasts from May to October, and the colder dry period lasts from November to April. Along the seaside, where it reaches a monthly maximum of 1,000 mm, rainfall is heaviest. The average temperature in Liberia has already risen by 0.8°C, and by the turn of the era, another rise of 1.4–2.4°C is predicted. Since the 1960s, total rainfall has declined; nevertheless, it is unclear how total rainfall will alter in the future. In Liberia, there is a considerable risk of riverine flooding, and the effects have gotten worse recently. Rainfall will be more intense due to climate change, which could intensify flooding and waterborne illness epidemics. In cities like Monrovia, informal settlements are most vulnerable to flooding and public health emergencies, particularly cholera outbreaks. Over the past few decades, there have been about 85,000 documented cases of cholera, with over 18,000 cases in 2003 alone. (ACAPS. Liberia: Risks; 2015. & Rebaudet et. al. 2013, A Systematic Review of Its Heterogeneous Environmental Determinants).

Table 1.3
Baseline climate scenarios of Liberia (1953 – 1982)

Year	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
Mean Temperature (0 C)												
1953-1982	290	290	300	300	290	320	300	310	290	280	280	310
Mean Rainfall (mm)												
1953-1982	1785	2047	2090	2355	4693	3945	3105	3740	3135	2844	2374	2103
Monthly sunshine (hr.)												
1953-1982	9.0	9.0	8.5	7.5	7.3	7.4	7.2	7	6.8	7	7.5	8.5
Mean Humidity (%)												
1953-1982	95	95	95	97	98	98	99	96	97	98	96	95

Source: Climatology Unit, Department of Geography, University of Liberia (1984)

Wetland

Wetlands can be permanent or ephemeral and are composed of still or moving water. Parts of seawater that are typically less than 6 meters deep at low tide may also be present with fresh or brackish water. Their soils are water-rich and non-draining, and they have aquatic flora. Since it was created in conditions with little oxygen, is exceptionally clay-heavy, or has a substantial amount of plant waste (peat), the soil underlying the wetlands is very different from conventional soils). Others protect waterways from flooding and silt, while others offer vital habitats for migratory waterfowl. Some serve like screens, eliminating and entangling impurities that might otherwise get into your drinkable water. Others provide leisure activities like fishing and boating. Wetlands are densely populated regions with a diverse range of animals and plants. In Liberia, there are four major types of wetlands: coastal, riverine, inland, and inland.

Table 1.4

Main wetlands

Wetlands	**Wetland Type**
Lake Piso	Coastal Lacustrine
Marshall	Inland Riverine
Mesurado	Coastal
Lake Shepherd	Coastal
Bafu Bay	Coastal
Gbedin	Inland Swamp
Kpatawee	Inland Riverine
Cestos-Senkwehn	Inland Riverine

Source: Liberia environmental profile

Table 1.5

Cities with water prior to the Liberian civil war

No.	**Town**	**County**	**Capacity(gallons/day)**	**Year of completion**
1	Greater Monrovia	Montserrado	16,000,000	1885
2	Gbarnga	Bong	160,000	1978
3	Sanniquellie	Nimba	94,000	1979
4	Voinjama	Lofa	125,000	1980
5	Zwedru	Grand Gedeh	100,000	1980
6	Buchanan	Grand Bassa	200,000	1984
7	Kakata	Margibi	580,000	1985

8	Robertsport	Grand Cape Mount	90,000	1971
9	Greenville	Sinoe	85,000	1970
10	Tubmanburg	Bomi	N. A	N. A
11	Maryland	Harper	N.A.	N.A.

Source: Liberia environmental profile

Scope of the Study

The review of literature includes the majority of the world's continents, including Europe, Africa, Asia, and others. The current study is focused on Liberia's fifteen counties/locations, where the lack of electricity and quality water supplies pose a significant barrier to the country's social and economic development. Less than 2000 mm in the hinterlands and more than 4500 mm at the coasts are the ranges of rainfall. In Liberia, the availability of clean energy is extremely low, with less than 3% of the population having access to it. Liberia has an abundant supply of water, with six major rivers making up nearly all of the nation's surface water. The literature review indicates that there is a shortage of exact or reliable data on wind speed, sun radiation, and meteorological stations to gather weather parameters. The purpose of using NASA satellite data in the models is to estimate and analyze wind and solar potentials.

Significance of the Study

21 percent of rural people and 70 percent of urban residents, correspondingly, Cook using coal, whereas 91 percent of remote residents use wood, the latest recent Census indicates (2008 numbers, published in 2009). The proportion of homes utilizing charcoal in Monrovia is much greater, at 85 percent. Only 2 percent of people possess a source of clean electricity and technology for cooking (World Bank 2014) Nowadays, transportation and economic production are the main uses of electricity and petroleum-based energy services. Kerosene, electricity, and liquefied petroleum gas are the main sources of modern energy services used in homes for lighting, cooking, and entertainment.

The goal of this investigation is to ascertain if wind and solar energy systems in 15 counties of Liberia are both environmentally and economically sustainable. using NASA date from 1982-2021 (39 years) period. This will serve as a source of clean energy and will also help to reduce the emission of GHG into the atmosphere. It is a significant contributor to global warming.

Problem Statement

Changing climate is currently the most urgent environmental concern as a result of the growth in greenhouse gas (GHG) emissions caused by the combustion of fossil fuels (Burton et al., 2019).

- ❖ Making use of a windmill or a photovoltaic (PV) module, you can turn wind or solar energy into electricity. In many nations, the electricity demand has been satisfied through the use of wind and PV systems however, Current stations recordings are generally of poor quality and challenging to get because of legislative restrictions, a lack of data distribution capability, or the expensive demand of data in many parts of Africa (Dinku et al., 2014)
- ❖ The energy crisis is also more difficult to resolve as compared to other social, environmental, and economic needs.
- ❖ For the past 50 years, Liberia has faced a serious energy and water problem that has caused widespread suffering among the populace and grave disruptions to social and economic activities.
- ❖ Environmental issues, global warming, and inadequate energy management practices
- ❖ Low energy and water supplies with high cost (especially poor water quality)
- ❖ Due to a lack of previous studies, financial parameters were based/assumed on bordering countries such as Nigeria, Ghana, Ivory Coast, etc.
- ❖ In 2014, LEC reported that 81.3% of the total population (Liberia) had not access to electricity, 4.9% used community generators, 4.4% used their diesel generators, and 4.5% supplied by LEC
- ❖ Low investment and weak government policy in the energy sector especially clean energy
- ❖ RETScreen software used to analyzed and design the PV System does not contain formula to calculate the effect of humidity on the solar radiation or the PV System

- Due to lack of previous studies, financial parameters were based/assumed on bordering countries such as Nigeria, Ghana, Ivory Coast, etc.

Methodology

The NASA metrological stations of the 15 locations in Liberia provided the prevailing winds and solar irradiance data that were used to estimate the wind and PV systems, as well as the minimum and maximum WDP and GHI. The wind speed data were analyzed using Weibull, and the proposed PV system's economic viability and environmental sustainability was assessed using the RETScreen model. Due to the lack of metrological stations, the research region (15 political subdivisions of Liberia) for which the wind speed and sun radiation statistics are gathered lacks actual data. As a result, the NASA data were retrieved after 39 years of collection (1982-2021).

Overview of the Thesis

The following examination demonstrated how this study is achieved: The summary of the study, the energy status, the rainfall, the climate, and the water resources of Liberia are all covered in Chapter 1. This comprises wetlands, groundwater, and surface water. The relevance and limitations of this thesis are also thoroughly described, along with the scope and goal of the study. Chapter 2 reviews pertinent literature on related studies on renewable energy in Liberia, analysis of wind and solar potential using NASA data to look into the viability and sustainability of other regions of the world, including Africa, as a substitute for clean and affordable energy sources, and related studies comparing actual and NASA data.

Chapter 3 Offers an in-depth look at the materials and procedures utilized in this thesis for data collection, analysis, and best candidate selection. For the 15 locations/counties of the thesis study areas, Chapter 4 focuses on the findings and discussions of the wind and PV systems based on the analysis, including the system's economic feasibility and environmental sustainability. The full research project, which focused on investigating the affordability and environmental viability of wind and solar power systems among the fifteen places in Liberia, is concluded or summarized in Chapter 5.

CHAPTER II

Literature Review

This chapter evaluates the previous research on renewable energy in Liberia and analysis of wind and solar potential using NASA data as an option for sustainable and reasonably priced energy sources, to look at the economic viability and environmental sustainability of other regions of the world, including Africa.

Review of Related Studies on Renewable Energy in Liberia

There have been a series of research in Liberia on renewable energy, for instance, using utilizing the trans log manufacturing and expense calculation, Wesseh Jr. et al 2015 Assessments of Renewable and Sustainable Energy Sources, [24, 122-130] access the potential for fuel and factor replacement involving capital, labor, fuel, and power generation in Liberia. The findings suggested that lifting the energy price cap in Liberia would typically result in lower energy consumption and increased capital and labor intensity. Price-based policies can be utilized in addition to capital assistance initiatives to reorient the application of technologies, according to the results. Oil will likely continue to cost more than the permitted capital contribution, according to the proportional technical convergence of the input vectors.

Wesseh Jr, P. K., & Zoumara, B. 2013, Causal independence between energy use and economic growth in Liberia: Results from a non-parametric bootstrapped causality test. Energy Policy, 50 (518-527), employing the bootstrap technique. The findings indicated that to meet the demand brought on by Liberia's economic growth, appropriate energy-related regulations, such as power subsidies or little power taxes, would be required.

A cost study was employed by MIQUEL et al. 2016 with the primary objective of estimating in financial terms the investing chances associated with the unrestricted sustainable energy quotas included in Africa's NDCs. Occasionally, both expenditures and capacities were expressed. The outcome showed that Liberia's contributions are constrained. The major energy matrix will have 30% renewable electricity and 10% renewable energy in 2030. It anticipates a During 2030, a 30-Megawatt biomass project will use 3.5percentage biofuels.

A. A. Fashina et al. 2019 By reviewing forms of sustainable power, such as biomass, wind, solar, and hydro as well as political, regulatory, intuitional, investment, information dissemination, and sociocultural aspects of Liberia's RE sectors, we can examine and discuss the status and potential of RE investment from the perspective of sustainable development. The results show that a variety of renewable energy resources, such as biomass, hydro, solar, wind, etc., are abundant in Liberia and have a sizable potential to satisfy the country's energy requirements. However, institutional, financial, market-related, political, technological, information-dissemination and social barriers also limit the development of RETs in Liberia

Wesseh Jr, et al (2015) create many circumstances to calculate the advantages of research and development financing for renewable electricity. It is possible to assess the worth of renewable energy technology in Liberia utilizing a real-options pricing technique, hands-on experience with renewable technologies, and considering the volatility of fossil fuel prices. Due to the probability that renewable energy may displace Results indicate that the use of renewable energy in Liberia might lower carbon dioxide emissions by about 13.9 percentage points in comparison to the amounts in 2008, relative to the use of non-renewable energy.

Evaluation of Liberia's Biomass Resources Prepared for the U.S. Agency for International Development (USAID) as part of the Liberia Energy Programme, Technical Report NREL/TP-6A2-44808 [April 2009]. (LEAP)aims to provide policymakers and industry mentors with information about the availability of biomass resources find high-probability regions in Liberia and provide a framework for future, more in-depth, and site-specific analyses using geographic information systems (GIS), agricultural, environmental, and socioeconomic data to examine statistically and graphically to achieve this goal. The result shows that the nation has a wide range of biomass resources with ample supplies and room for the growth of electricity under three different scenarios: expanding cash crops on 10%, 25%, and 50% of the acreage currently used for cultivation.

Al Sherif, O. V. Review and Recommendations for Renewable Energy Policies and Rules to Encourage Independent Business in Liberia (2020), the study aims to provide directives for legislative and regulatory actions that will boost the involvement of the private sector in Liberia's electrical sector through examination and analysis of Liberia's energy laws, the renewable energy regulations in Nigeria, Ghana, and Sierra

Leone, as well as information on renewable energy regulations from other West African nations. The literature analysis made it clear that Liberia lacks the guidelines and legislation necessary for the private enterprise to participate in the production, transfer, and distribution of renewable energy. The conclusions and recommendations of this study call for the adoption of new renewable energy laws and related policies, including those governing Setting tariffs, implementing fiscal and financial policies, taking administrative and legal action, and adhering to professional standards.

Alfaro et al (2017). Liberia's Rural Renewable Electricity generation: Results and Possibilities from a Consultation with Stakeholders with the objectives to promote communication, find synergies, and stimulate cooperation Using a participatory workshop which was held in Monrovia in January 2017 with assistance from the University of Michigan's Institute for Sustainable Ecosystems. Almost 60 individuals from governmental, non-governmental, nonprofit, and commercial organizations participated in the event. The training found several gaps and stakeholder priorities, and a proposed research plan, that may be leveraged to improve the efficacy of efforts to electrify rural areas and keep igniting stakeholder cooperation.

Sandikie, J. S. (2015), presents a Summary of the Liberia Renewable Energy for Everyone (SE4All) Action Plan for the development and expansion of the country's energy industry to satisfy the country's 2020 and 2030 energy access goals as well as the political goals of the ECOWAS. It offers an assessment of the National Energy Policy of Liberia (NEPL), which was approved in 2009, and examines the gaps in the situation at the moment as well as the updated NEPL targets. The outcome demonstrates that Liberia will be able to attract sizable by the implementation of reforms to liberalize the power sector engagement of the private industry, initiatives under the ECOWAS Renewable Power Policies and Renewable Energy Policy.

White, J. G., & Samikannu (2022) to promote the utilizing sources of renewable electricity in Liberia's mix of fuels, this research analyzes the community's energy status. Techno-economic evaluations of the seven recommended design parameters were carried out using HOMER. After all, simulations were finished, configuration No. 03 was found to have the lowest LCOE. Unfortunately, this system includes a diesel generator that releases 37139 kg of CO2 annually. Although the system in configuration No. 06 has a lower Levelized cost of energy (LCOE) than configuration No. 3 by 10.9 percent, it emits 99.99 percent less CO2 and other greenhouse gases.

Mohsin et al (2022) objective is to evaluate the connection between new technology, renewables, and sustainable economic growth (SEG) by assessing the impact of public spending. In this study, the data envelopment technique is used (DEA) estimates approach to examine research and development (R&D), the utilization of renewable energy, and GEG in the Economic Community of West African States (ECOWAS) between 1990 and 2018. Findings show that ECOWAS governments investing in human capital and R&D for renewable energy sources would provide sophisticated technological production methods that can achieve low-carbon growth, but the results differ throughout the region's different nations.

TEPO TOGBA, A. (2020) to give a cost comparison between off-grid standalone systems and grid extensions, used the research to conceive using a situational analysis of pump hydro storage (PHS) and rechargeable battery packs with solar (PV) in Liberia, researchers examined the techno-economic viability of incorporating RETScreen into the country's grid. The findings both demonstrate and overestimate the need for greater solar integration in Liberia in response to the problems with the country's low cost of electricity. Given the geographic accessibility of lower and upper reservoirs, PV plus pumped hydro storage continues to be the ideal structural design when contrasted to photovoltaic combined batteries for independent off-grid installations. If PV costs could be reduced, more people would have access to power in the nation. The expense of photovoltaic continues to be the greatest essential element in the price of the ideal scheme in both city and remote scenarios

Satheesh Nair, B. A technological and financial strategy utilizing stand-alone photo - voltaic (PV) petrol engine hybrid systems for a decentralized generation was presented in the doctoral dissertation of Murdoch University entitled "Techno-economic modeling of standalone PV diesel hybrid systems to promote private investment in rural Liberia." to meet Liberia's ambitions for green electricity. In conclusion, assistance for RE projects is predicted to result in a favorable and significant change in Liberians' quality of life. This is according to the project analysis of the country's present rural electrification needs.

Review of Related Studies Using as a Source of Meteorological Data, the NASA (National Aeronautics and Space Administration) Database

As an alternative to clean and reasonably priced energy sources, other scientists have looked at the possibilities of sunlight and wind power data to study the economic viability and environmental sustainability in various regions of the world, including Africa.

For illustration, Zhou et al. 2016 examined the Chinese onshore wind energy prospective utilizing weather data between 1979 to 2008. They learned that the nearby offshore windmills had a capacity of roughly 146,336 GWh.

In 2019, Ahmed et al. 2019 assessed the 300 MW combined capacity of two Egyptian wind farms that had been built. According to the data, the newly built windmills are shaped at approximately 1130 kilowatt hours, with an expected decrease in electricity prices to €1.96-2.09/kilowatt hour.

The possibilities for turbines of GaliMa-aba, Ghoubbet, and Bada Wein in the Republic of Djibouti were investigated by Dabar et al. in 2019. According to the study, 1073 GWh of energy would be produced yearly, with costs averaging 7.03 to 9.67 US cents per kilowatt hour are typical.

The cost of wind-generated electricity in Trinidad and Tobago islands was assessed by Chadee et al, 2018. The researchers found that the cost of energy was somewhat expensive compared to the island's present household subvention rate.

The potential of solar energy was investigated by Parikh et al. in 2019. According to the findings, the projected solar PV facility might provide up to 173.6 megawatts of power. Rehman et al. 2017 have looked at the viability of the 10 megawatts of solar arrays connected to the grid at 44 locations in Saudi Arabia. They discovered that Bisha would be the ideal location for solar systems in the coming.

Adaramola et al. 2014 evaluated a techno-economic study of a Jos, Nigerian solar power plant, using the Homer software. The projected plant's capacity factor was found to be 40.4% with a 331.536 GWh yearly power production

NASA data were utilized by Youssef et al. 2021 to examine the economic and solar viability of wind and solar-generated electricity in 17 chosen sites in the Red Sea State of Sudan. According to the findings, buildings in the chosen areas might generate electricity effectively using vertical-axis wind turbines. Additionally, the PV system was deemed to be more suited to producing power for the selected sites owing to the significant sun's rays.

According to Youssef et al., 2021, there is a chance to construct grid-connected photovoltaic systems with two axes that track at 4.2 kilowatts in 25 designated Mediterranean seaside settlements dispersed throughout numerous Arab countries (2021), the suggested system generates roughly 8824kW yearly, which lowers CO2 emissions. The cost of producing one kWh of energy is estimated to be between 0.0337 and 0.00475 dollars. It was concluded that the suggested method can effectively address energy poverty in developing nations while having significant positive environmental and socioeconomic consequences.

To determine whether 0ne of Northern Cyprus's biggest and best hospitals Near East University Hospital (NEU Hospital), may produce grid-connected solar PV power to cover daytime energy needs and reduce expenditures. Using actual measurement, the Surface Radiation Data Set-Heliosat (SARAH), the Satellite Application Facility on Climate Monitoring (CMSAF), and the ERA-5 produced by the European Centre for Medium-range Weather Forecast—Youssef et al. (2021) NEU Hospital. According to the research, the sun energy in the chosen area is excellent (class 5), which means that the global solar energy ranges from 1843.8 to 2035.9 kWh/m2.

will focus based on the fiscal and economic evaluations of the possibilities for sun and airstream energy in nine precisely designated Libyan locations. Because there is a severe lack of meteorological data, such as wind speed and global sun energy, as a result of the country's civil war, Youssef et al. chose to assess the wind and solar potential using weather information from the NASA (National Aeronautics and Space Administration) database (2020). In contrast to wind generation capacity, the findings indicated that the nation had an enormous prospect for solar energy.

To fulfill the growing need for freshwater and lessen the harmful effects of using fossil fuels, employing A good choice for seawater and brackish distillation electricity could be renewable energy. to evaluate the practicality of using solar and wind energy in a case study location of the Güzelyurt region to desalinate domestic groundwater (agriculture region). 33 years of meteorological statistics were employed in the evaluation of the region's possible wind and solar power. Youssef (2021).

According to the findings, the solar potential is appropriate or good (1775.89 kWh/m2) and the wind potential is weak (Class 1) for use as an energy source.

Review of Related Studies Comparing Actual and NASA Data

For example, Youssef et al.2020 examined actual global energy from the sun per month for several places in Northern Cyprus using a database of satellite imagery. The findings showed the projected amount of solar energy from space (GSR) data and the real data were fairly close.

Gairaa & Bakelli et al. (2013) used measured radiation from the sun, the NASA SSE (Surface meteorological and Solar Energy service) model and the Solar-Med-Atlas to evaluate the potential of solar energy of the Ghardaa area, Algeria. The findings demonstrated that the measurement data and the estimated database agreed.

The monthly GSR results that were obtained for three sites in Tunisia were examined and contrasted with satellite irradiation datasets by Belkilani et al. in 2018. The findings showed that there a close connection existed between the estimated and actual GSR data. To analyze the possibilities for solar energy in the chosen regions, NASA's average monthly was used.

CHAPTER III

Material and Method

This thesis explains how we checked if wind and solar energy would work in 15 places in the study area. We collected and studied data to see if it was financially stable. Chapter 3 explains this process in detail. Liberia is a country in West Africa.

Study Area

Liberia is a country in Africa that can be found in the southwestern area of the continent's west coast, within the Mano River valley. The Atlantic Ocean is at the south, Sierra Leone is at the west, Guinea is at the north, and Côte d'Ivoire is at the east. The place is located at 4 degrees, 18 minutes north latitude and 8 degrees, 30 minutes north longitude. It is also at 7 degrees 30 minutes and 11 degrees 30 minutes west longitude. This place is 111,370 square kilometers big. Most of it, 96,160 square kilometers, is land. There's also some water inside, 1,505 square kilometers worth. Before people arrived, the area was mostly filled with tropical forests in the Upper Guinea Forest area. Monrovia is the biggest city and the capital of the country. Liberia is split into 15 sections, which are determined by an estimated population of 4. 702 million people January is the warmest month with the highest average temperature of almost 30 degrees Celsius. August has the lowest and highest temperature of any month, with an average of 26. 2°C April has the coldest average temperature of all the months, with a temperature of 26. 2°C The coldest months of the year are August and July, with an average low temperature of 24. 1°C A group in the University of Liberia called the Climatology Section in the Geography Department made a report in 1984.

The temperature in Liberia has gone up by 0. 8°C and is expected to go up by 1. 4-24°C more by the end of the era. Since the 1960s, there has been less rain; but we don't know if it will continue to be less in the future. Flooding from rivers is likely to happen a lot in Liberia, and it has become more serious lately. Climate change will cause heavy rain, which may increase floods and diseases that spread through water. In places like Monrovia cities, poor neighborhoods are at high risk of floods and diseases like cholera. In the last few years, about 85,000 people have gotten sick with cholera - a disease that can make you very ill. In just one year, 18,000 people got sick with it. ACAPS stands for Assessment Capacities Project. It is an organization that helps people in emergencies by providing information on the situation. They collect and analyze data on things like natural disasters, conflicts, and disease outbreaks, and share that information with aid organizations and governments. The goal is to help decision-makers respond quickly and effectively to the needs of affected people. In 2015, there were dangerous situations in Liberia. A complete study on the different things that affect the environment, done by Rebaudet and others. This text just says "2013" and does not require simplification as it is already very simple.

Before the Civil War, the Liberia Hydrology Department took care of 28 water sites. They collected important information about water in 11 areas of the country. Most parts of Liberia have two seasons during the West African monsoon except for the very south where it always rains. In the future, some places may get more rain than they do now. One projection says that the western coast will get the most rain in 2050. However, there is also a pattern of where rain will fall when we compare now and 2050. It's going to rain more near the coast in the rainy season, but in July it will be very dry towards the east. The quantity of precipitation in proximity to the coast will continue to rise. During December to February, a dry wind goes over land and comes to Liberia. This wind brings fog, dust, and cold nights. Even when it rains a lot, there are still sunny days. However, there are also times of heavy rain, fog, and dust, but they don't happen all the time.

Figure 3.1

Photovoltaic power potential map of Liberia

Source: World bank group. Global solar atlas 2.0, solar resources data, solargis

Table 3.1

The 15 countries of Liberia and coordinates of the study area

County/Location	**Period**	**Latitude** (N)	**Longitude** (W)
Bong	1982-2021	7.302536^0	-9.321899^0
Gbarpolu	1982-2021	7.493196^0	-10.228271^0
Grand Bassa	1982-2021	6.500899^0	-9.299927^0
Grand Cape Mount	1982-2021	7.253496^0	-10.733643^0
Grand Gedeh	1982-2021	6.20609^0	-8.679199^0
Grand Kru	1982-2021	5.036221^0	-8.162842^0
Lofa	1982-2021	8.21149^0	-9.92067^0
Margibi	1982-2021	6.577303^0	-10.003052^0
Maryland	1982-2021	4.981505^0	-7.910156^0

Montserrado	1982-2021	6.358975^0	-10.69519^0
Nimba	1982-2021	6.525873^0	-8.624268^0
Rivercess	1982-2021	6.031311^0	-9.283447^0
River Gee	1982-2021	5.484768^0	-7.943115^0
Sinoe	1982-2021	5.550381^0	-8.547363^0
Bomi	1982-2021	6.893707^0	-10.859985^0

Data

Researchers use statistical models when they don't have enough actual weather data to study the atmosphere and climate of certain places. This helps them make predictions and understand changes in the weather despite the limited information available. Africa has not paid much attention to studying and analyzing how much energy can be generated by using solar and wind power. This study uses information from NASA to check if it is possible to use solar power and wind systems in 15 different places in Liberia. They will look at this for 39 years, from 1982 to 2021, to see if it is good for the environment and if it makes sense for businesses to use. This will reduce the amount of greenhouse gases that can cause warmer temperatures in the atmosphere. It's important because most of the people in Liberia don't have access to electricity.

Satellites and other tools can show us what the outside and air around our planet looks like. Satellites give us pictures of planets besides Earth. When we look at Earth from space, we can see how the land looks different over time, there are clouds close to the ground, the ocean levels change, there is ice covering some areas and the air around the Earth is made up of different gases. We use this information to keep track of changes in the weather and how it behaves over time. Moreover, it is used to support many studies (Eyres et al. , 2022)Satellites that look at Earth are getting better and there are more of them. This information is becoming really helpful for us to learn about the world and its surroundings. We don't know much yet about how using data from EO satellites is affecting the people who study it, and we're not sure what new ways we might use this data in the future.

NASA Data

There are not many tools to measure how fast the wind is blowing or which way it is going in Liberia because of the war that happened there. They checked the speed of the wind in different places in Liberia by using new information from NASA. Some research used information from NASA to figure out where wind farms could be placed. For example, Arreyndip and his colleagues. In 2016, scientists used information from NASA from 1983 to 2013 to see if there were places in Cameroon that had enough wind to use a machine that makes energy called a wind turbine in the future. Rafique and his team used a software called RETScreen. In 2018, some people looked into putting a really big wind farm in Saudi Arabia that could make a lot of electricity. The writer is using wind speed information from NASA to talk about how fast the wind blows in different cities each month. For example, some people called Gökçekuş et al. In 2019, we checked how fast the wind was blowing in 8 different parts of Lebanon using a free online tool. To find out how much wind power a country could generate, they looked at real information and NASA's wind patterns from the last 37 years.

RETScreen

The RETScreen program was made to help decide if renewable energy projects are good ideas. The RETScreen PV model can now be used for both on-grid and off-grid purposes. There are three types of pumps: standalone, hybrid, and water pumps. The app helps people design systems by guessing which size batteries, pumps, or arrays they should use. Users can improve the performance of their system by changing some settings related to weight, weather, and usage time. This will make their system more efficient and innovative. This study talks about different copies of parts used to predict how much power can be made by solar systems. The study looks at things like the environment and how the system is set up to make these predictions.

RETScreen is a tool made by the Canadian government and some other people to help businesses and the government plan and manage energy projects. It is also used for teaching and studying in universities and colleges all over the world. RETScreen Expert has different ways to make power, heat, or cool for big buildings or homes. It can use things like biomass, heat pumps, or solar heating. We can use both traditional and eco-friendly sources of energy, like gas/steam turbines and combustion, to generate power, or we can use a combination of them called cogeneration. The analytical worksheets have links to maps showing where the world's energy comes from. They also have information about different products, projects, and measurements related to water and weather. Computers are useful and trustworthy for testing if clean energy sources will work. This tool doesn't have a way to make the perfect design. This means "Lee and others wrote this in 2012. "

RETScreen Expert is managed by a group called CanmetENERGY Varennes Research Centre. They also provide money to help keep it going. The main team gets help from many different experts in business, government, and schools. They also work with other big groups from around the world. This project has several key contributors including the World Bank, GEF, REEEP, IESO of Ontario, NASA's Langley Research Center, and York University's Sustainable Energy Initiative POWER Data Access Viewer website.

Figure 3.2

Map of the study locations

Solar Energy Data

Scientists used data from satellites to study how much energy from the sun is available in that place. For example, Obeng and others used solar power from NASA to get energy. In 2020, experts studied how much energy from the sun UENR's Nsoatre Campus could use. Owolabi and his team used information from a NASA database. In 2019, six areas in Nigeria were evaluated for their solar energy potential. Many studies have shown that satellite information about solar radiation is trustworthy. They did this by comparing the data with statistics calculated from measurements taken on the ground all over the world. The researchers in Kassem et al. 2020 looked at how much energy the sun gives every month in different parts of Northern Cyprus. They used pictures from a satellite database. The results showed that the amount of sunlight predicted to come from space was very similar to the actual amount. Gairaa and Bakelli and others. In 2013, researchers measured how much energy from the sun could be used in Ghardaa, Algeria. They used special models from NASA and a book called Solar-Med-Atlas to figure it out. The findings indicated that there was parity between the gathered information and the estimated data. Belkilani et al. studied the monthly GSR results at 3 places in Tunisia and compared them to satellite data on how much sunlight those places receive. Last year The results showed that the estimated and actual GSR data were closely related. NASA checked how much sunlight the chosen places get every month to see if they are good for solar power.

Two-Axis Tracking PV Arrays

Solar tracking systems are used to get more sun because they help the solar panels make more power. This text is saying that a group of people called Fernandez and others published a research paper in the year 2020. These machines can spin in one direction or in two directions. A solar system with two axes that can move by itself can make the most energy. The solar panels in two-axis Photovoltaic systems are mounted on a structure that enables them to move in two directions, as depicted in Figure 1. A photovoltaic system needs two motors to move the axes. Reca-Cardena and other authors. 2018: the year that just passed. The two-axis tracker system moves the solar panels to follow the sun. Usually, a computer brain is needed to direct this system. An SR sensor is responsible for determining the orientation of solar panels in solar tracker PV systems. I cannot rewrite the text without additional context or information. Please provide more details. This was written by Cheng and others in 2013. The performance of a solar panel system is affected by the weather and its parts. Nowadays, power companies are trying to make sure that they operate and maintain solar panels really well to get the most energy out of them. I'm sorry, there is no text provided to rewrite. Please provide the text you would like me to simplify. This is a reference to a research study done by Cheng and colleagues in 2013. One important part of solar panels is called O&M. When we take care of our machines and equipment better, we can save money on energy and make more money from our investments. The PV system has many problems during its life, like weather, broken parts, and getting older naturally. Iftikhar and others. This text is already very simple and doesn't contain any complex words to simplify. A plan that covers fixing broken things, keeping things in good shape, and watching for problems can help with maintenance tasks. Because PV systems need to be regularly inspected to make sure they are working well, tracking them can increase maintenance costs.

The PV Power System's Design

We picked a part called mono-Si-CS6X-300M for a 5kW solar power system. The building uses solar panels made of a special type of silicon that can make up to 300 watts of power. To cover a space of 28 square meters, you will need 17 modules. This study tested a machine called FRONIUS SYMO 4. 5-3-M It makes solar energy into electricity and is very efficient, getting a score of 97. 9 out of 100. It can make 4. 5 kilowatts of electricity at a time. You can find out about the Solar panels and inverter's features by looking at Kassem et al 2020 and "Fronius Symo et al 2021".

Owolabi and others. In 2019, a group of people called Kassem et al. did something In 2020, it was recommended to consider certain factors when building a solar power plant.

Power generating factor:

$$\text{PGE} = \frac{\text{Solar irradiance} \times \text{Sunshine hours}}{\text{Standard test condition irradiance}} \quad (1)$$

Solar PV energy required:

$$\text{The energy required from PV modules} = \text{Peak energy requirement} \times \text{Energy lost in the system} \quad (2)$$

PV module sizing:

$$\text{Total Watt peak rating} = \frac{\text{Solar PV energy required}}{\text{panel generation factor}} \quad (3)$$

$$\text{PV module size} = \frac{\text{Total Watt peak rating}}{\text{PV output power rating}} \quad (4)$$

Inverter sizing:

$$\text{Inverter size} = \text{Peak energy requirement} \times \text{Factor of safety} \quad (5)$$

Suggested Standards for Wind /PV Modules

Liberia needs more energy because its population and economy are growing fast. So, in the future, the electricity we use needs to come from sources of energy that can be easily renewed, like solar and wind power.

It is very important to check if both small and large wind/solar energy systems in Liberia are practical and can work well. This research focused on Liberia as its main topic.

This section looked at whether it was a good idea to install small wind turbines and solar panels on rooftops in different areas. The goal was to see if it was worth it financially and technically and if they could be connected to the power grid. This section includes a study of how profitable it would be to connect a 50-Megawatt wind and solar energy system to a power grid in different areas. The RETScreen program was used to figure out if the project would make money.

Economic Analysis

The RETScreen Professional app was used to figure out if the project was financially possible. Here are the formulas for the following measures.

Net present value (NPV):

$$\mathrm{NPV} = \sum_{N=0}^{N} \frac{\mathrm{Cn}}{(1+r)^{n}} \tag{6}$$

Levelized cost of energy (LCOE):

$$\mathrm{LCOE} = \frac{\text{sum of cost over lifetimes}}{\text{of electricity generated over the lifetime}} \tag{7}$$

The internal rate of return (IRR):

$$\mathrm{EP} = \sum_{N=0}^{N} \frac{\mathrm{Cn}}{(1+\mathrm{IRR})^{n}} \tag{8}$$

Simple payback (SP):

$$\mathrm{SP} = \frac{\mathrm{C-IG}}{(\mathrm{Cener+Ccapa+CRE+CGHG}) - (\mathrm{Co\&M+Cfuel})} \tag{9}$$

Equity payback (EP):

$$EP = \sum_{N=0}^{N} Cn \quad (10)$$

The annual life cycle savings (ALCS):

$$\mathrm{ALCS} = \frac{\mathrm{NPV}}{1/\mathrm{r}(1-1/(1+\mathrm{r})^{N})} \quad (11)$$

GHG emission reduction cost (GHG-E-RC):

$$\mathrm{GHG-E-RC} = \frac{\mathrm{ALCS}}{\Delta\mathrm{GHG}} \quad (12)$$

Benefit-Cost ratio (B-C):

$$\mathrm{B-C} = \frac{\mathrm{NPV}+(1-\mathrm{fd})^{C}}{(1-\mathrm{fd})^{C}} \quad (13)$$

This sentence talks about how much money a project can make over time. Cn is the amount of money made after taxes in one year, N is how long the project lasts, P is how strong the project is, Pout is how much energy the project makes each year, and r is how much less valuable the money becomes over time. The starting cost of the project is called C, and its overall advantages are named B, IG, and Center, which means the money saved every year from using less energy or earning more money. CGHG means earning money by reducing greenhouse gases, CCAPA means savings or earning money for producing a certain amount of energy every year, CRE means earning money for producing renewable energy every year, and Co&M means the expenses for maintaining renewable energy projects. Renewable energy projects do not have to pay for fuel every year. When greenhouse gas emissions decrease, it is called GHG.

Capacity factor (CF):

$$\mathrm{CF} = \frac{\mathrm{Pout}}{\mathrm{P}\times 8760} \quad (14)$$

Wind Data Analysis Procedure

Wind Speed Data

There aren't many tools for measuring wind speed and direction because of problems in Liberia. So, we looked at information about how fast the wind blows in different parts of Liberia from 1982 to 2021 using data from NASA. Some studies have used information from NASA to predict where wind turbines could be built. For instance, Arreyndip and colleagues. In 2016, researchers looked at information from NASA from 1983 to 2013 to see if there is enough wind in different parts of Cameroon. They wanted to see if it was a good idea to build a machine (called a wind turbine) that could make electricity from the wind. Rafique and his team used a computer program called RETScreen. Scientists looked into whether it was possible to use a huge wind machine that would make 100 megawatts of electricity and connect it to the power system in Saudi Arabia. Information provided by NASA was utilized by scientists to study the velocity of wind flow in selected cities on a monthly basis. For example, Gökçeku and others. In 2019, researchers studied how fast the wind was blowing in 8 locations in Lebanon by using a database that was free to access. NASA shared wind data from 39 years on its website. They looked at this data to see if there is enough wind potential for energy in the country.

Probability Using the Weibull Function of Density

The Weibull distribution function with two parameters (2W) is frequently utilized in research to analyze the dispersion of speed of wind (v) at the designated domain. The following is how [Kahan et al. 2018 & Kassem et al. 2019] portray the 2W:

Probability distribution function (f(v)):

$$\mathrm{f(v)} = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e - \left(\frac{v}{c}\right) k \tag{15}$$

Cumulative distribution function (f(v)):

$$\mathrm{f(v)} = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{16}$$

Moreover, the mean velocity is calculated using Equation (17) as the Weibull variables' equation:

$$v = cI\left(1 + \frac{1}{k}\right) \tag{17}$$

where k is the distribution's shape factor while c is its scaling variable in m/s. The greatest probability technique is used to estimate 2W's parameters.

The density of Wind Energy

The amount of wind energy number is a numerical representation of the amount of wind energy that is accessible somewhere. It is seen as a crucial sign of the possibility of wind energy. Probable wind speed (Vmp) is another crucial wind speed indication [Fezelpour and Komleh -Pishgar- et al 2015 &2017].

$$\mathrm{Vmp} = \mathrm{c}(1 - 1/\mathrm{k})^{1/k} \quad (18)$$

Maximum energy-carrying wind speed (VmaxE):

$$\mathrm{VmaxE} = \mathrm{C}(1 + 2/\mathrm{k})^{1/k} \quad (19)$$

The wind power density (WPD) typically estimates the amount of wind present at the place.

The formula is:

$$\mathrm{P/A} = 1/2\ \rho\mathrm{v}\ 3 \quad (20)$$

$$\mathrm{P/A} = 1/2\ \rho\mathrm{v}\ 3\ \mathrm{f(v)} \quad (21)$$

It can also be calculated as a function of the Weibull variables using the formula under.

$$(\mathrm{P/A})\ \mathrm{W} = \int \frac{1}{2\rho\mathrm{v}} 3\mathrm{f(v)dv} = 1/2\mathrm{pv}3I(1 + \frac{3}{k}) \quad (22)$$

The mean WPD is also calculated using Equation (23), according to [Fezelpour and Komleh -Pishgar- et al 2015 &2017]: $P/A = 1/2^{\rho\mathrm{v}3}$

f(v) P is the wind power density in Watt/m2, P is the mean wind power density in Watt/m2, A is the swept area in m^2 and is the air density in kg/m3 where is the probability density function (PDF) and v is the mean wind velocity in m/s., and

The difference between the actual and predicted values of the WPD is calculated using Equation (24):

$$\mathrm{Error} = \frac{\left|\left(\frac{P}{A}\right)w - \left(\frac{P}{A}\right)A\right|}{\left(\frac{P}{A}\right)w} * 100\% \quad (23)$$

(In which (P/A)W is the projected WPD by 2W and (P/A)A is the actual WPD.

Wind Parameter Correction

To calculate the wind speed (v) at various wind turbine heights, the power-law model is employed (z).

This is expressed as follows:

$$V/V10 = (Z/Z10)\ \alpha \qquad (24)$$

In which v10 is the wind speed at the measured height z10, and α is a measure of surface roughness.

$$\alpha = 0.37 - 0.088\ln(v10)\ /1 - 0.088\ln(z10/10) \qquad (25)$$

CHAPTER IV

Results and Discussion

Section 4 talks about what we found when we looked at information from 15 different places in Liberia over the past 39 years. We used the same methods we explained earlier.

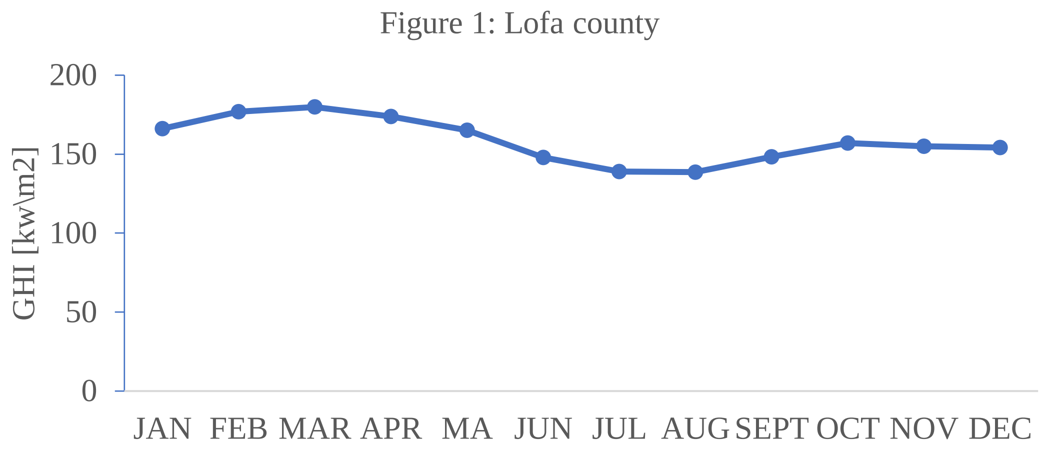
As we said before, GHI was used to check how much solar power the country could produce. Table 8 shows how much sun the selected regions get each year, based on different types of solar power. This is sorted into categories based on how much sun they get (shown in Table 7). We picked sunny areas that had a lot of sunlight and were labeled as good, great, or fantastic. The regions of Sinoe and Montserrado have abundant sunlight which is ideal for utilizing solar energy. The places with the most sunshine, Sinoe and Montserrado, are the best for making big solar power systems.

Figure 1 shows the amount of sunlight for each month in different places. In Lofa, the sun is strongest in March, with 180 Kw/m2, and weakest in August, with 130 Kw/m2. In Bomi, the sun is strongest in March, with 160 Kw/m2, and weakest in August, with 120 Kw/m2. In July, the sun's energy was not as strong with only 110 kilowatts per square meter (kW/m2), while in March (in Bong), it was strongest with a maximum of 160 kW/m2. In March (in Garpolu), the weakest sun energy was 130 kW/m2, and the strongest was 170 kW/m2. In July and August, the sun's energy was weak with only 110 kW/m2, while in March (in G) it was the strongest with 170 kW/m2. In Bassa, the least amount of sunlight (GHI) is observed during July and August while the maximum amount is recorded in March. In Cape Mount, the lowest amount of sunlight is in July and the highest is also in March. This text shows how much sunshine different places get at different times of the year. In Gedeh, the least amount of sunshine is in July and August, while the most is in March and April. Grand Kru has the lowest sunshine in August and the most in March. Margibi has the least in June and the most in March. Maryland has the lowest in July and the most in March. Nimba has the least in July and the most in March. River Cess has the least in June and July and the most in March. River Gee has the least in December and the most in April and May. Finally, Sinoe has the least in December and the most in May, and Montserrado is not mentioned.

In simple words: The GHI, which is a measurement of how much sunlight energy falls on an area, ranges from 160kw/m2 to 200kw/m2 in different parts of Liberia. The highest amount is in Sinoe and Montserrado counties in May, and the lowest is in Grand Kru in March and April. So basically, all of the places have lots of sunlight and are good for making electricity.

Figure 4.1

Monthly variation of GHI for all selected locations



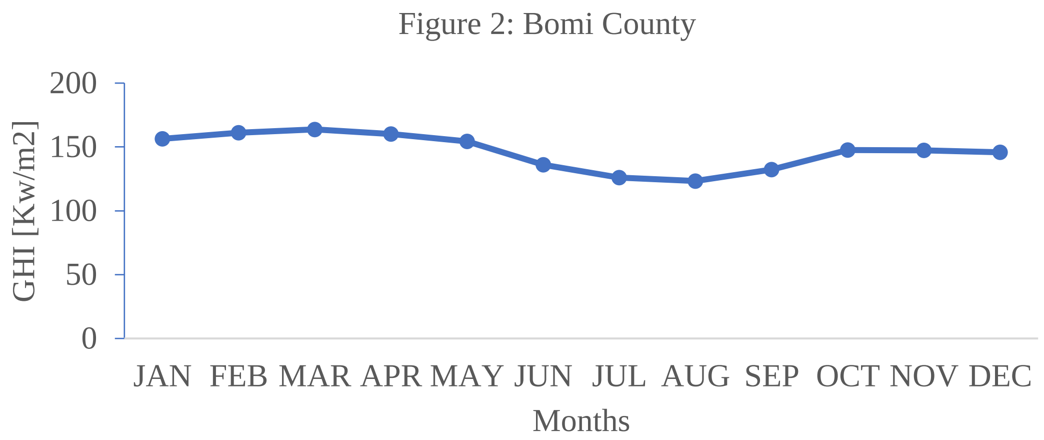
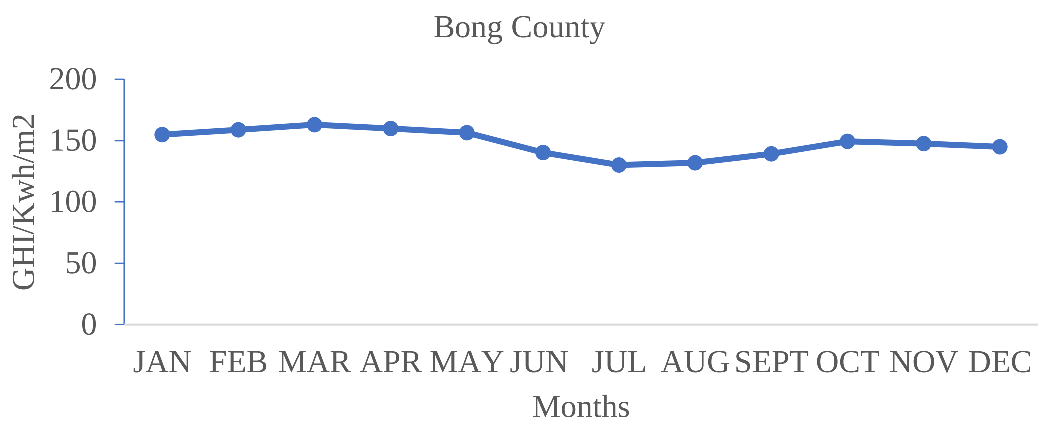
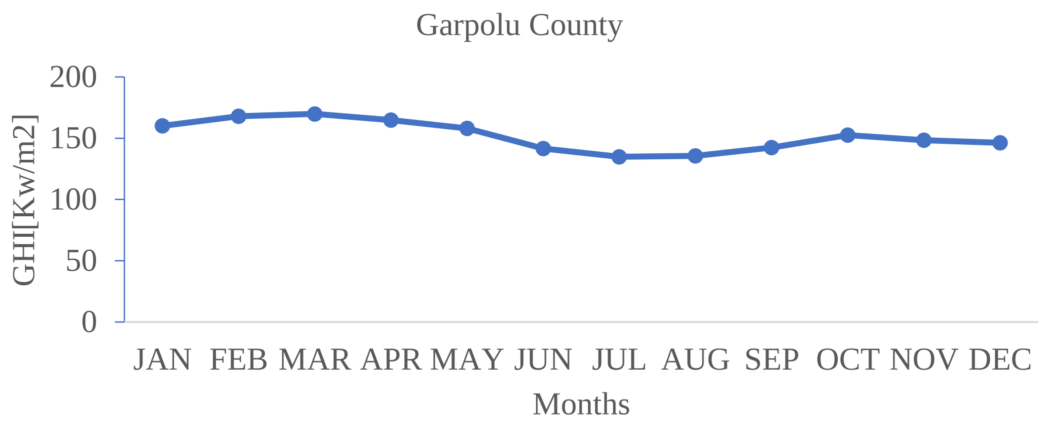


Figure 4.1 continued





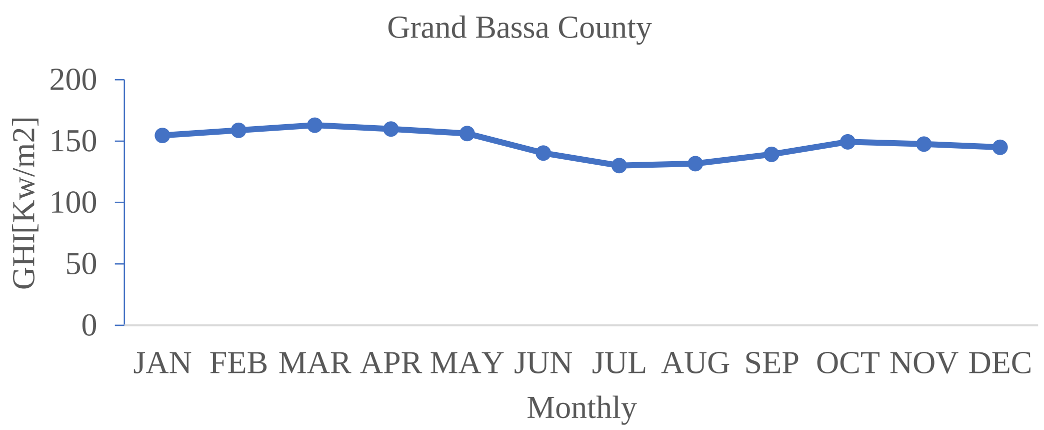
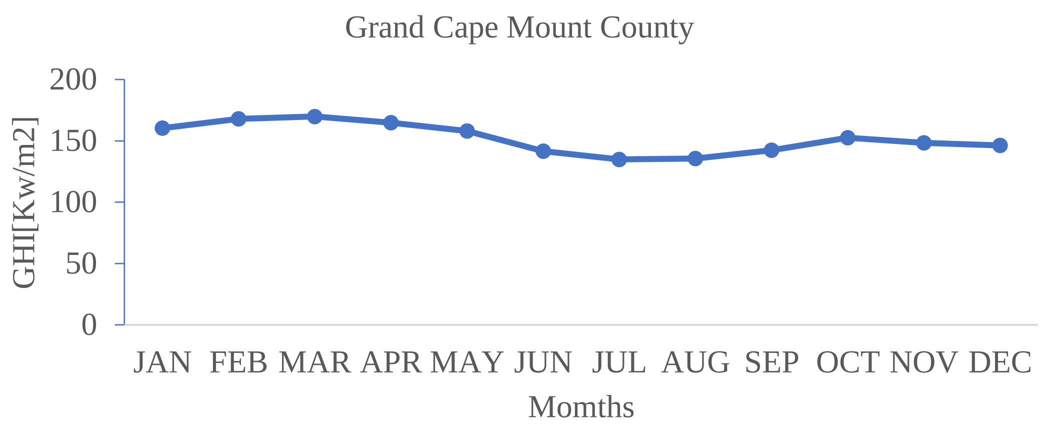
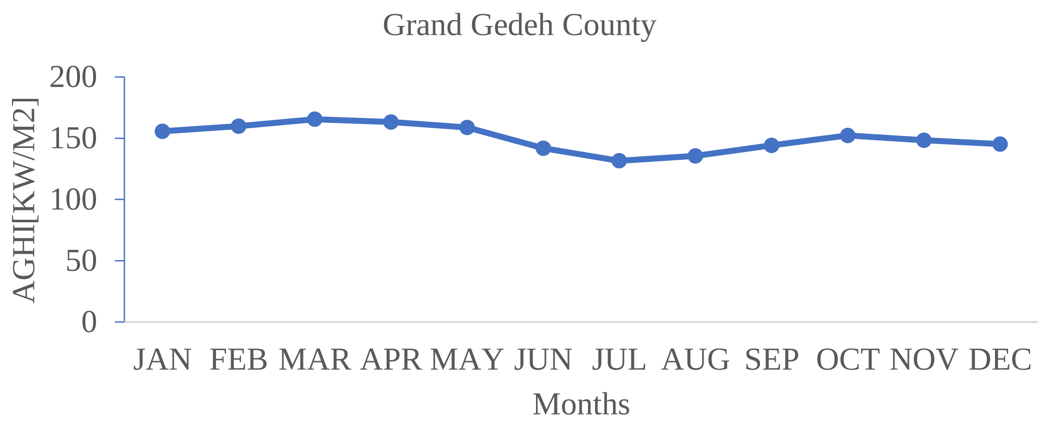


Figure 4.1 continued





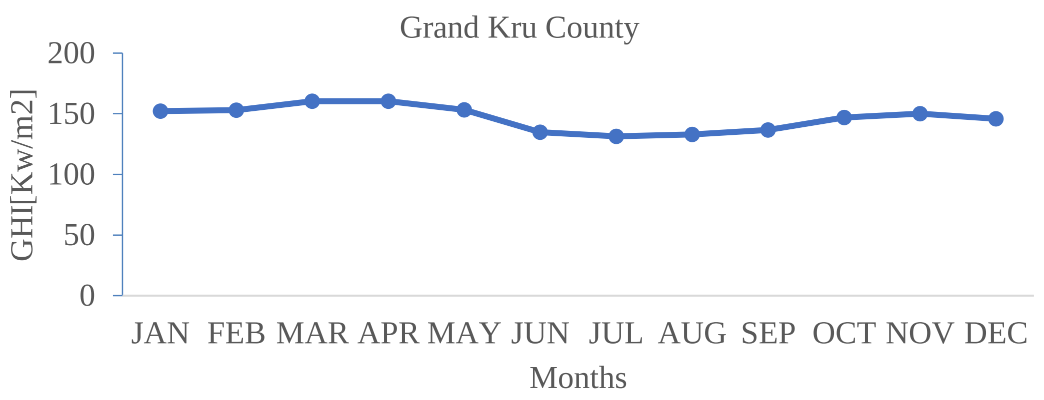


Figure 4.1 continued

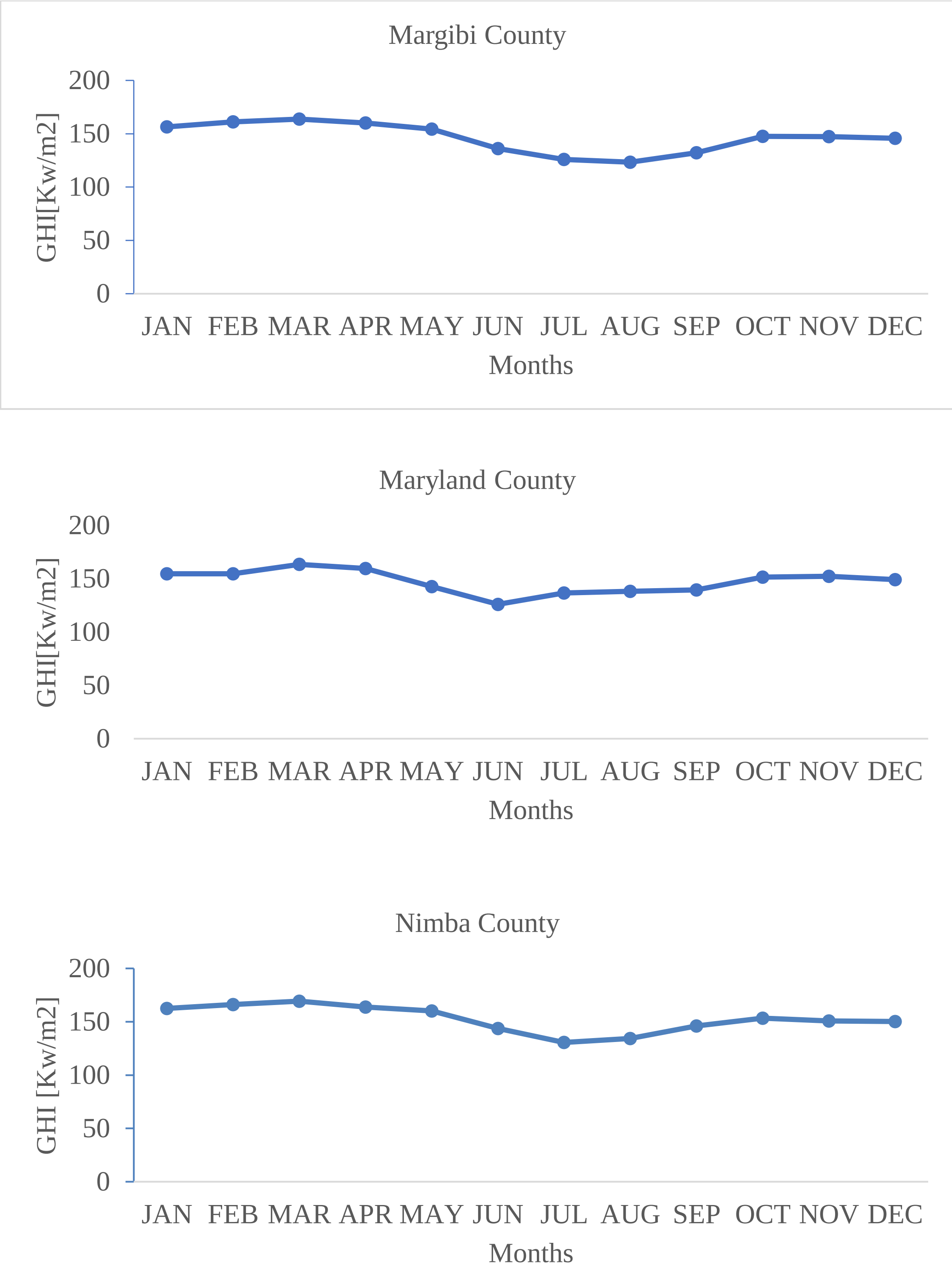
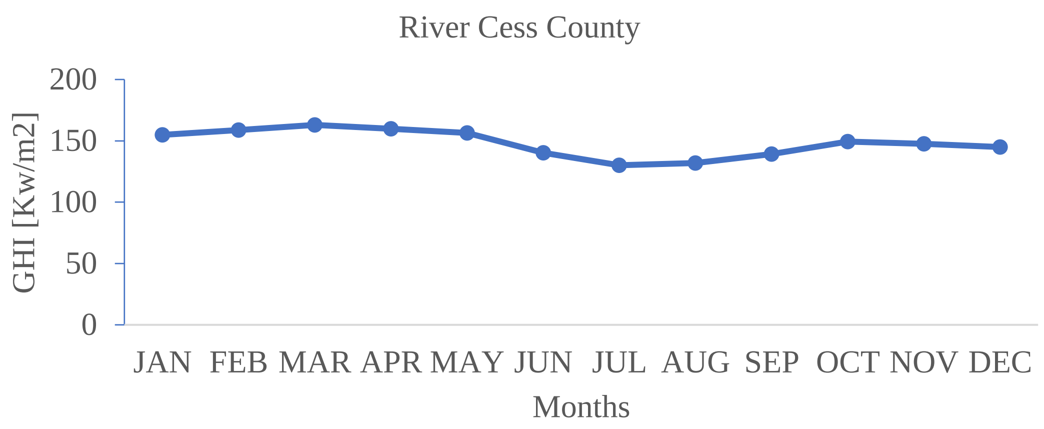
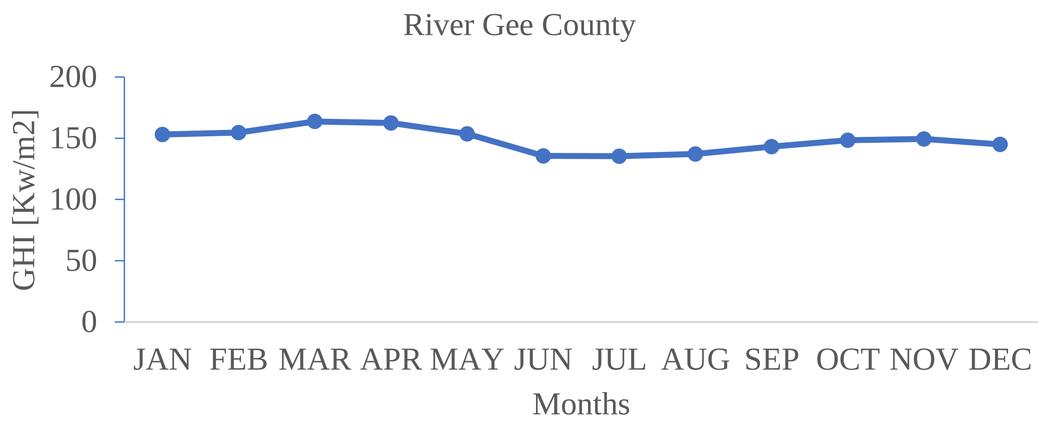


Figure 4.1 continued





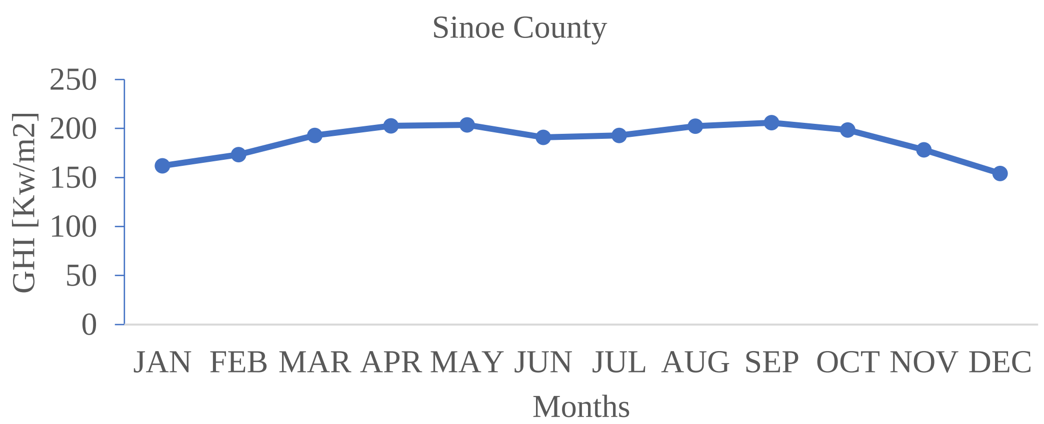


Figure 4.1 continued

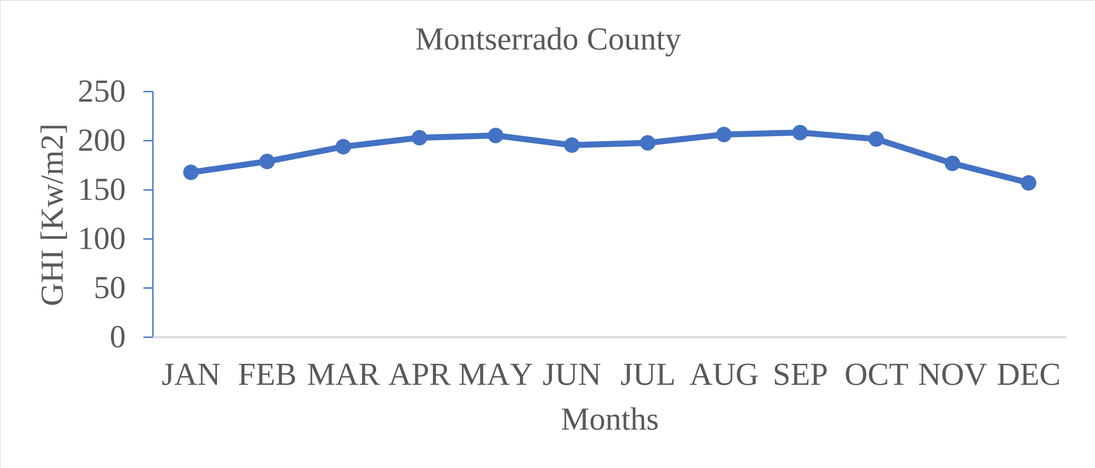


Table 4.1

Solar potential classification based on annual GHI

Class	Annual GHI (Kwh/m2) Adaramola et al, 2012
Poor	<1191.8
Marginal	1191.8-1491.7
Fair	1419.7-1641.8
Good	1641.8-1843.8
Excellent	1843.8-2035.4
Outstanding	2035.9-2221.8
Superb	>2221.8

Table 4.2

Solar classification based on NASA data

Location	Annual GHI (kwh/m2)	Class
Lofa County	1911.77	Excellent
Bomi County	1754.029	Good
Bong County	1834.368	Good
Garpolu County	1822.376	Good
Grand Bassa County	1766.145	Good

Grand Cape Mont County	1822.376	Good
Grand Gedeh County	1802.405	Good
Grand Kru County	1757.545	Good
Margibi County	1754.029	Good
Maryland County	1768.379	Good
Nimba County	1831.243	Good
River Cess County	1776.145	Good
River County	1781.374	Good
Sinoe County	2258.203	Superb
Montserrado County	2292.678	Superb

Investigation of the Economic Impact and Possibility of a 5-Kilowatt PV System Connected to the Grid

The report found that it's not helpful to use small wind turbines to make use of the wind power in different areas because they don't consider all the important factors. According to the 2015 SE4All Action Agenda report, Liberia's target for 2025 is to achieve nothing.47 GWh of electricity from wind power. The results showed that the selected areas have a lot of sunlight and were rated as having good, excellent, or superb potential for solar energy. According to the International Renewable Energy Agency, solar panels have witnessed a price reduction of 80% since 2009, while wind power has seen a reduction of 30-40%. So, more people are using small solar systems because they are cheaper now. This part shows how much money you can save by putting solar panels on the roof of your home and connecting them to the power grid. It talks about different places where you can do this.

Evaluation of the Performance of Photovoltaic System

We looked at how well it would work and make money if we connected a 5-kilowatt solar panel system in the chosen areas using a program called RETScreen. Pictures 5 and 6 show how much electricity is made each year and how well a solar power system works with the performance ratio. The amount of electricity used each month is found to be between 700 and 900 kilowatt hours. The highest average EG is 900kWh and it was found in fourteen places in January and December. The lowest average was 700kWh and it was found in Grand Kru in August. The numbers in Pictures 5 and 6 show how much energy was produced and used each year by the plans that were proposed. The yearly energy production of solar panels with two-axis tracking systems was discovered to be in the range of 7652 to 9054 kWh by researchers. Out of the fourteen places, only Grand Kru has the highest value. All the other places have the lowest value. In simpler words: Figure 5 showed that the highest amount possible of meteorological data was reached. This means situations or events that occur between 9:00 pm and 9:65 pm, which is equivalent to 9:00 pm and 10:05 pm. The percentage does not make sense in this context and may require more information for clarification. It was found that the capacity factor numbers were between 21. 30% and 1820% This means that the places chosen are good for making solar power systems. It's possible to build a solar system in Liberia that can produce power. According to Figure 5, the ideal choice is to opt for mono-crystalline silicon systems, which are reflected in the "performance ratio" measurement.

Financial and Emission Reduction Analysis Simulation Results

We need to do a study to see if the project will work well and make enough money. Investors and governments learn and get good things from studying if a solar power plant is doable and profitable. We checked to see if the proposed system would be cost-effective and how it would affect the environment. The information about the economy in Table 12 comes from research done in other countries before. The study found that the cost of the system is about $5100. This estimate is based on information about what people are currently paying for similar systems. The guess is correct and matches the prices that were made public. The RETScreen app used the given values to figure out things like NPV, ALCS, LCOE, SP, and EP. We looked at other African countries as well when deciding on the money requirements. The main ways to measure if a solar project is financially strong are NPV and payback period, as said by Owolabi and others in 2019. The results of the test show that all the places where the project can be done will make a profit. This means the project is a good idea both for making money and for managing money well.

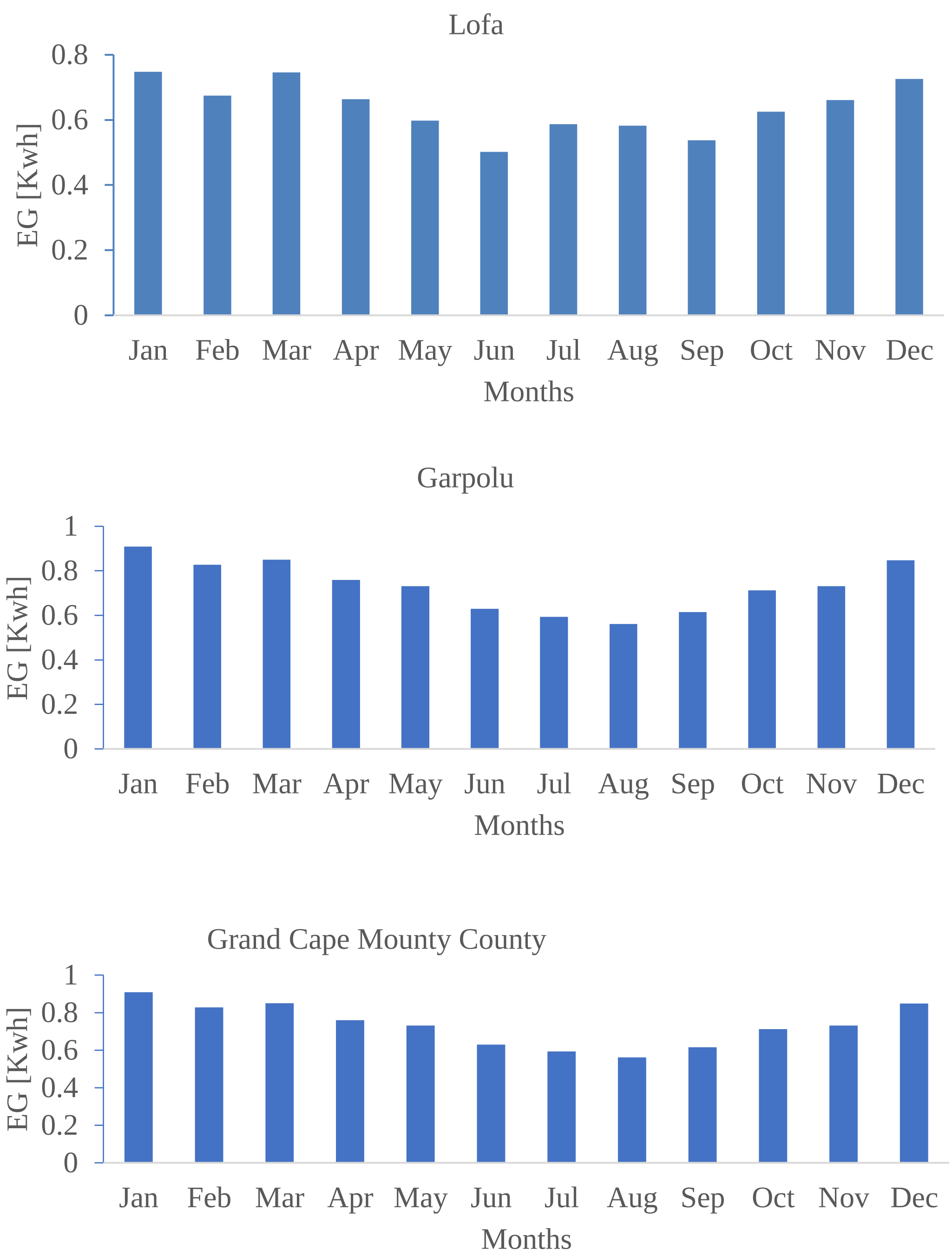
The least EP value belongs to Lofa County, and the most extended EP values of 3 are held by Grand Gedeh, River Gee, Maryland, and Grand Kru.3 years (28 years) among all the areas with built PV systems. Some places in Liberia had a higher number for SP (life expectancy) than others. Grand Gedeh, River Gee, Maryland and Grand

Kru had the highest SP with 6. 3 Lofa County had the lowest SP with 5. 4 This information can be found in Table 12. These results prove that putting in PV panels is a good financial choice no matter where you do it. Grand Bassa has the smallest amount of money per year called ALCS ($1017/year), while Lofa County has the largest amount of money per year called ALCS ($1333/year). The regions with the highest COE values, namely Grand Gedeh, River Gee, Maryland, and Grand Ku, have all scored 0 in comparison to other regions.033 to 0036 USD/kWh Grand Gedeh, River Gee, Maryland, and Grand Ku emit the least amount of carbon dioxide, with a value of 5. 4 On the other hand, Grand Ku has the highest emission of carbon dioxide with a value of 5. 71

In simple words: The more energy you use, the more expensive power becomes. In Lebanon, the price of electricity is based on the amount you utilize. If you use less than 100 kilowatt hours, it costs 0. 0255 dollars per kilowatt hour. If your usage falls within the range of 100 to 300 kilowatt hours, you won't be charged.04 dollars per kilowatt hour. If you use between 300 and 400 kilowatt hours, it costs 0. 0584 dollars per kilowatt hour. If you use between 400 and 500 kilowatt hours, it costs 0. 0875 dollars per kilowatt hour. If you use more than 500 kilowatt hours, it costs 0. 146 dollars per kilowatt hour. Syria charges different amounts of money for electricity depending on how much you use. If you use less than 100 kilowatt hours, it costs $0. 005 per kilowatt hour. If you use between 101 and 200 kilowatt hours, it costs $0. 007 per kilowatt hour. If you use between 200 and 400 kilowatt hours, it costs $0. 01 per kilowatt hour. If you use between 401 and 600 kilowatt hours, it costs $0. 015 per kilowatt hour. If you use between 601 and 800 kilowatt hours, it also costs $0. 015 per kilowatt hour. If you use between 801 and 1000 kilowatt hours, it costs $0. 061 per kilowatt hour. If you use between 1001 and 2000 kilowatt hours, it costs $0. 071 per kilowatt hour. If you use over 2000 kilowatt hours, it costs $0. 081 per kilowatt hour. If you use more than 200 kilowatt hours of energy in Palestine, it will cost you between 15 and 17 cents per kilowatt hour. Electricity usage in Egypt, Algeria and Tunisia is charged based on the per-kilowatt hour rate paid by families. The amount is 0. 045$,04$,077$ depending on the country. In the chosen countries, the expense of producing energy through the suggested methods would be comparable to the electricity bill paid to traditional power providers. The results proved that the suggested method can help solve problems with electricity and water shortages while also reducing pollution that harms the environment. This means that the current way of checking the project's money situation is good and helps us see how well it's doing in all places.

Figure 4.2

Monthly variation of EG (Electricity Grid) for all selected locations



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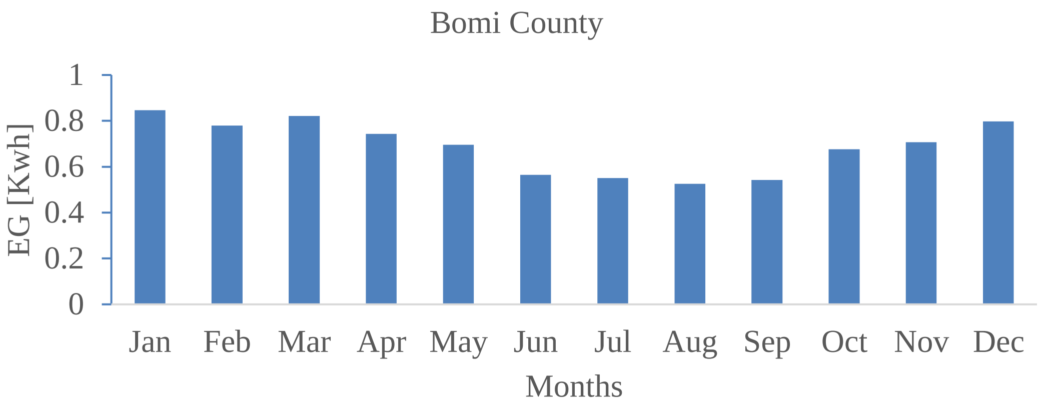

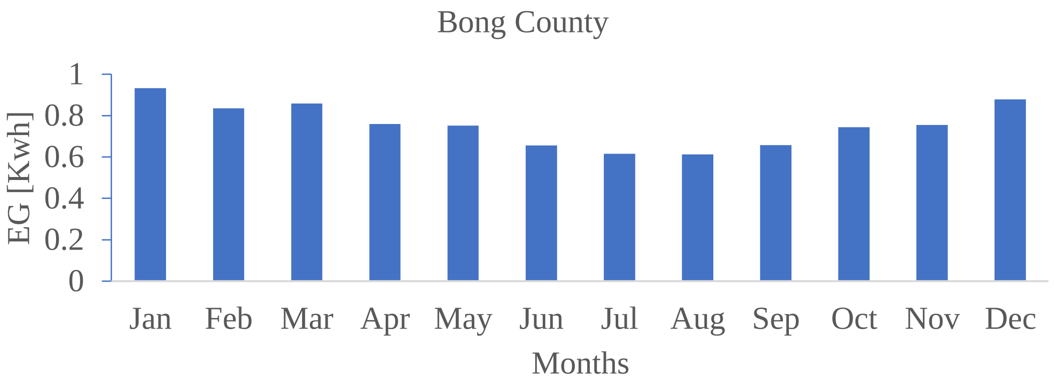

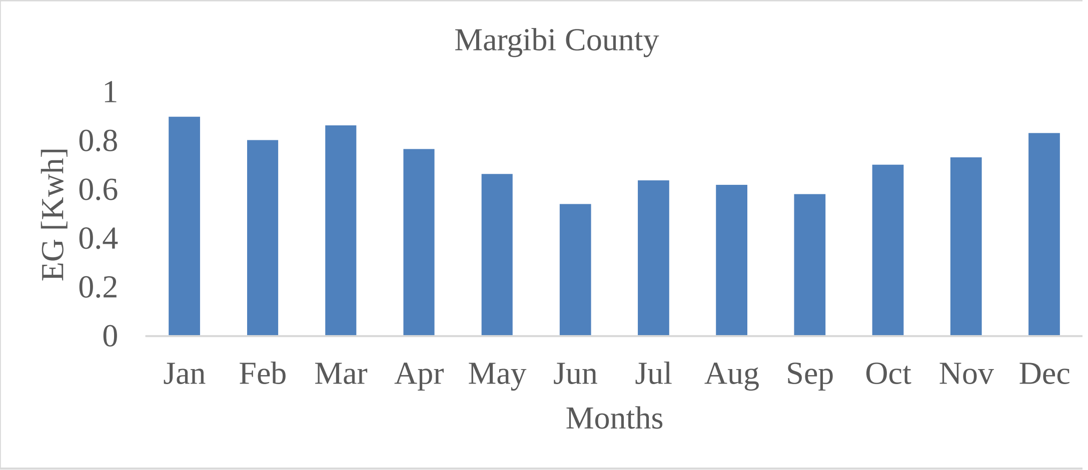

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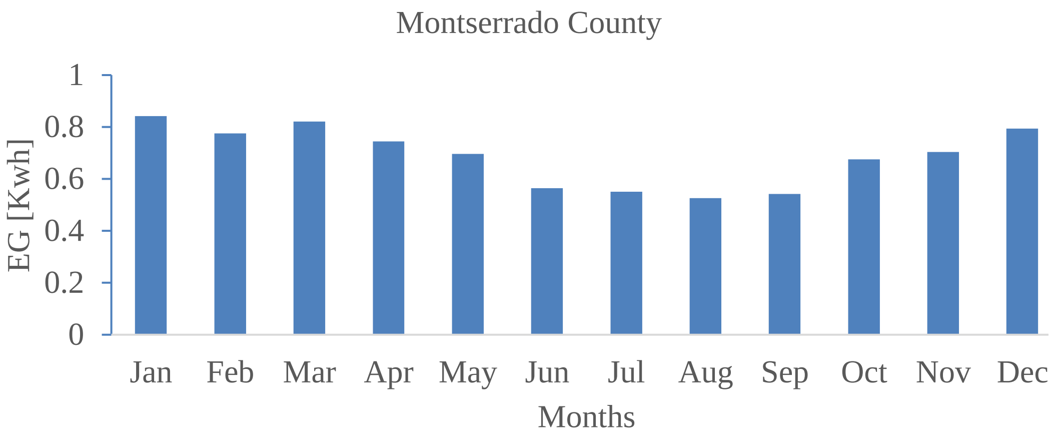

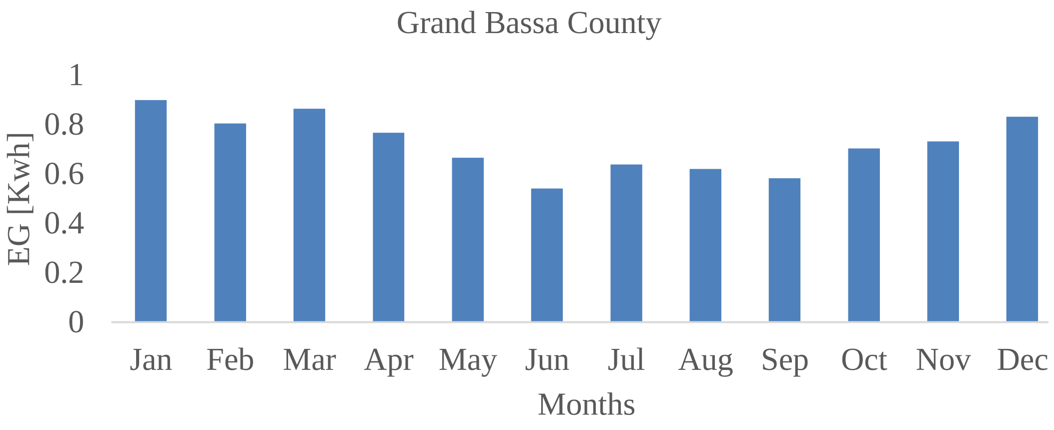

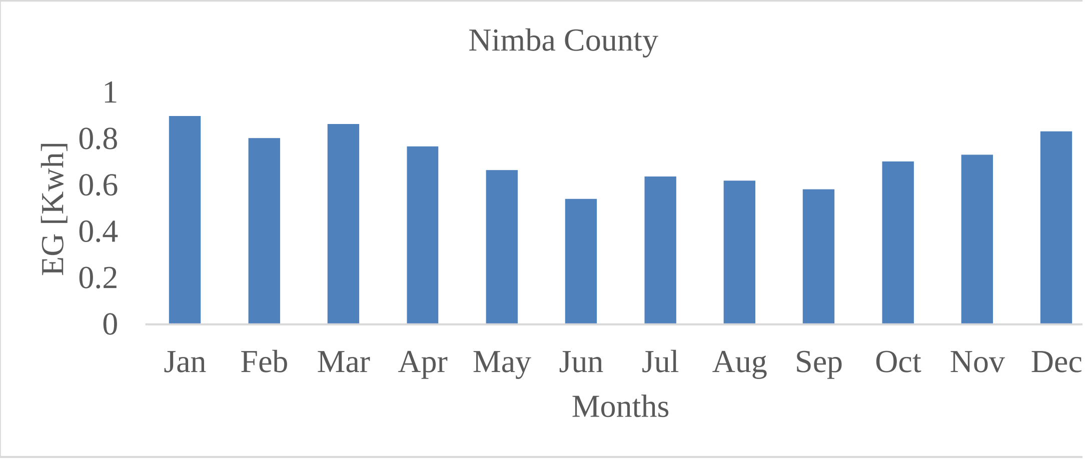

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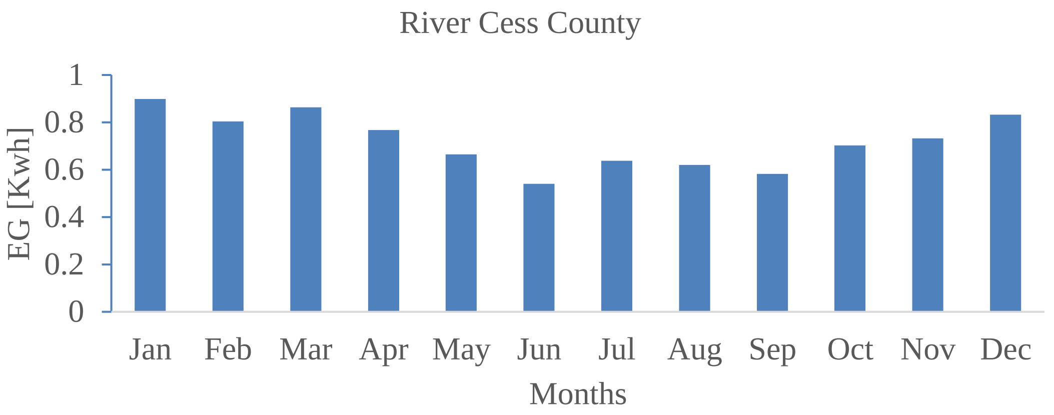

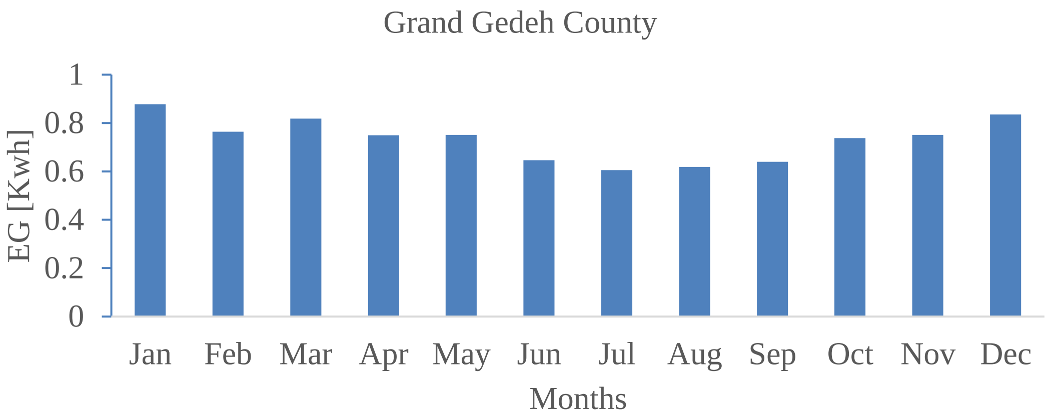

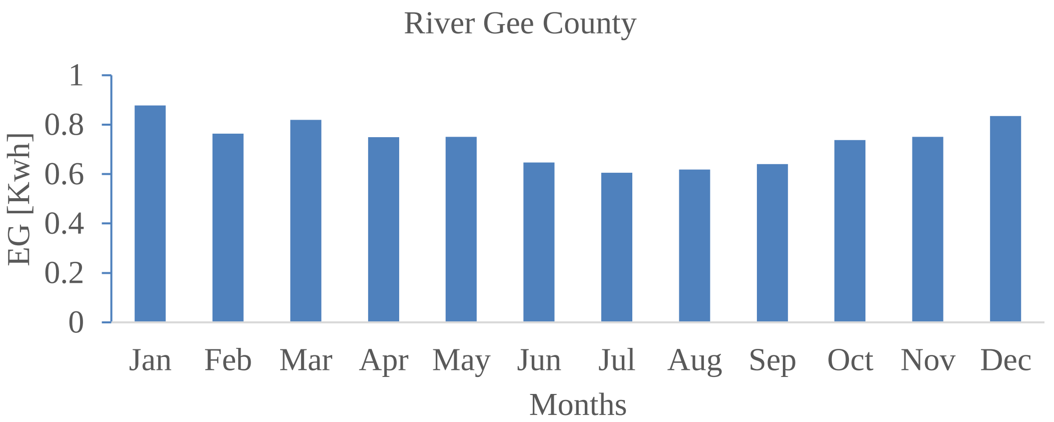

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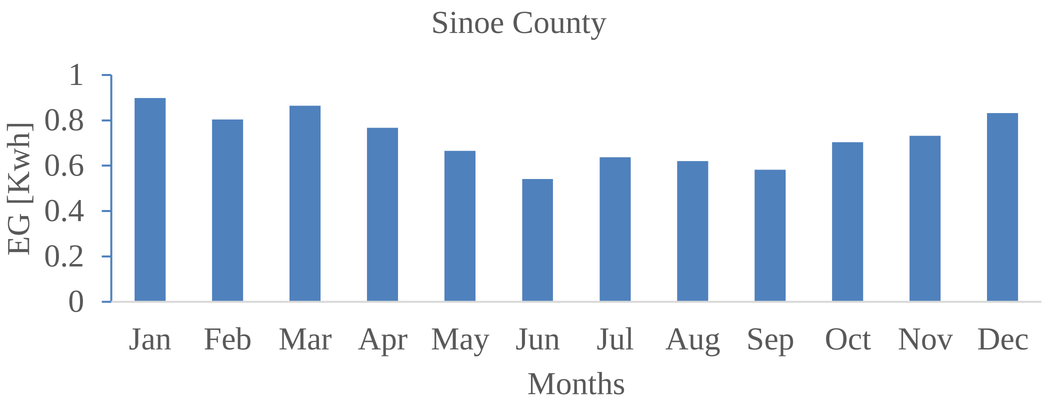
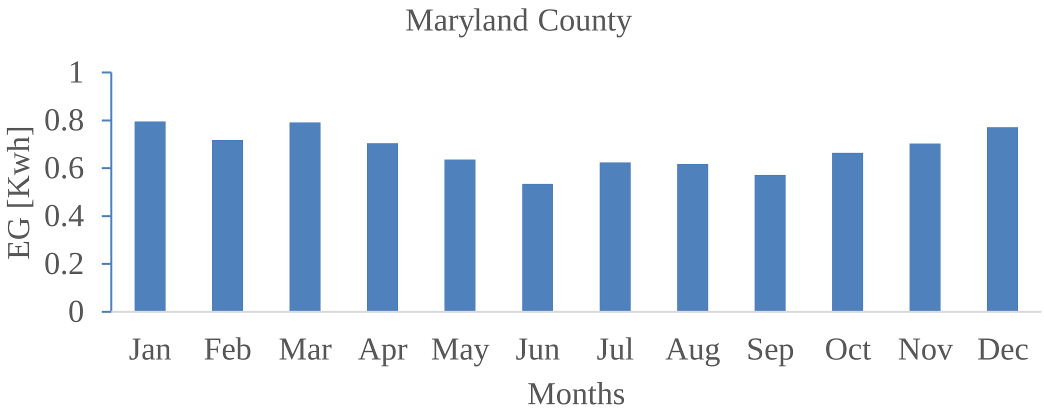




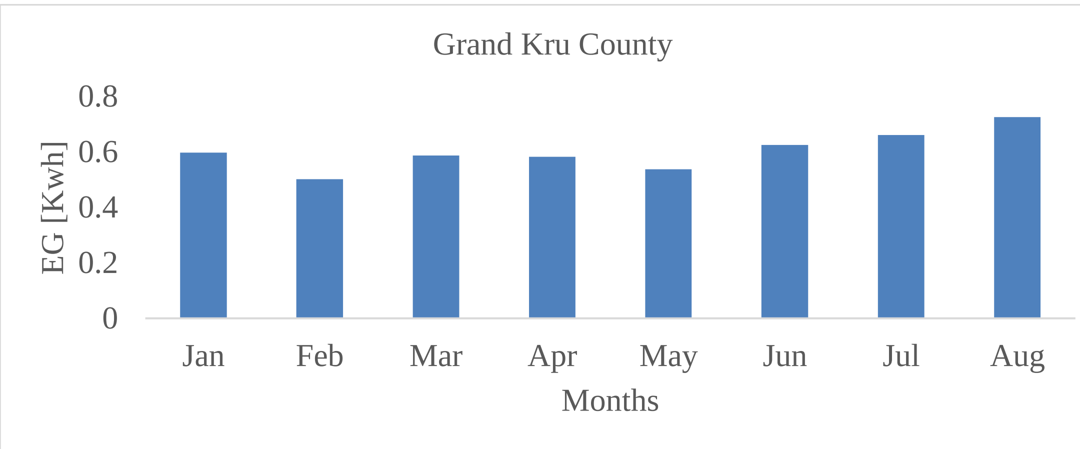


Table 4.3

Financial parameters

Factor	Unit	Value
Inflation rate	%	2
Discount rate	%	6
Reinvestment rate	%	9
Project life	Year	25
Debt ratio	%	50
Debt interest rate	%	0
Debt term	Year	20
Electricity export escalation rate	%	2

Sources: (EL-Shimy et at 2009, Himri et al 2020, Mohammadi et al 2018, Weida et al 2016, Adaramola et al 2012, & Kebede et al 2015)

Table 4.4

Annual Electricity Grid (EG) table of the 15 (fifteen) locations

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lofa	0.748	0.675	0.746	0.664	0.598	0.502	0.587	0.582	0.538	0.625	0.661	0.726
Garpolu	0.909	0.828	0.85	0.759	0.731	0.629	0.593	0.561	0.615	0.712	0.731	0.848
Cape mount	0.909	0.828	0.85	0.759	0.731	0.629	0.593	0.561	0.615	0.712	0.731	0.848
Bomi County	0.846	0.779	0.822	0.743	0.696	0.564	0.55	0.525	0.542	0.676	0.707	0.798
Bong County	0.933	0.835	0.858	0.76	0.751	0.655	0.615	0.613	0.657	0.744	0.755	0.878
Margibi County	0.899	0.804	0.864	0.767	0.665	0.541	0.638	0.62	0.582	0.703	0.732	0.832
Montserrado	0.842	0.776	0.821	0.744	0.697	0.565	0.551	0.526	0.542	0.675	0.704	0.794
Grand Bassa	0.899	0.804	0.864	0.767	0.665	0.541	0.638	0.62	0.582	0.703	0.732	0.832
Nimba County	0.899	0.804	0.864	0.767	0.665	0.541	0.638	0.62	0.582	0.703	0.732	0.832
River cess	0.899	0.804	0.864	0.767	0.665	0.541	0.638	0.62	0.582	0.703	0.732	0.832
Grand Gedeh	0.878	0.764	0.819	0.75	0.751	0.647	0.606	0.619	0.64	0.738	0.751	0.835
River Gee	0.878	0.764	0.819	0.75	0.751	0.647	0.606	0.619	0.64	0.738	0.751	0.835
Sinoe County	0.899	0.804	0.864	0.767	0.665	0.541	0.638	0.62	0.582	0.703	0.732	0.832
Maryland	0.795	0.718	0.792	0.705	0.636	0.534	0.624	0.618	0.572	0.664	0.703	0.771
Grand Kru	0.748	0.675	0.746	0.664	0.598	0.502	0.587	0.582	0.538	0.625	0.661	0.726

Figure 4.3

Variation of (Capacity Factor) for all selected locations

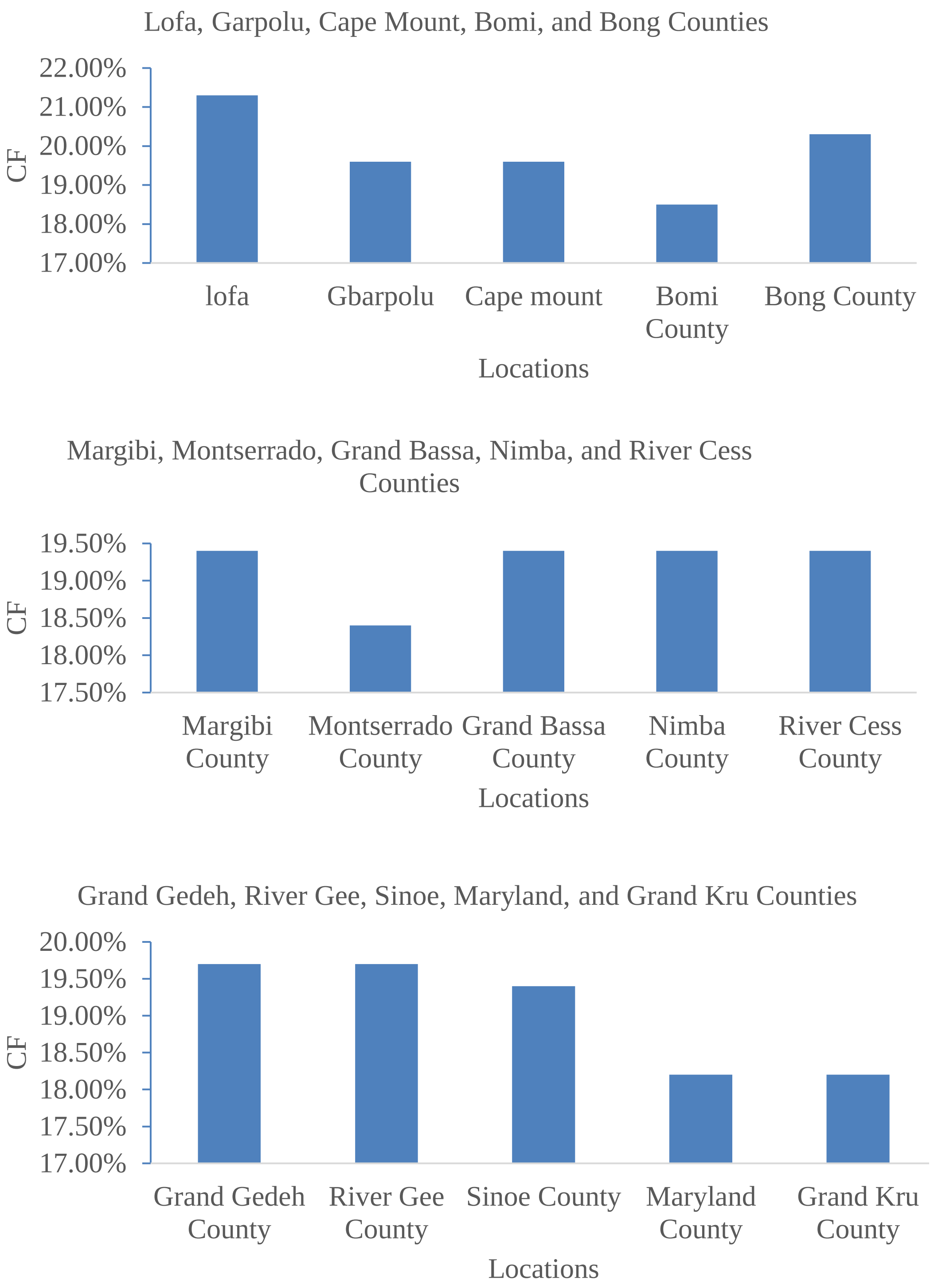


Table 4.5

Capacity Factors (CF) of the 15 (fifteen) locations classified or grouped into three

Location	Lofa County	Garpolu County	Cape Mount	Bomi County	Bong County
CF1	21.30%	19.60%	19.60%	18.50%	20.30%
Location	Margibi County	Montserrado	Grand Bassa	Nimba County	River Cess
CF2	19.40%	18.40%	19.40%	19.40%	19.40%
Location	Grand Gedeh County	River Gee County	Sinoe County	Maryland County	Grand Kru
CF3	19.70%	19.70%	19.40%	18.20%	18.20%

Table 4.6

Economic performance of the proposed PV system for all selected locations

Location	**NPV ($)**	**SP (year)**	**EP (year)**	**ALCS ($/year)**	**COE ($/KW/h)**	**GA-GHG (tCO2)**
Lofa County	17034	5.4	2.8	1333	0.033	5.71
Garpolu County	15395	5.8	3	1204	0.036	5.55
Cape Mount County	15493	5.8	3	1205	0.036	5.56
Bomi County	14247	6.2	3.2	1114	0.038	5.43
Bong County	16040	5.6	2.9	1255	0.035	5.62
Margibi County	15172	5.9	3.1	1187	0.036	5.53
Montserrado	14234	6.2	3.2	1114	0.038	5.43
Grand Bassa	11666	5.9	3.1	1017	0.041	4.64
Nimba County	16029	5.6	2.9	1254	0.035	5.62
River Cess County	17482	5.9	3.1	1240	0.034	5.89
Grand Gedeh County	14016	6.3	3.3	1096	0.039	5.4
River Gee County	14037	6.3	3.3	1098	0.039	5.41
Sino County	15420	5.8	3	1206	0.036	5.56
Maryland County	13997	6.3	3.3	1095	0.039	5.4
Grand Kru County	1407	6.3	3.3	1095	0.039	5.4

Evaluation of Wind Energy Potential

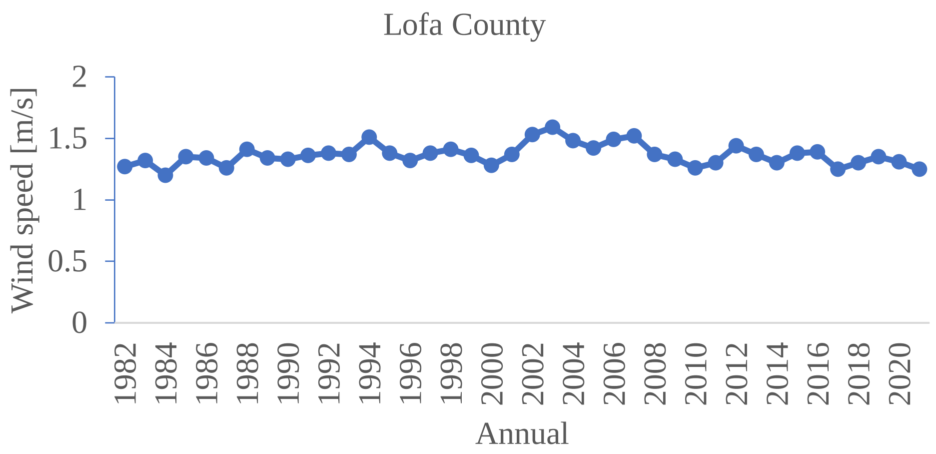
To find out if there is enough wind to make electricity from it, and to create a place where this can happen, we measured how strong the wind is at that location. Researchers used equations from (15) to (25) to calculate the WPD, as stated by Ayodele and colleagues. In 2014, a group of researchers named Mohammadi and others published a study. This text is already written in simple words. Table number 10 shows information about the wind speed measured at each location. The wind usually blows at a speed of 2 to 5 meters per second. The fastest wind speed in August was in Maryland County at 5. 0 The slowest wind speeds were in Nimba County in January and Bong County in December, both at 2. 0 The Wind Power Density (WPD) exhibits negligible discrepancies.472213w/m2 and 3758611w/m2Throughout the period of 1982-2021, Nimba County experienced consistently sluggish wind speeds, averaging at 0.55 m/s each year. In Maryland, the wind was stronger, with an average of 2. 8 m/s each year. This place doesn't have much wind energy (class 1), according to a study called WPD. The wind energy can range from 0. 47W/m2 in Nimba County to 37. 59W/m2 in Maryland County. (Khan et al.) This year (2019). Therefore, a small wind turbine can use wind power to create electricity for buildings.

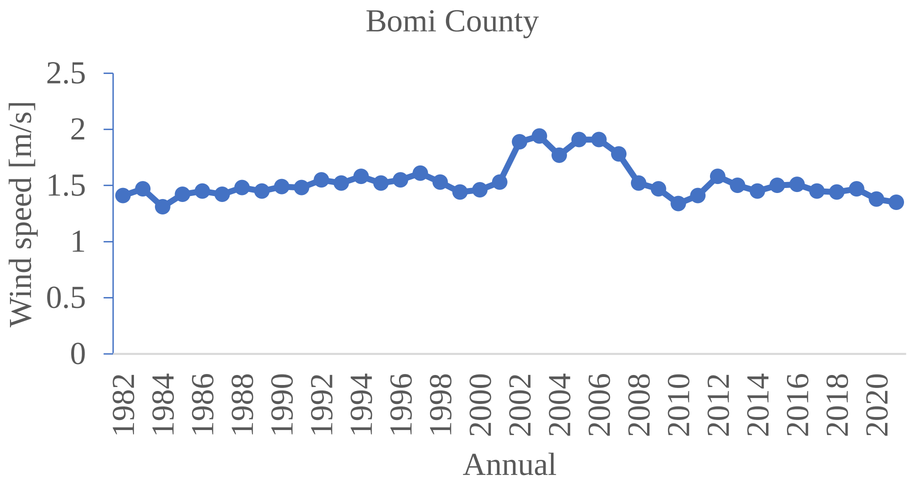
Assessment of Liberia's Potential Solar and Wind Energy Resources: Summary

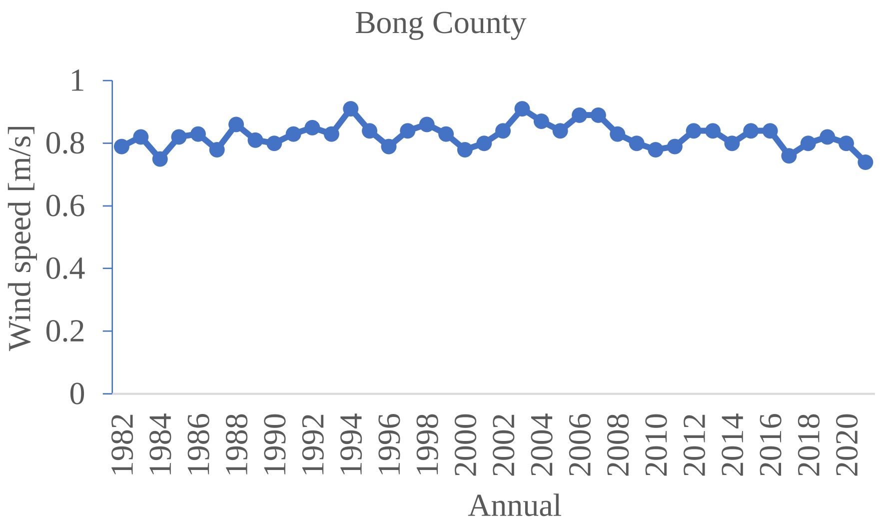
Liberia can use solar energy in all areas because they get a lot of sunlight, which could help them save money. The amount of energy that can be produced from the sun is different in different places and can be between 1754 to 2292 kilowatt hours per square meter. This is more changeable than the amount of energy that can be produced from wind. A study looked at how much wind power 15 places could harness over 39 years. Liberia doesn't have much wind power potential, only 37. 58611 W/m2 on average. Most big wind turbines are 84 meters tall and were designed using NASA's wind data collected at a lower altitude. Basically, it is better to use solar energy instead of wind energy in Liberia because the areas where they want to use it are not good for wind energy.

Figure 4.4

Variation of annual wind speed [m/s] for all selected locations







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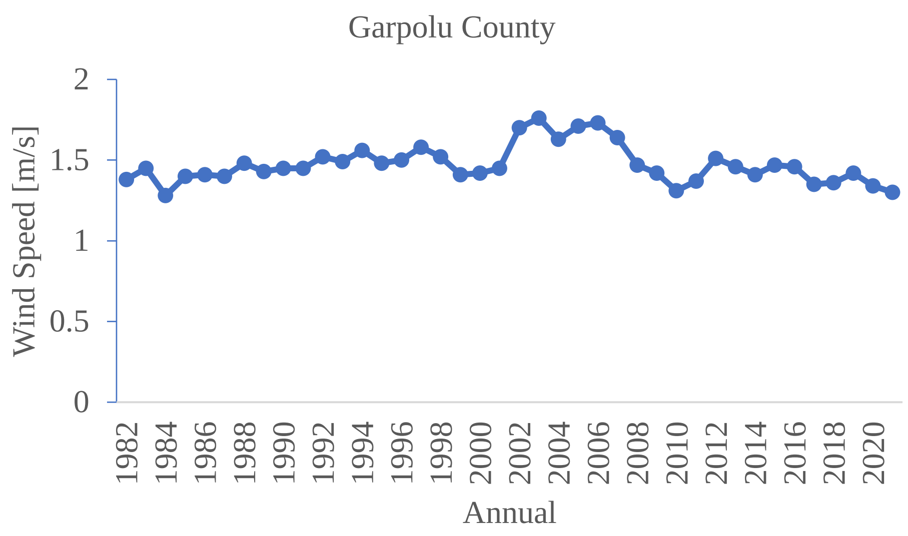

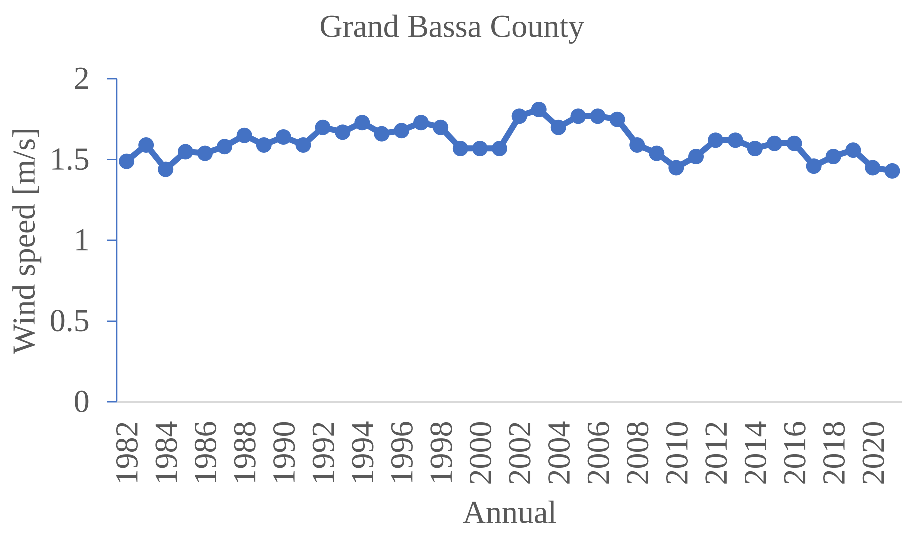

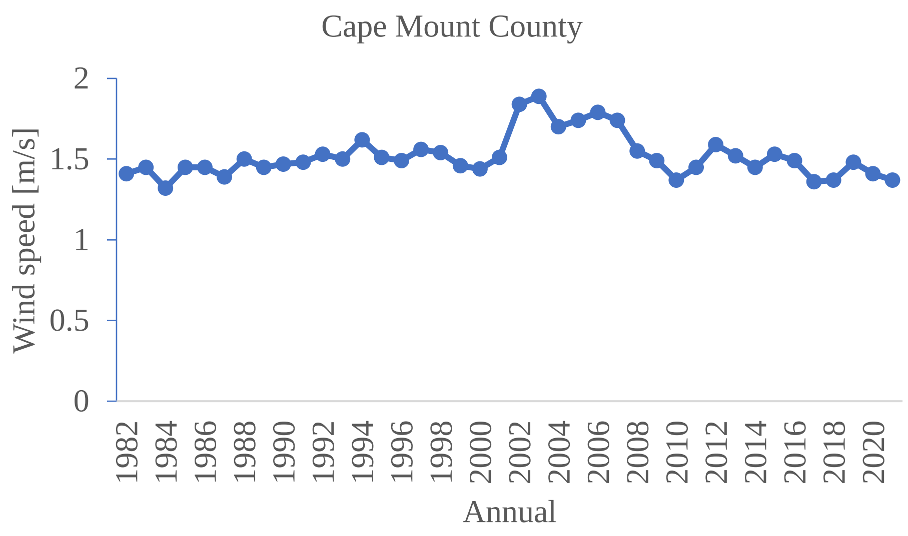

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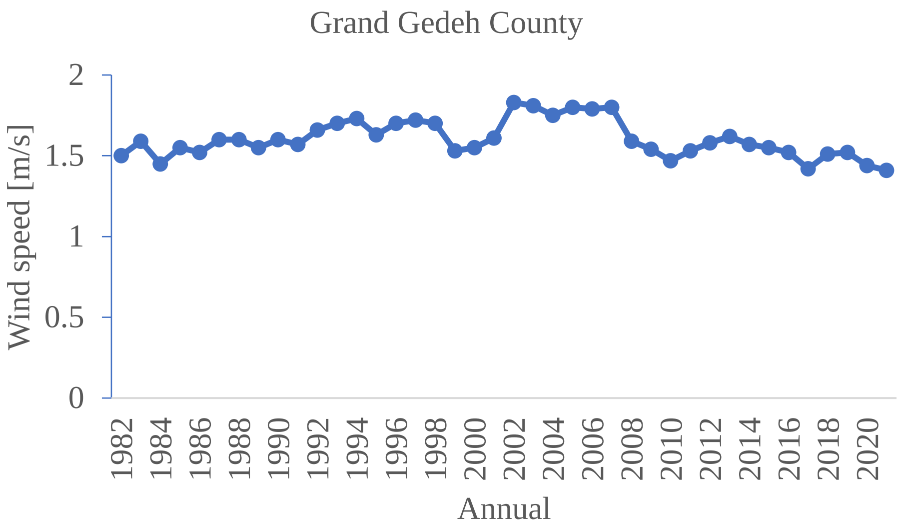

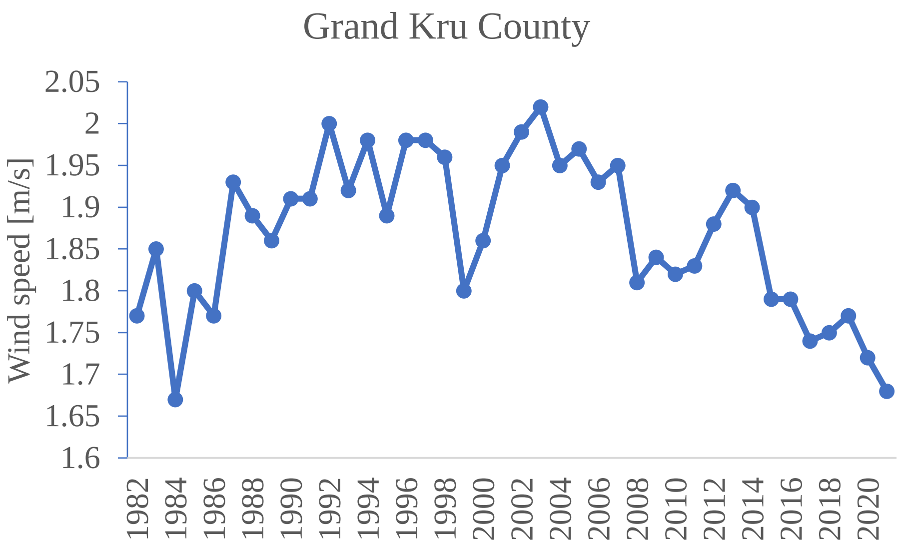

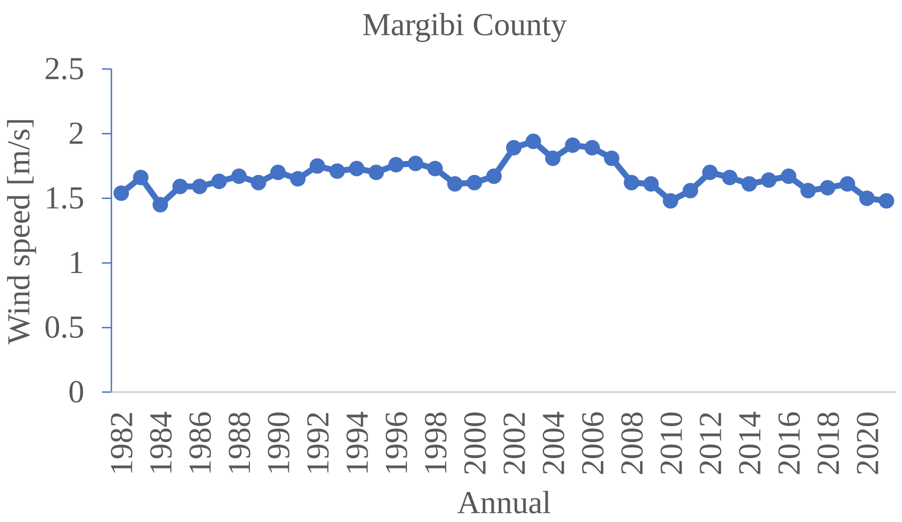

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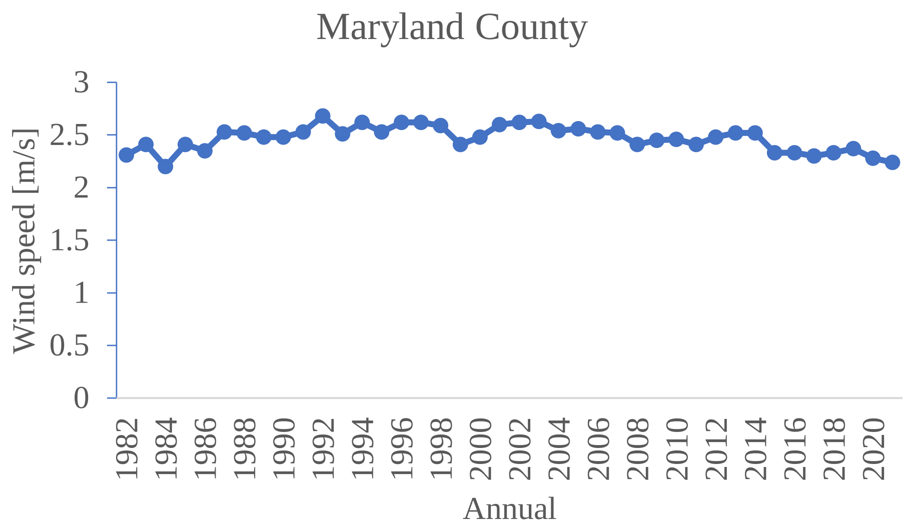

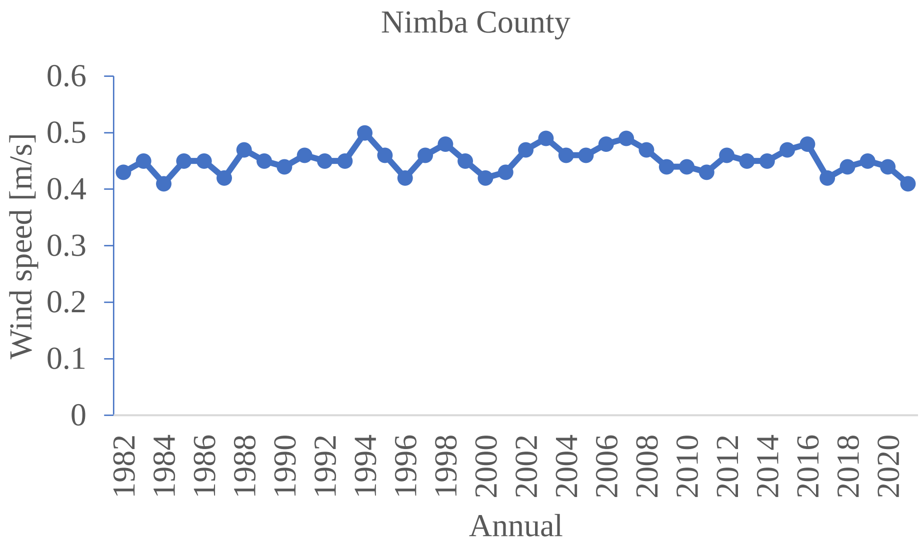

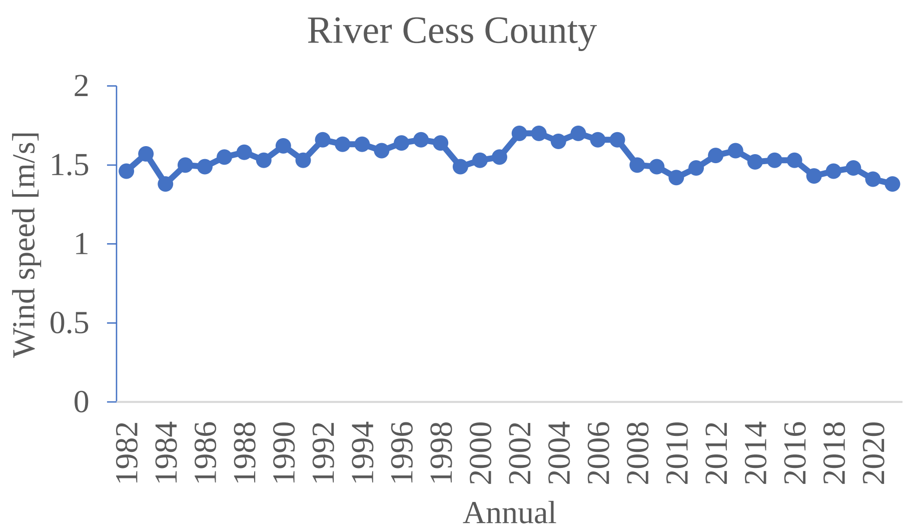

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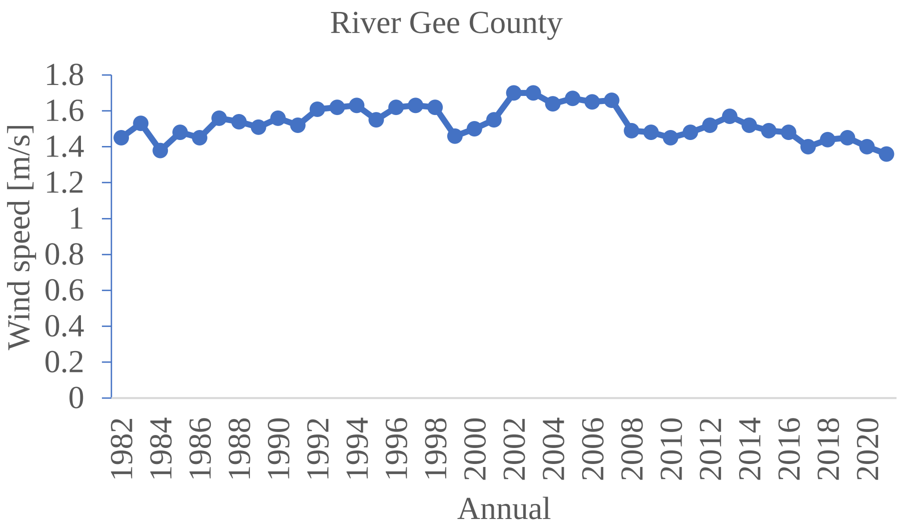
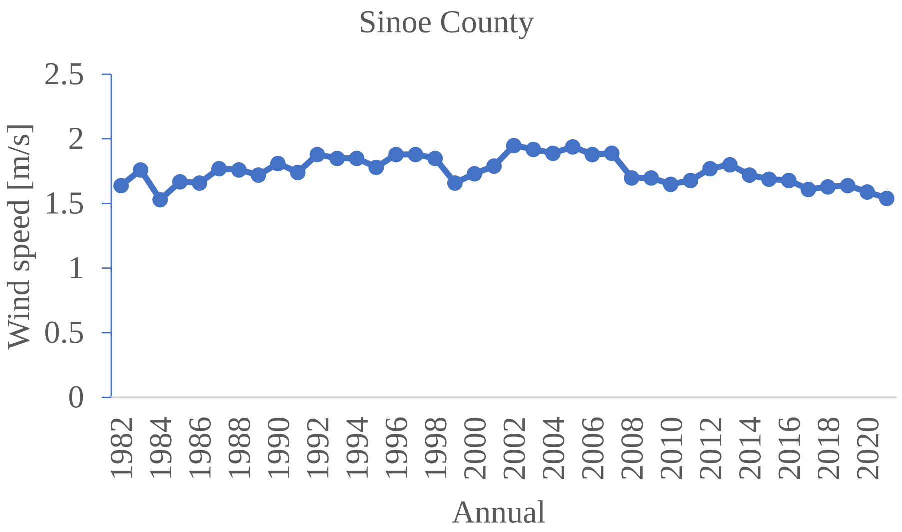




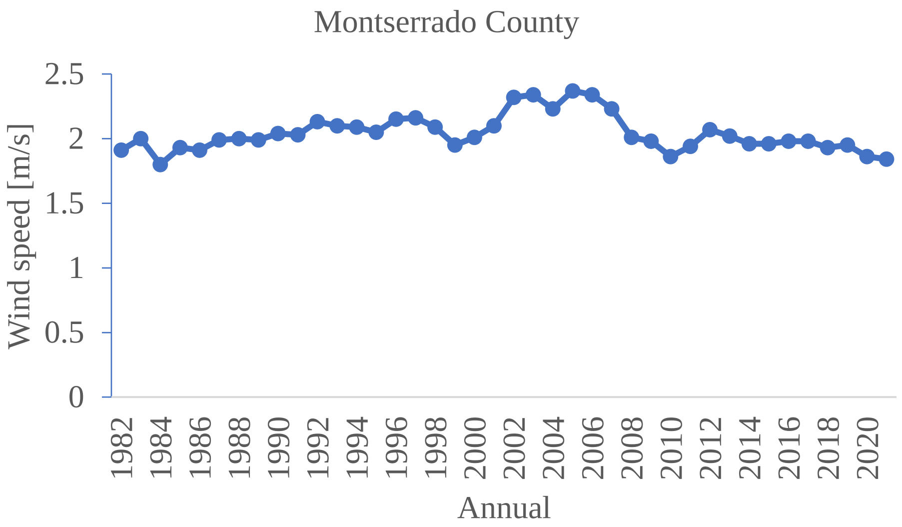
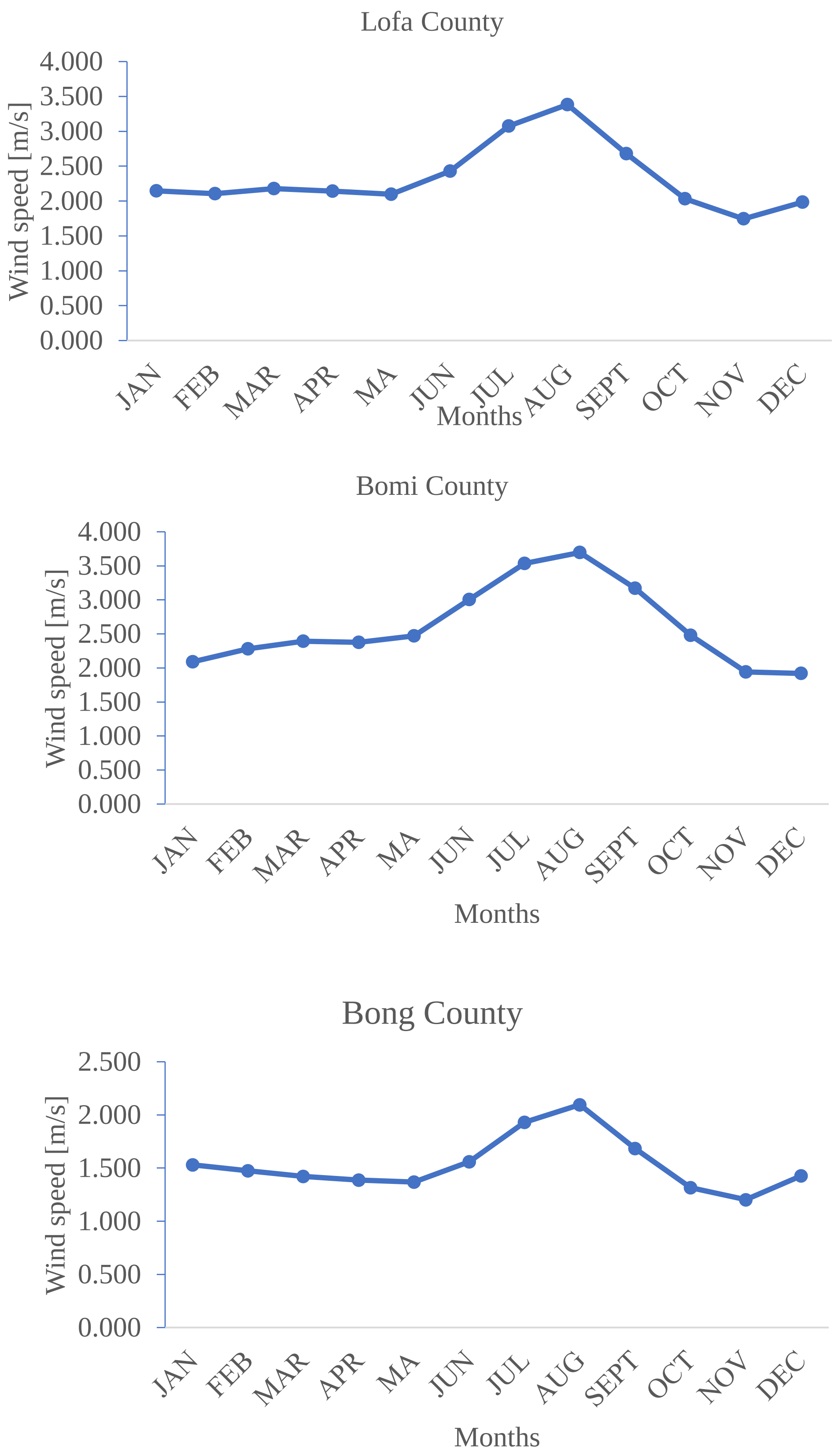


Figure 4.5

Variation of monthly wind speed [m/s] for all selected locations



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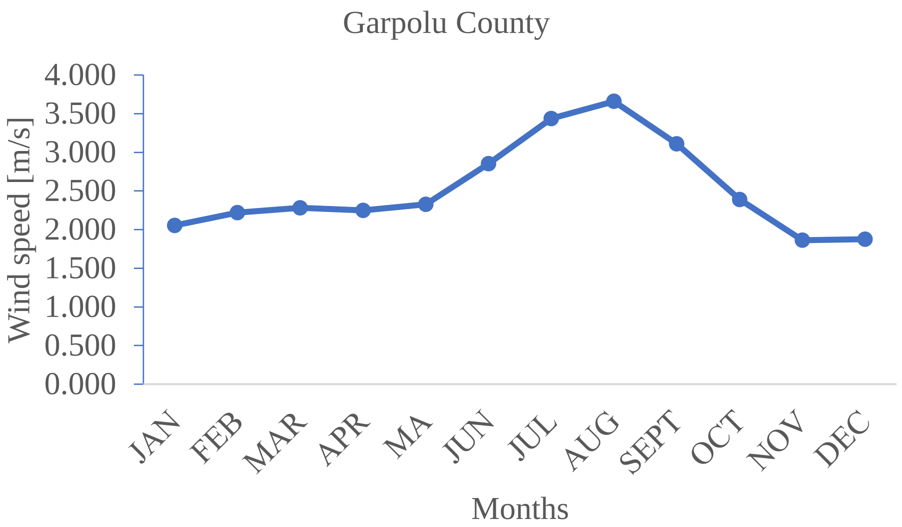

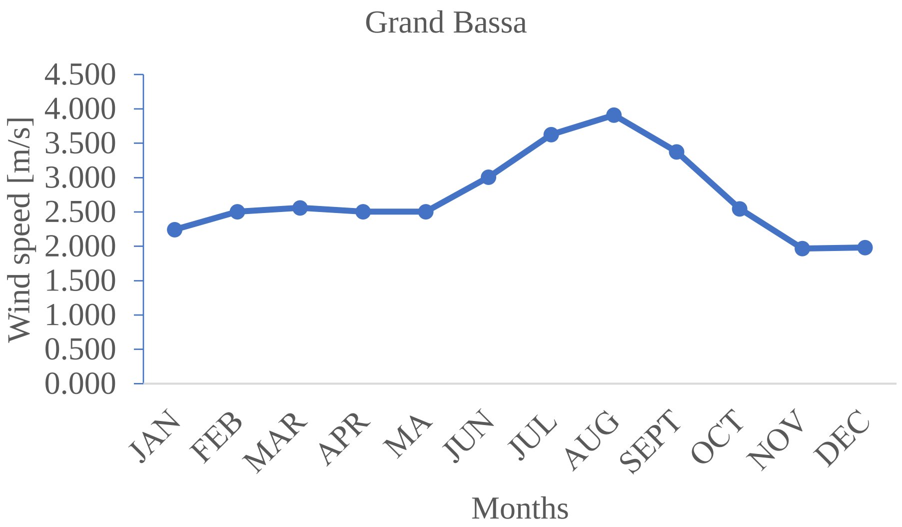

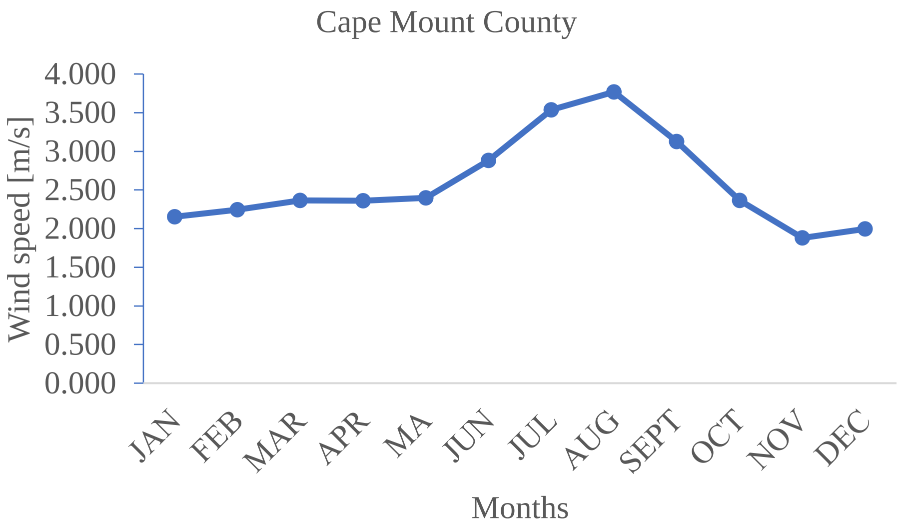

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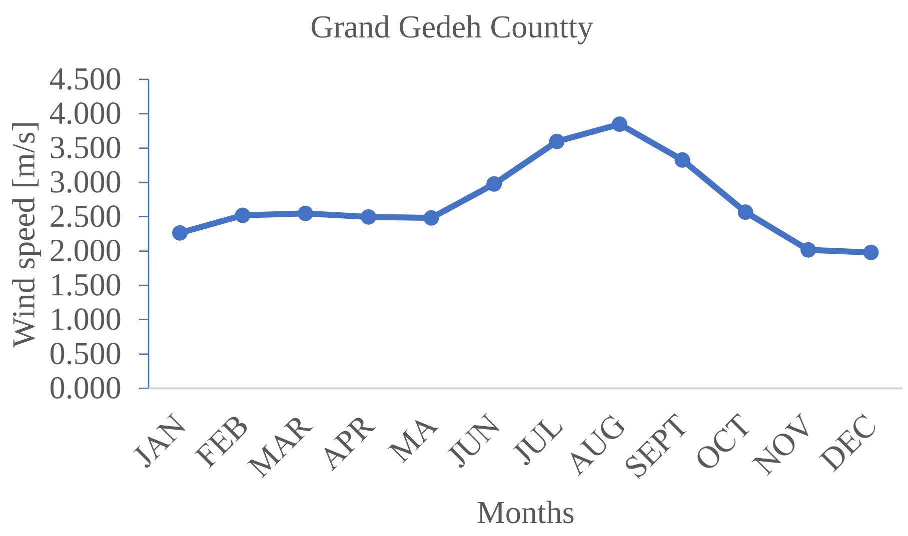

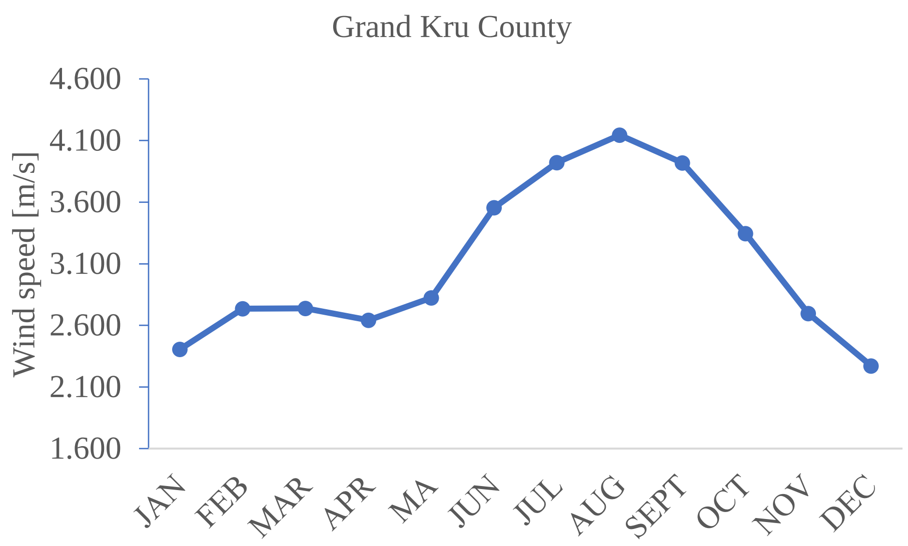

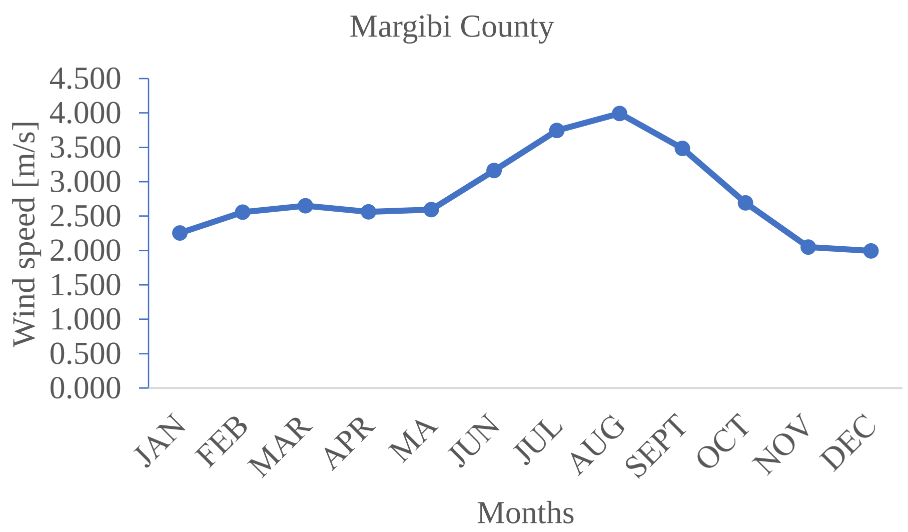

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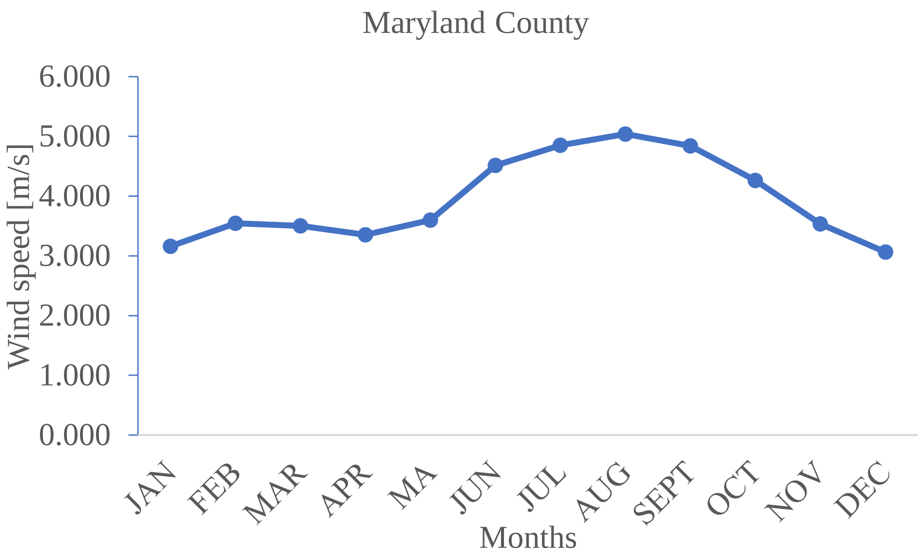
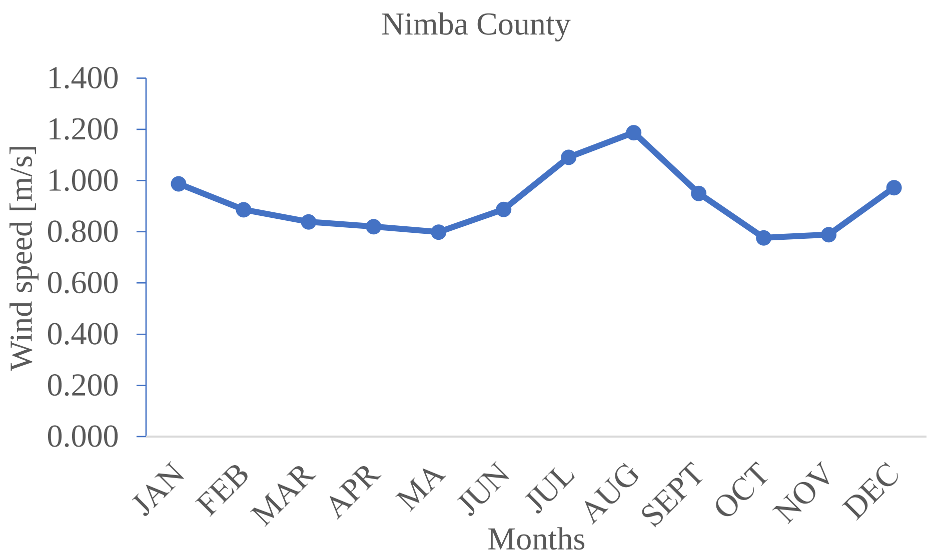




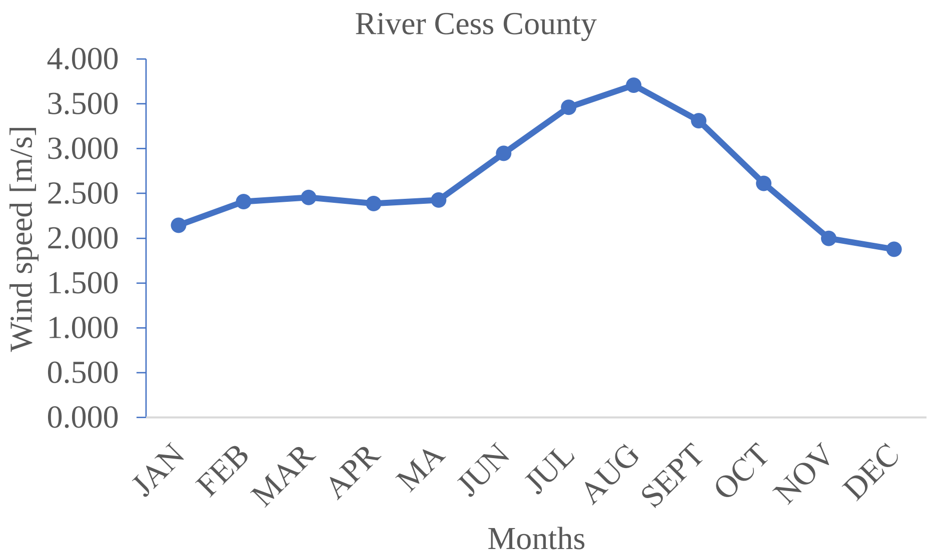
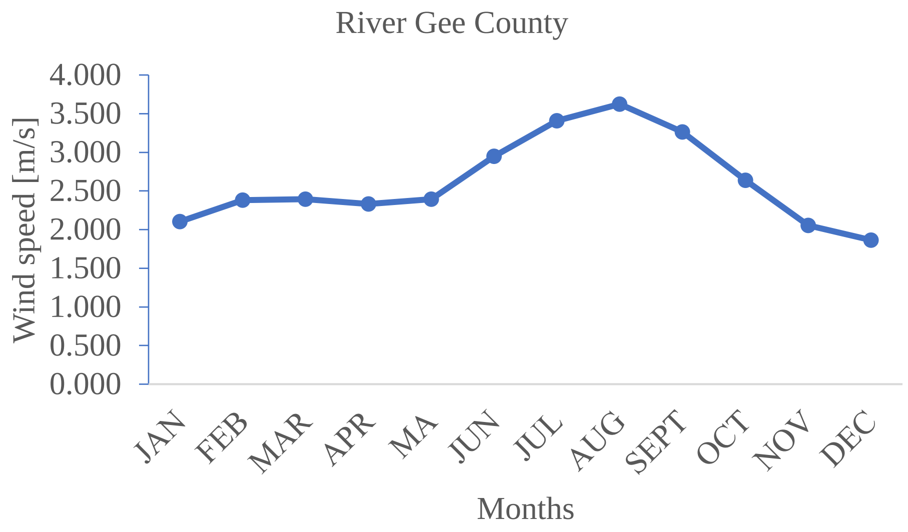
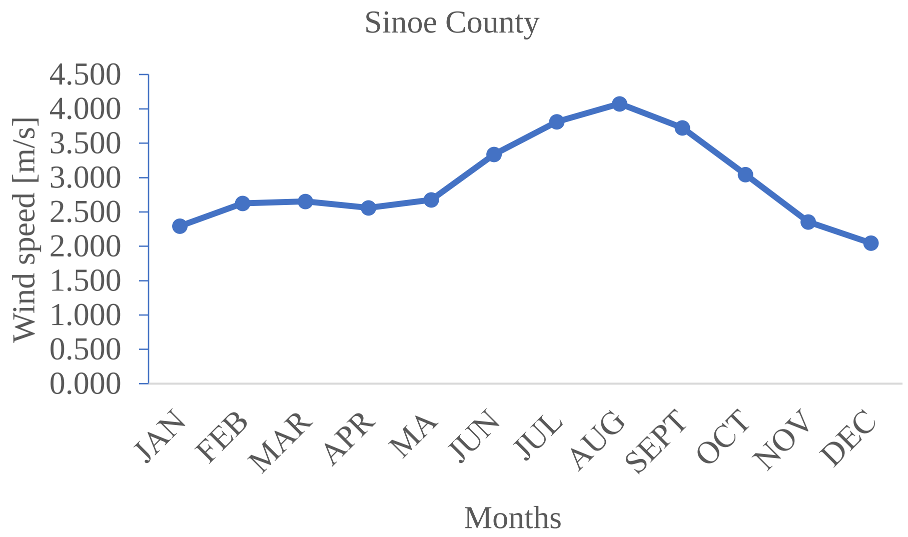


Figure 4.5 Continued





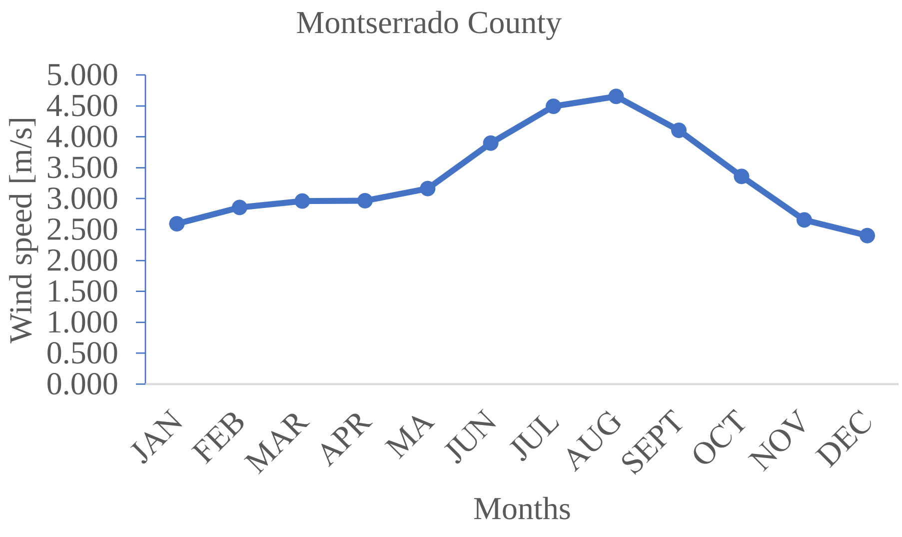


Table 4.7

Descriptive statistics of wind speed data for the investigation period

Locations			Locations		
Lofa	Shape	4.979	Grand Kru	Shape	5.435
	Scale [m/s]	2.529		Scale [m/s]	3.36
	WPD (Weibull)	8.891261		WPD (Weibull)	20.73967
	WPD (actual)	7.812416		WPD (actual)	18.329
Bomi	Shape	4.787	Margibi	Shape	4.796
	Scale [m/s]	2.849		Scale [m/s]	3.066
	WPD (Weibull)	12.75404		WPD (Weibull)	15.8932
	WPD (actual)	10.96864		WPD (actual)	13.66878
Bong	Shape	6.081	Maryland	Shape	6.264
	Scale [m/s]	1.643		Scale [m/s]	4.235
	WPD (Weibull)	2.416775		WPD (Weibull)	41.37491
	WPD (actual)	2.215749		WPD (actual)	37.58611
Garpolu	Shape	4.583	Nimba	Shape	7.332
	Scale [m/s]	2.76		Scale [m/s]	0.9717
	WPD (Weibull)	11.6477		WPD (Weibull)	0.500379
	WPD (actual)	9.917246		WPD (actual)	0.472213

Grand Bassa	Shape	4.769	River Cess	Shape	4.974
	Scale [m/s]	2.973		Scale [m/s]	2.877
	WPD (Weibull)	14.49803		WPD (Weibull)	13.09092
	WPD (actual)	12.47494		WPD (actual)	11.37372
Cape Mount	Shape	4.597	River Gee	Shape	5.11
	Scale [m/s]	2.827		Scale [m/s]	2.843
	WPD (Weibull)	12.51245		WPD (Weibull)	12.60758
	WPD (actual)	156.106		WPD (actual)	11.02084
Grand Gedeh	Shape	4.952	Sinoe	Shape	4.978
	Scale [m/s]	2.957		Scale [m/s]	3.194
	WPD (Weibull)	14.21857		WPD (Weibull)	17.91135
	WPD (actual)	12.3663		WPD (actual)	15.53339
Grand Kru	Shape	5.435	Montserrado	Shape	4.867
	Scale [m/s]	3.36		Scale [m/s]	3.642
	WPD (Weibull)	20.73967		WPD (Weibull)	26.60384
	WPD (actual)	18.329		WPD (actual)	22.9522

CHAPTER V

Conclusions and Recommendations

Chapter 5 explains how solar power and wind turbines can help solve the energy and water problems in all 15 regions of Liberia, based on the research project conducted.

Conclusions

We studied if it is possible to use wind or solar energy in the 15 areas of Liberia. By utilizing mathematical techniques (Weibull distribution functions), we analyzed the wind and evaluated its potential for producing energy. We looked at data from NASA about how fast the wind blows from 1982 to 2021. The amount of energy from wind at a height of 10 meters is not very good. It is about 37. 59 watts per square meter. This means that sometimes it's not a good idea to use bigger wind turbines to make electricity in certain places with wind.

We used Statistic to look at how much sunlight there is in the study areas, to see if we could use it for energy. According to the findings, the sun in the designated zones is evaluated as satisfactory, outstanding, and outstandingly good. The research shows that solar power is a big source of energy in the selected places. There is a lot of sunlight in certain places, and we can use it to make more electricity and water because we don't have enough right now.

We used a computer program called RETScreen to figure out if small solar power plants would work well and make sense financially for powering homes and distillation systems in certain areas. We studied a machine that moves to follow the sun in two directions. The study showed that the amount of electricity produced by newer systems varied from 1754. 029 kWh/m2 to 2292. 678 kWh/m2 every year. This energy production would greatly reduce how much the country needs to use fossil fuels and decrease the amount of carbon being produced. A type of power system that uses sunlight can help solve problems with water and electricity. It costs less for people connected to this system than for people who use the regular electrical system.

Recommendations

When we burn fossil fuels for energy, we release more greenhouse gases into the air. This causes the earth's temperature to rise, which is called global warming. Scientists must quickly find ways to make energy that is clean, cheap, and can keep going for a long time. This energy should use wind and sunlight to help reduce the amount of harmful gases in the air. Some countries have used wind and solar power to get electricity and water. NASA data was used for 39 years (1982-2021) in Liberia because there wasn't enough accurate data available on wind pressure and solar radiation. However, the NASA data may not be completely accurate. So scientists need to do more studies because of these reason:

.

1. More research needs to be done to see if NASA's data is useful for figuring out how much wind and solar energy we can get in Liberia. This will involve comparing NASA's information to what we find on the ground in Liberia. If the numbers are the same, it means NASA's information is dependable.
2. We need to set up a weather station that works well and gives accurate information. This way, we can keep a record of Liberia's climate and understand its different factors.

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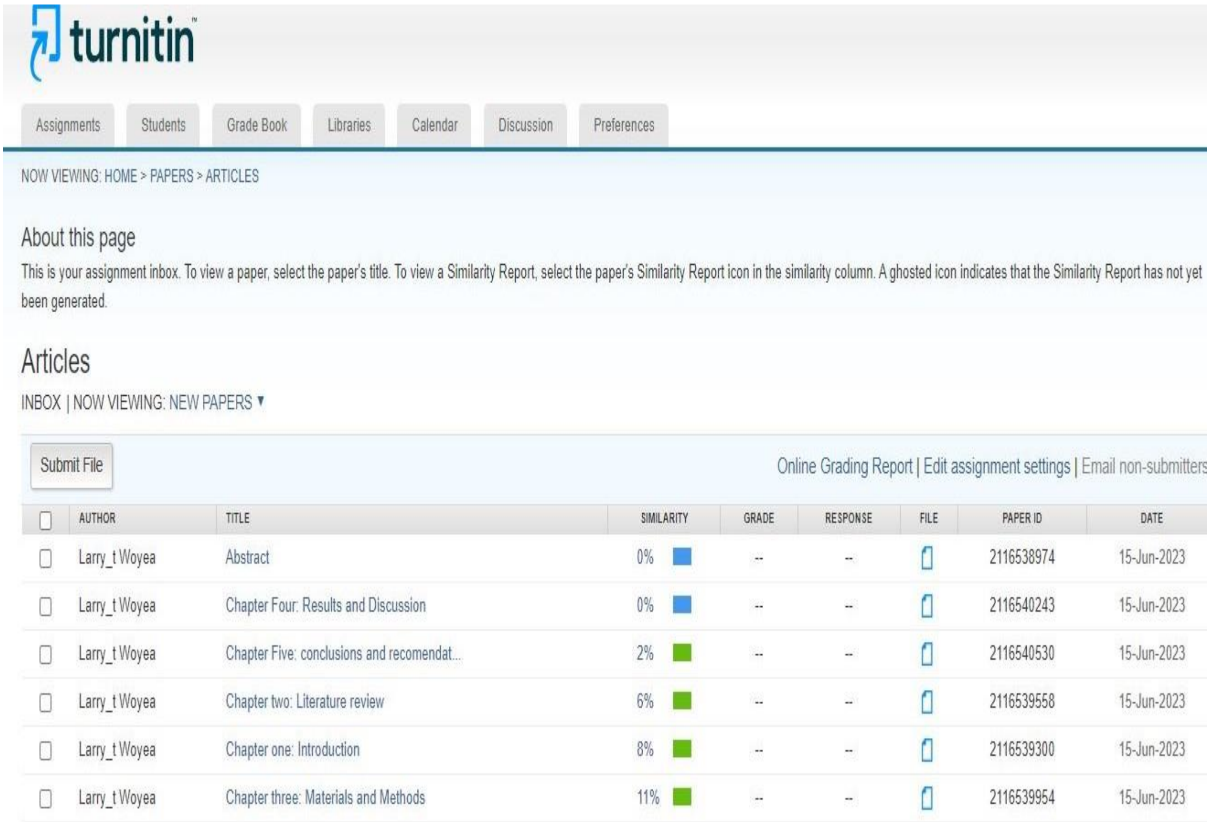
APPENDICES

Appendix A

Similarities Report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