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Electricity in Senegal

An Analysis into Potential Strategies to Increase Electrification Rates

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Abstract

Senegal is a West African country dependent on imported fossil fuels for power generation. The population of Senegal is 15.85 million, with the urban and rural electrification rates at 87.7 and 38.3, respectively. Over half of the population lives in rural areas with limited to no access to electricity. Across the country the demand for electricity is increasing at a rate of 6.2 percent per year indicating a need to increase energy production and rural electrification rates.

The objective of this paper was to analyze the potential renewable energy sources and determine the best method for increasing electrification in Senegal. These energy sources include solar, wind, biomass and hydro power. The physical and economic potential for each source was calculated to evaluate its potential in Senegal. The levelized cost of electricity was determined for these sources and used to compare them to each other and with historic values for natural gas, coal, and diesel. Additionally, the benefits and challenges for each source were discussed and potential strategies for increasing the electrification rates in Senegal were evaluated using an evaluation matrix.

The results in this paper were used to identify methods to reduce dependence on imported fossil fuels and increase electrification rates, especially in rural areas in Senegal. The current dependence on imported fossil fuels subjects Senegal to unstable market conditions and negative environmental effects, thus the focus of this paper was on renewable energy sources.

From the analysis completed in this paper, it was identified that Senegal could diversify its energy portfolio through a mix of solar, wind, biomass, and hydro power investments. Solar power was identified as the best method to increase electrification rates in rural locations without access to the grid. Wind, biomass, and hydro power were determined to have significant potential in Senegal but would require access to the national grid or an isolated system to distribute power. The levelized cost of electricity for the renewable energy sources analyzed were within the historic range of levelized costs for fossil fuels.

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1. Introduction

Energy consumption around the world is increasing due to a growth in global population and gross domestic product (GDP) (Crastan, 2014). Approximately 80 percent of the current energy demand in the world is met by fossil fuels. In 2011, the global energy demand was equivalent to 550 exajoules, the breakdown of which can be seen in Figure 1 (Siirola, 2014).

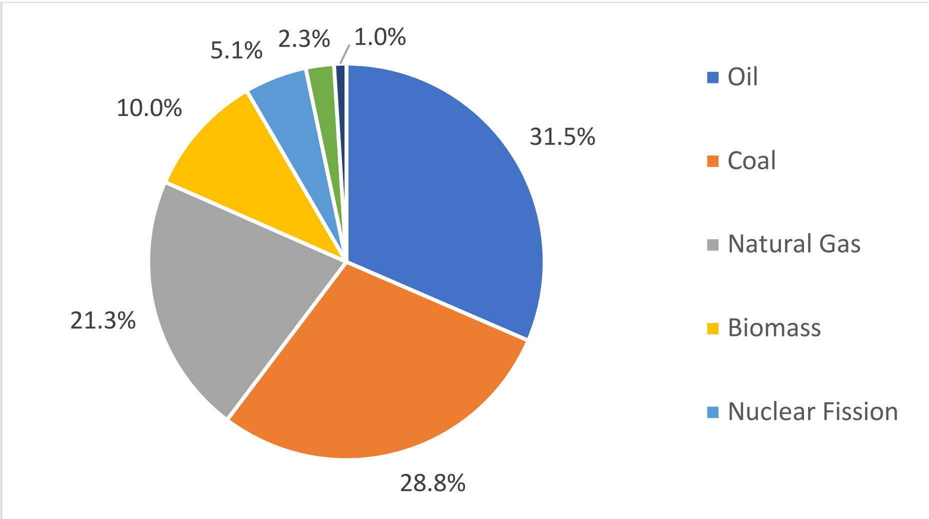

Figure 1: Percent breakdown of World Energy Sources in 2011 (Siirola, 2014)

In 2017, there was a 2.2 percent growth in global energy demand and a 1.6 percent increase in carbon emissions as a result of energy consumption. This increase in global energy demand and carbon emissions is directly related to a higher than expected increase in global GDP from industrial activity. The global renewable power share has also increased from 7.4 to 8.4 percent due to a significant growth in wind and solar power production (BP, 2018).

The global energy demand is expected to increase by 30 percent by 2035, with an average growth rate of 1.3 percent per year. This is driven by the increasing population in developing countries. Thus, the current energy industry needs to adapt to meet the increase in demand and take into consideration the public's growing environmental concerns (Oil and Gas Journal Editors, 2017). The largest increase in future energy consumption will occur in the least developed countries, 33 of which are located in Africa, as the population in these countries are expected to nearly double from a current population of around 1 billion to 1.9 billion by 2050 (Kazeem, 2017).

1.1 Background on Senegal

1.1.1 Location

Senegal is a West African country with a population of approximately 15,850,000 and an area of 197,000 km^2 (World Bank Group, 2017). Senegal is bordered by Mauritania, Mali, Gambia, Guinea, and Guinea-Bissau, with 531 km of coastline along the Atlantic Ocean. The capital city, Dakar, is one of the most important harbours in West Africa, as well as an economic and cultural centre. The ecology in Senegal varies from grassland to oceanfront to tropical rainforest, resulting in a large variety of animal and plant life (Camara et al., 2018). The three main rivers are the Senegal, Casamance and Gambia Rivers, with the Senegal River being the most important due to its path through the interior of the country (United Nations Industrial Development Organization, 2016) The climate in Senegal is tropic. From May to November, it is hot and rainy, and from December to April, it is dry (Boslaugh, 2012). The average annual rainfall in Senegal ranges from 340 mm to 1,550 mm, with an average of 570 mm of rain per year in Dakar (United Nations Industrial Development Organization, 2016).

Figure 2: Map of Senegal (United Nations Geospatial Information Section, 2004)

1.1.2 Population and Demographic

The total population has a growth rate of 2.6 percent per year due to a high fertility rate of 4.78 children per woman. Approximately 43 percent of the population is under 14 years old, and the median age in the country is 18 years old (Boslaugh, 2012). The life expectancy in Senegal is 61 years old, which is among the highest in sub-Saharan Africa (Camara et al., 2018).

More than half of the total population (about 8.4 million people) live in rural areas, with an annual growth rate of 1.98 percent (World Bank Group, 2017). Approximately 40 percent of rural villages in Senegal have a population of less than 500 people, which is equivalent to over 2 million people. This equates to 20,000 homes in rural Senegal, with approximately 10 individuals per household. These small villages are characterized by low incomes and low standard of living, they are not often priorities in electrification programs (Diouf et al., 2013).

Society in Senegal over the past few decades has been defined by an increasing amount of poor people and an unequal distribution of poverty, where poverty is defined as the lack of income required to meet elementary needs (Odekon, 2015). About 54 percent of the population in Senegal are living below the poverty line and 48 percent are unemployed (Purdy, 2012). The per capita income is 1,900 USD (Purdy, 2012). The Human Development Index for Senegal is very low at 0.470 (Odekon, 2015). Additionally, the literacy rate remains one of the lowest in the world (Camara et al., 2018).

Senegal was a former French colony that gained its independence in 1960 (Odekon, 2015). French is still the official language in Senegal, but up to 39 other languages are spoken, including Arabic. Traditional Senegalese culture is based on collectivism. The majority of the population practices Islam, along with a very small population that practices Christianity. Despite the constitution prohibiting discrimination by gender, in many parts of the country it is prohibited for women to inherit land and due to traditional religious beliefs, men are mainly recognized as the head of the household (Camara et al., 2018).

1.1.3 Current Energy Situation

By the early 21st century, three quarters of the population in Senegal lacked access to electricity. Since then, electrification rates have increased such that by 2016, 64.5 percent of the population had access to electricity, with the urban and rural electrification rates at 87.7 and 38.3 percent, respectively. However, access has continued to be unstable, especially in rural areas, as can be seen in Figure 3. The instability is a result of insufficient reserve capacity, challenges with imports, and air conditioning demand peaks during the rainy season (Purdy, 2012). Additionally, outdated infrastructure leads to frequent shut downs and transmission losses of approximately 19 percent (Africa-EU Renewable Energy Cooperation Programme, 2016).

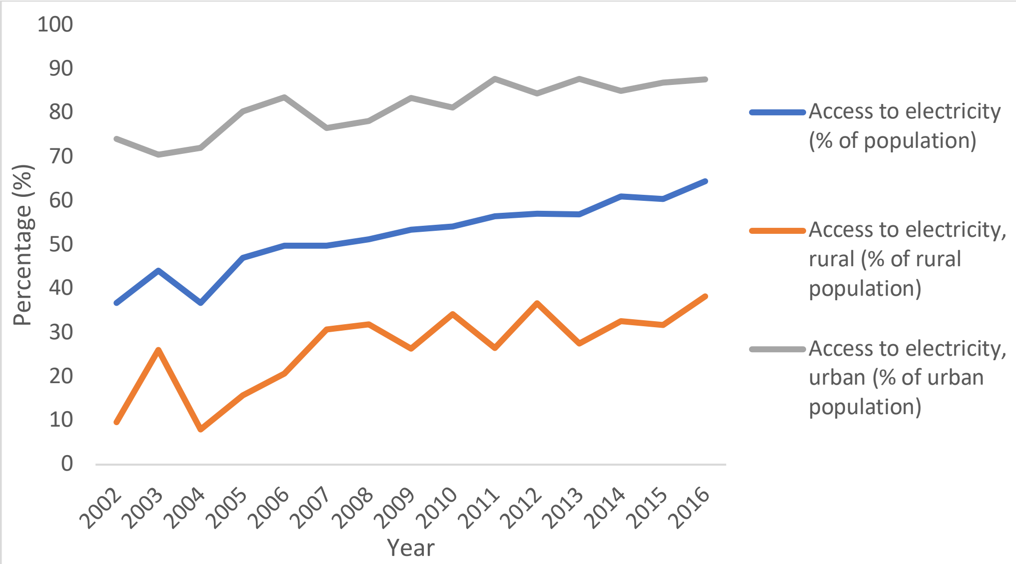

Figure 3: Access to Electricity (World Bank Group, 2017)

Electric energy in Senegal is transmitted and distributed by the Senegalese Electric Company (SENELEC). SENELEC is responsible for about half of the current energy generation in Senegal. The country is dependent on imported oil and diesel for power generation. The imported crude oil is processed and refined at Société Africaine de Raffinage (SAR), Senegal's only oil refinery (Africa-EU Renewable Energy Cooperation Programme, 2016). The current grid system is monopolized by SENELEC, and composed of a 90-kV and a 225-kV grid, which together totals about 13,000 km. The grid mainly supplies urban areas. Isolated networks are utilized to support rural areas (Energypedia, 2018).

In 2010, the total electrical capacity in Senegal was 690 MW, however, only 520 MW of that electricity was available for use as a result of aging equipment. Around 90 percent of this electricity was provided by liquid fuel-based thermal plants with the remainder coming from hydroelectric plants. Approximately, 60 MW of hydroelectric power used in Senegal comes from the 200 MW Manantali hydroelectric power plant at the border with Mali. Additional hydroelectric power is generated from the Felou hydroelectric plant, shared with Mauritania and Mali (United Nations Industrial Development Organization, 2016). By 2018, the installed electric capacity reached 843 MW. The breakdown of electricity sources in Figure 4 identifies a significant increase in the amount of solar power produced compared to 2010 statistics (U.S. Agency for International Development, 2018).

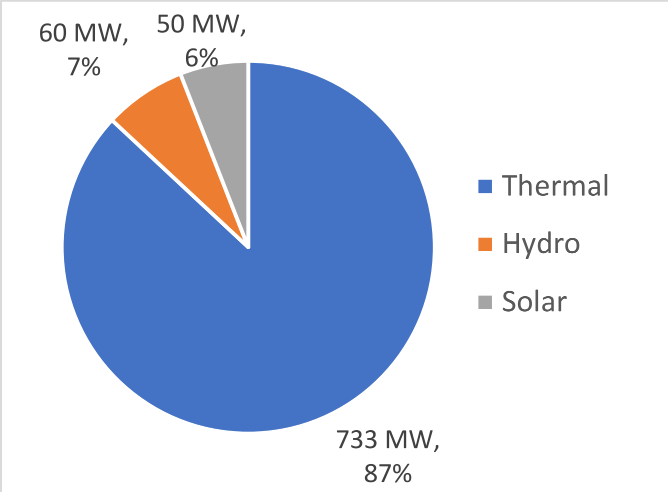

Figure 4: Installed Electricity Capacity (U.S. Agency for International Development, 2018)

Demand for electricity has been growing at a rapid rate of 6.2 percent per year for the last decade (Moser, 2013). To meet the increase in demand, Senegal has been working to utilize newly discovered gas reserves off the coast and install new diesel and coal generation plants. These include a 125 MW coal power station in Sendou and a 52 MW diesel plant. New thermal stations that are able to run on either gas or diesel are expected to be built in the near future. As a result of these new initiatives, generation capacity in Senegal is expected to reach 1600 MW by 2030 (Africa-EU Renewable Energy Cooperation Programme, 2016).

Additionally, the government has proposed several solutions to increase rural electrification rates including expanding the grid, implementing small photovoltaic systems locally, or building privately managed diesel power plants. However, these solutions to not address the feasibility of implementation in regards to small villages with less than 500 inhabitants (Diouf et al., 2013).

1.1.4 Electricity Consumption

In a year, the Senegalese consume approximately 1.4 terawatt-hours of electricity (Purdy, 2012). This is equivalent to each person in the country consuming about 88 kWh of electricity annually (determined by dividing the total electricity consumption by total population). This figure is quite low due to the low electrification rate in Senegal and the lack of universal electricity access in the country. For reference, the annual global electricity consumption per person is 731 kWh and a modern refrigerator uses about 350 kWh per year (Wilson, 2013). In other words, to power a single refrigerator in Senegal the available energy for four people is required. This information highlights the need for increased electricity production and access within the country.

The residential sector in Senegal consumes the majority of the energy supply. In 2016, the residential sector consumed 33 percent of the country's total consumption, as shown in Figure 5. This is due to a high usage of biomass fuels for domestic purposes, such as heating and lighting. Currently, wood fuels dominate Senegal's energy consumption, especially in the residential sector, representing 53 percent of total consumption in the sector (Moser, 2013). Wood fuels are primarily used for household cooking. However, the large consumption of wood has put pressure on the Senegalese forests and led to deforestation in many areas. Due to this agricultural land clearance, 40,000 hectares of forest are lost every year, and the price of firewood and charcoal is more than double the cost it was 10 years ago. In the future, this will lead to energy accessibility problems for the poorest households in the country (Energypedia, 2018).

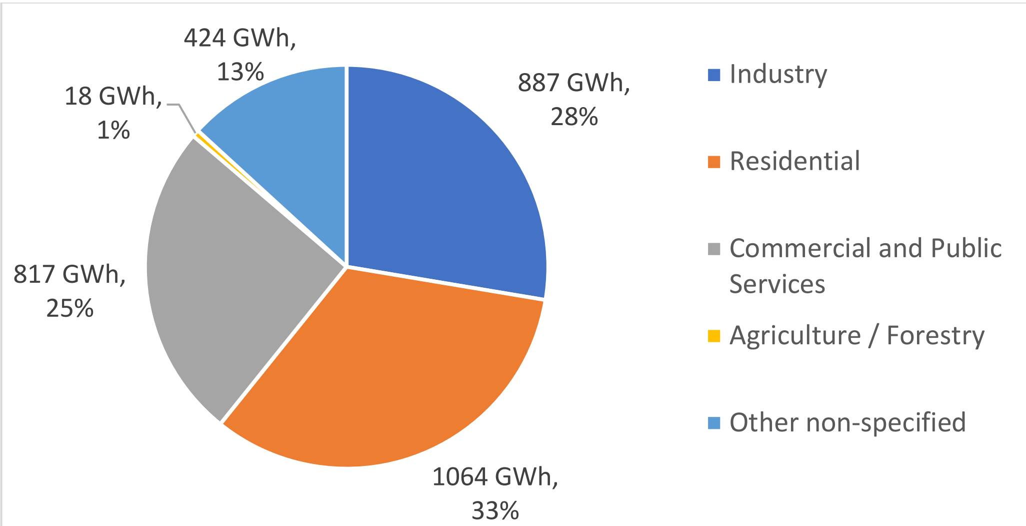

Figure 5: Electricity Consumption (Africa-EU Renewable Energy Cooperation Programme, 2016)

1.1.5 Renewable Energy Potential

This section will explore the significant renewable potential in Senegal. Each section will analyse the current situation and potential to increase the production of solar, wind, hydro and biomass power in Senegal.

1.1.5.1 Solar Power

Senegal experiences 3,000 hours of sunshine per year (Purdy, 2012). The Global Horizontal Irradiation or the total amount of shortwave radiation received from the sun, across most of the country is greater than 2,000 kWh/m^2/year, as seen in Figure 6. The highest solar radiation level in Senegal was observed to be 2,233 kWh/m^2/year. The northern part of the country receives approximately 2,179 kWh/m^2/year of solar radiation, whereas in the centre and eastern parts of Senegal, solar radiation is around 2,160 kWh/m^2/year and 2,127 kWh/m^2/year, respectively (Diaw et al., 2017). The average global daily irradiation in Senegal is approximately 5.43 kWh/m^2/day. These values indicate significant potential for photovoltaic and solar thermal technology projects in Senegal (Africa-EU Renewable Energy Cooperation Programme, 2016).

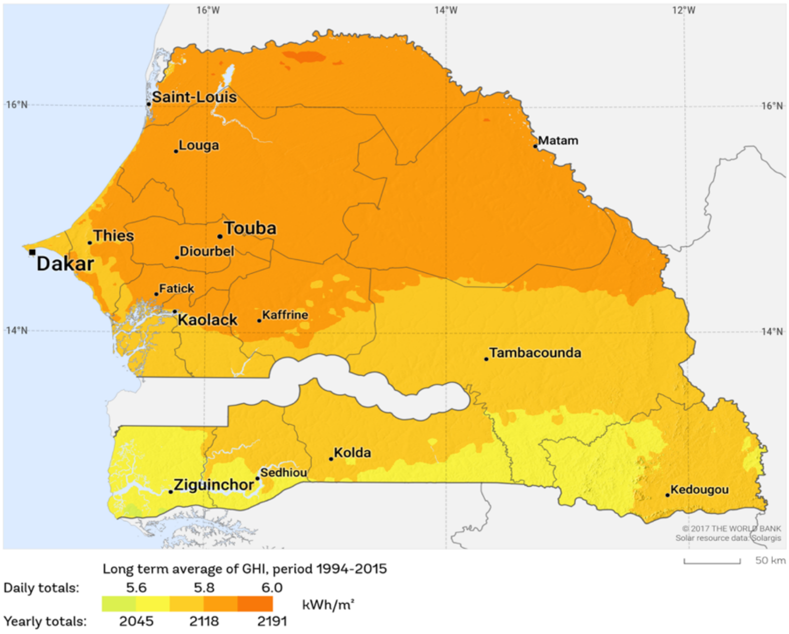

Figure 6: Global Horizontal Irradiation in Senegal (SolarGIS, 2019)

The cost for the components required to produce solar power, such as photovoltaic panels and batteries, has been decreasing as a result of improving technologies (Africa-EU Renewable Energy Cooperation Programme, 2016). However, since the government has previously refused to create tax breaks to incentivize the usage of solar energy, foreign investment has been vital to expand this sector (Purdy, 2012).

Many of the companies currently involved with solar power systems in Senegal are focused on the installation and servicing requirements for subsidized systems (Energypedia, 2018). Currently, solar power is being used to create new mini-grids and improve existing ones (PERACOD, n.d.). The unsubsidized systems market is small (Energypedia, 2018). Thus, due to low purchasing power, market growth is dependent on the expansion of related national and international projects (Africa-EU Renewable Energy Cooperation Programme, 2016). For example, a 30 MW solar park in Santhiou Mékhé, Senegal (northwest of Dakar) has been connected to the grid. Construction began in 2016 at a cost of 46.9 million USD, over half of which is from foreign investors. Funding for this project was made easier due to the International Finance Corporation's Scaling Solar program that provides financing and guarantees for investors to reduce risks associated with funding solar projects in risky environments (Bellini, 2017).

1.1.5.2 Wind Power

The wind power potential in Senegal is concentrated on the north coast between Dakar and St. Louis, where wind speeds range from 3.7 to 6.1 m/s. Inland wind velocities range between 2 to 3 m/s, which is not significant enough to produce wind power. Economic electricity generation can be obtained at wind speeds between 5.3 and 6.3 m/s (Loy Energy Consulting et al., 2004).

Previously, wind power has primarily been used to operate water pumps, with installation promoted by non-governmental organizations with assistance from the European Union (Loy Energy Consulting et al., 2004). The first utility scale wind power project in Senegal, Parc Eolien Taiba N'Diaye (PETN), began construction in 2018. The wind farm will be located in on the coast between Dakar and St. Louis. It is expected to be operational by the end of 2020. There will be 46 wind turbines with 3.45 MW capacity each, and the plant is expected to produce 450,000 MWh per year. The plant is expected to generate 158 MW of power for the grid (Lockhart, 2018)

1.1.5.3 Biomass

The potential for biomass power in Senegal is estimated at 2,900 GWh. The agribusiness by-products, such as peanut shells, cotton stalks and rice husks, and the approximately 3.3 million dry tonnes of agricultural waste are potential sources for on- and off-grid electricity generation (Africa-EU Renewable Energy Cooperation Programme, 2016).

Biomass is currently a significant source of energy in Senegal, however, most of the current biomass sources are not sustainably used or obtained. As mentioned in Section 1.1.3 Current Energy Situation, the primary source of biomass is currently wood, which has been putting pressure on Senegalese forests and causing deforestation (Energypedia, 2018).

1.1.5.4 Hydro Power

Senegal currently imports hydropower from the hydro power plants, Manantali and Felou, located in Mali. The Manantali plant produces 200 MW of hydro power by partially exploiting the estimated 1,200 MW of hydroelectric potential of the Senegal River (Moser, 2013). However, only 60 MW of the hydro power from the Manantali plant is utilized by Senegal, the rest is consumed by neighbouring countries (United Nations Industrial Development Organization, 2016). Additionally, the Gambia river has a hydro power potential of 200 MW that remains untapped (Africa-EU Renewable Energy Cooperation Programme, 2016).

1.1.6 Other Potential Energy Sources

This section will explore the potential of other possible energy sources in Senegal. Each subsection will analyse the current situation and potential to produce power through fossil fuels, marine energy technologies, and nuclear power.

1.1.6.1 Fossil Fuels

Fossil fuels, including oil and gas, have traditionally been imported to Senegal and represent 87 percent or 733 MW of the current installed capacity. Resources have recently been discovered in Diamniadio, Sangomar, Casamance, and off the Atlantic coast. Exploration contracts for extraction, refining and delivery have already been issued (Tchanche, 2017).

1.1.6.2 Marine Energies

Senegal has 531 km of coastline on the Atlantic Ocean, where there is potential to produce electricity using marine currents, salinity and thermal gradients, and sea winds. Technologies to convert these energy sources into electricity are currently under development, for example, tidal turbines and tidal power plants. However, there is currently limited to no research related to evaluating this potential in Senegal. Thus, a future path for research could be analyzing the availability, predictability, depth, and distance to coast of this potential (Tchanche, 2017).

1.1.6.3 Nuclear Power

Due to a lack of uranium deposits located in Senegal and the trend of policies towards favouring more environmentally friendly energy sources, this is not a feasible option to pursue.

1.1.7 Power Market Development

Before the 1980s, all domestically produced energy came from thermal plants. When hydroelectric plants were built along the Senegal River, it created cheaper and more accessible electricity that could be purchased from other countries. Despite the diversification in electricity sources, access has still been unstable, especially during the rainy season. Electricity costs have continued to increase but power outages have remained a daily occurrence. To reduce the number of power outages, the government promised to create energy sector reforms and increase capacity, as well as invest in alternative energy sources (Purdy, 2012).

The Ministry of Energy and Renewable Energy Development in Senegal is responsible for all significant energy decisions, especially those related to on-grid electricity. The ministers formulate, organize and set the objectives, policies, strategies and direction for the entire energy sector in Senegal, including the sub-sector for renewable energy (Africa-EU Renewable Energy Cooperation Programme, 2016).

Due to an institutional reform in 1998, the electricity sector in Senegal was split into three segments: SENELEC, ASER and CRSE.

SENELEC is a state-owned national utility provider in Senegal. As mentioned in Section 1.1.3 Current Energy Situation, the Senegalese Electric Company (SENELEC) has a monopoly on the transmission and distribution of electric energy in Senegal. It is also responsible for approximately half of total energy generation (Africa-EU Renewable Energy Cooperation Programme, 2016). It lacks access to funds for investments to meet increasing demand and has an inefficient organizational structure (Energypedia, 2018). Thus, it is unable to invest in alternative energy plants and maintenance for aging assets (Moser, 2013). Additionally, since the majority of its production is from thermal sources, SENELEC's revenue is negatively impacted by increasing oil prices. This indicates vulnerability to unstable oil prices and high production costs (Sanoh et al., 2012).

The Agence Sénégalaise d'Electrification Rurale (ASER), also known as the National Rural Electrification Agency, was founded to focus solely on rural electrification and take the responsibility of increasing rural electrification rates from SENELEC (Moser, 2013). It provides support to local, national, and international initiatives for rural electrification (PERACOD, n.d.). ASER is financed by international donors and the Senegalese government. It finances 70 percent of rural electrification projects and manages them for private investors (Energypedia, 2018).

The Commission de Régulation au Secteur de l'Électricité (CRSE) is the electricity regulatory board in Senegal. It is an independent authority responsible for the regulation, production, transportation, distribution and sales of electric energy. CRSE was created to ensure impartial treatment for all stakeholders. It also does consulting work for the Ministry of Energy. CRSE obtains funding through licensing and appraisal fees. (Africa-EU Renewable Energy Cooperation Programme, 2016).

Through the 1998 Electricity Law, Senegal began allowing private sector participation into their electricity industry. The law encourages private sector investment in electricity generation and distribution (Moser, 2013). Independent power producers in Senegal are challenged with technical difficulties, grid instability, and variable fuel quality, reducing their electricity output. The government has been working to resolve these issues as they are relying on private investment production to meet the increasing demand (Africa-EU Renewable Energy Cooperation Programme, 2016).

A major element in this reform was decentralization, where nongovernmental organizations and local governments were significantly involved in implementation. This is beneficial for the renewable energy sector, as it has been suggested that despite the government's commitment to increasing solar energy capabilities, the lack of progress has been a result of not wanting to create competition for SENELEC. In electrified areas, it was illegal to utilize solar energy for anything except for back up purposes. Despite the high costs for solar power materials, the government refused to promote it through tax breaks. Since these reforms were put in place, the government has implemented tax incentives making solar energy more affordable and has allowed electricity to be purchased from private suppliers (Purdy, 2012).

1.1.8 Key Findings

The key findings from this section are summarized in the following paragraphs.

Senegal is a West African country dependent on imported oil and diesel for power generation. Previous research has identified that there is significant solar, wind, biomass, and hydro power potential in Senegal that has yet to be utilized. As of 2016, the urban and rural electrification rates were 87.7 and 38.3 percent, respectively. Electricity demand in Senegal is increasing at a rate of 6.2 percent annually.

SENELEC is a state-owned national utility provider that has a monopoly on transmission and distribution of electricity. However, it lacks access to funds to create investments to meet the increasing demand and stabilize the grid. ASER is the agency responsible for increasing rural electrification rates and is primarily financed by international donors.

Since Senegal is primarily dependent on foreign investors to meet the increasing electricity demand, the unfavourable investment conditions are a concern. There are several key challenges to be faced to increase the electrification rates in Senegal, including issues related to inefficient technologies, lack of regulatory framework, weak financial structures, and a low-density distribution grid. Additionally, approximately half of the rural population live in villages with less than 500 people, which require high investment cost, but result in low revenues, which makes them of little interest to private investors (Energypedia, 2018).

1.2 Paper Structure

This paper analyzes the physical and economic potential of different electricity sources in Senegal in terms of feasibility of powering remote villages. Three different scenarios will be reviewed including best case scenario, most likely to occur, and business as usual.

Section 2 discusses relevant literature related to this topic, including existing energy policies, energy demand, and physical energy potential of different resources.

Section 3 identifies the research question for this paper and explains the methodology utilized to calculate the physical and economic potential, as well as the levelized cost of electricity for the different technologies analyzed.

Section 4 summarizes the results from the calculations and states all assumptions specific to this paper. Additionally, the implications of the results on the energy industry are assessed.

Section 5 discusses the benefits and challenges related to each energy source and the three potential paths to electrification for Senegal.

Section 6 recognizes the limitations of the results, concludes the paper, and identifies the next steps for future research.

2. Literature Review

The objective of this paper is to analyze the potential energy sources in Senegal by comparing three potential scenarios for increasing rural electrification: best case, most likely, and current situation. Before comparing energy sources, existing literature on the topic must be examined. The following sections include a review of literature on energy policies, energy demand, and the physical potential of energy sources in Senegal. Additionally, the gap in literature that this paper seeks to fill will be identified at the end of this section.

2.1 Energy Policies

Kofi Adom et al. (2012) researched the relationship between carbon dioxide emissions, economic growth, industrial structure, and technical efficiency for three African countries, including Senegal, to determine the policy implications. For Senegal, they determined that carbon dioxide emissions were not a factor in limiting economic growth, as economic growth leads to an increase in carbon dioxide emissions. Thus, establishing strong energy efficiency techniques can reduce carbon dioxide emissions when the economy grows. This is also beneficial as it decreases the negative environmental effects of carbon dioxide emissions. The authors state that policies related to reducing carbon dioxide emissions should focus on improving efficiency and modifying industrial structure, which can be enabled through technology and renewable energy investments (Kofi Adom et al., 2012).

2.2 Impact of Energy Demand on Cost

The literature reviewing the impact of energy demand on cost is categorized into two sections: the demand for gasoline when prices fluctuate, and the costs related to increasing electrification rates.

2.2.1 Gasoline Demand

Sene (2012) analyzed the gasoline demand in Senegal between 1970 and 2008 to determine the impact changes in world oil prices had on Senegal. This topic is relevant because increasing oil prices are often associated with unemployment, electric supply shortage, and increased food prices, especially in rural areas. Both short- and long-term elasticities of demand in terms of income and gasoline prices were studied (Sene, 2012).

Senegal is a non-oil producing country, with a weak economy, thus it faces challenges when adjusting to oil price shocks. The demand for oil is a function of economic activity, specifically GDP and income. Additionally, an increase in population will result in an increase in demand for gasoline, which could cause prices to rise. The long-term demand for gasoline is dependent on how favourable it is switch to other energy sources. Additionally, the slow development of new technological processes indicates that oil demand in Senegal will most likely remain important for the near future. The author concluded that the demand for gasoline in Senegal is inelastic based on income and cost for both short- and long-term runs. This indicates that consumer purchasing habits remain the same regardless of oil price changes (Sene, 2012).

2.2.2 Costs Related to Increasing Electrification Rates

Sanoh et al. (2012) analyzed the cost drivers and implications related to increasing electricity access. The authors believe that if the current electrification strategies remain the only options, expansion to new areas will be slow due to low load factors, high investment costs, and little demand. Thus, the objective of their paper is to provide policy guidance for local and national planners. In Senegal, they compared electrification costs in Leona, a 400 km^2 local area in northern Senegal, to the electrification costs for the entire country. They looked at three scenarios for increasing electrification, including extending the grid, diesel generators and solar power. Each scenario was compared based on its capital costs, power delivered, and recurring costs. They determined that between 20 to 50 percent of the population without access to electricity live in areas where expanding the grid is more cost effective than implementing decentralized energy producing technologies. However, the cost and access to electricity fluctuates due to demand, and capital costs of grid technologies, such as transformers and Medium Voltage lines (Sanoh et al., 2012).

2.3 Physical Energy Potential

Literature focused on the physical energy potential of solar and wind power are analyzed in the following sections.

2.3.1 Solar Power Potential

2.4.1.1 Estimation of Solar Potential in Senegal

Diaw et al. (2017) determined that the north and west part of Senegal have the highest radiation levels in the country. They recorded a value of 2,179 $kWh/m^2/year$ in the northern part and

2,233 kWh/m^2/year in the western part of the country. The solar potential in Senegal was calculated to be 63,919 MW, which the authors believe can meet a major part of the energy demand in Senegal (Diaw et al., 2017).

The authors utilized the NASA Surface Meteorology and Solar Energy database to determine the global horizontal irradiance levels for 65 locations in Senegal. Through the exclusion of airports, railroads, roads, residential, protected, and sloped areas, they determined that approximately 42,000 km^2 or 21 percent of land in Senegal is available and suitable for solar power development. To determine the available solar power potential, they assumed that only 3 percent of available land is utilized. The available area for PV varies across the regions in Senegal due to population density and vegetation. From their results, the authors determined that Tambacounda (located in the middle of the country) has the largest available area due to flat landscape, and thus the largest solar power potential. The authors note that despite excluding airport, railroad and residential areas, these areas can be still be used by implementing rooftop solar panel systems (Diaw et al., 2017).

2.4.1.2 Solar Power Potential Using a Service-Based Cost Model

Diouf et al. (2013) investigated the potential for implementing a service-based fee model for electricity access in rural areas. The authors believe that centralized solutions and grid expansions could be sufficient for large villages, however, this would not be a feasible option for small villages due to high cost. They researched the potential for individual solar energy systems to increase access to electricity in rural areas, through a two-year pilot project in Couré Mbatar, Senegal (Diouf et al., 2013).

From their pilot project, the authors determined that the average family in Couré Mbatar spent 9 USD per month on energy expenses. The photovoltaic systems they implemented retailed at 180 USD each, and provide lighting and cell phone charging. They charged a monthly fee of 6 USD for the service of cell phone chargers and two lamps. Their project will break even in 2.5 years. The authors clarify that in reality, the total cost of the system for a fee-for-service model would be higher due to operation, maintenance and insurance costs, therefore, increasing the return on investment time frame from 2.5 to 3.75 years (Diouf et al., 2013).

The authors recommend individual photovoltaic home systems for small villages as they can guarantee high quality electricity service at low prices and the distribution problem will be avoided. They also highlight the difficulty in expanding fee-for-service models without a further influx of capital. They state that the feasibility of implementing fee-for-service models at a large scale requires government commitment to subsidize and protect the systems for many years. However, they believe that rural electricity access can be a sustainable business model as long as the proposed service costs less than or equal to the current expenses for candles, kerosene lamps, and phone charging fees.

2.3.2 Wind Energy Potential

Ould Bilal et al. (2013) researched the potential for wind energy to generate electricity on Senegal's northwestern coast. They looked at the wind potential in eight areas in Senegal, Kayar, Potou, Gandon, Sakhor, Sine Moussa Abdou, Botla, Dara Andal, and Nguebeul. For reference, the location of the eight sites can be seen in Figure 7.

Figure 7: Location of eight wind potential sites evaluated (Ould Bilal et al., 2013)

For each site, wind speed data was collected for a year and used to calculate the annual mean wind speed and the power density. Annual mean wind speed and power density across regions varies from 3.10 m/s to 5.28 m/s and 30.05 W/m^2 to 120.01 W/m^2, respectively. The highest monthly wind speeds were recorded in April and May, and the lowest were observed in September and October (Ould Bilal et al., 2013).

The authors analyzed the suitability of six different wind turbines, both large and small, from several manufacturers to determine the best option for these locations. For each wind turbine, energy output and capacity factor were calculated based on placement in each region. Wind turbines with large output energy and capacity are the best for electricity applications, where the capacity factor of a wind turbine is the actual production relative to theoretical production.

For rural locations with no access to the grid, high capacity wind turbines are required to allow for longer operation and ensure the highest quantity of output is available to meet the local demand. Wind power can be used for stand-alone or off-grid systems but requires batteries, a charge controller, and power conditioning equipment to convert the electricity into usable power. Excess energy can be stored in batteries, compressed air storage and hydrogen fuel cells. For grid connection, wind turbines with the ability to generate a significant amount of energy output are the best option (Ould Bilal et al., 2013).

2.3.3 A Photovoltaic Panel versus a Wind Turbine

The objective of the Thiam (2011) paper was to prove that solar power technologies are better than wind technologies to power remote rural areas without access to the grid, thereby reducing the poverty level. The author considered both a photovoltaic panel and a wind turbine for implementation in three Senegalese regions, Diourbel, Fatick and Kaolack. To compare technologies with the current system, a life cycle cost analysis was implemented. External and environmental costs were also included. To decide on the best solution, the levelized electricity cost (LEC) was used, which determines the cost in kWh of electricity for each technology. Based on their calculations, the LEC and life cycle cost was the same for both photovoltaic and wind technologies in two of the three regions, with solar power being the better option for one region. Thus, it was concluded that photovoltaic technology is a viable solution to increase access to electricity and reduce poverty (Thiam, 2011).

2.4 Gap in Literature

From this literature review, it can be seen that the solar and wind power potentials in Senegal have previously been evaluated. However, the available energy and costs related to each potential energy source are not identified under the same conditions. Thus, using the existing information it is difficult to determine the best option for rural electrification in Senegal. It is also evident that published literature proposes conflicting solutions on how to proceed with rural electrification in Senegal.

This paper seeks to evaluate the potential for solar, wind, biomass, and hydro power in Senegal and the ability to harness this power to electrify rural locations. Through calculations and data analysis, recommendations will be provided on which energy sources could be used to increase rural electrification rates in Senegal.

3. Methodology

This section is split into two parts: Physical and Economic Potential, and Electricity Generation Costs. In the first part, the methodology used to determine the physical and economic potential for solar, wind, biomass, and hydro power in Senegal is described. A brief explanation of how each technology works is also included. In the second part, the procedure used to determine the Levelized Cost of Electricity (LCOE) and complete a cost benefit analysis is detailed. Additionally, all general assumptions will be stated throughout the section. All results are summarized in Section 4 Results.

3.1 Physical and Economic Potential

3.1.1 Solar

Solar power is harnessed using technologies, such as photovoltaic (PV), solar heating and cooling (SHC), and concentrating solar thermal (CST), that convert sunlight into usable forms of energy. For the purposes of this report, the characteristics of PV technology will be implemented in the electricity potential calculations, as it is the most advanced solar power technology. PV technology uses a photovoltaic cell to convert the solar energy into direct current electricity (Péréz-Denicia et al., 2017) .

To calculate the electricity potential of solar power in Senegal, the solar irradiation levels are required. Solar irradiation levels have the units of kWh/m^2 per day and are given as a yearly average. The potential is calculated by multiplying the daily irradiation level, I, by the area, A, that experiences the irradiation. The values for different locations are summed to determine the total solar power, P_{solar}, that Senegal receives daily, as shown in Equation 1 below.

$$P_{solar} = \Sigma\, I * A \tag{1}$$

The previous equation assumes that 100 percent of the power that reaches the country is able to be converted into energy. It also assumes that Senegal experiences 15 hours of direct sunlight every day. However, this is not always the case due to inefficiencies in converting sunlight into electricity, unsuitable land, and weather changes.

Majority of solar panels have an efficiency range from 15 to 17 percent. The highest efficiency solar panel on the market, SunPower in 2019 has an efficiency of 22.2 percent (Aggarawl, 2019). For the purposes of this paper, we will use the lowest efficiency rating to depict the worst-case scenario. The most efficient solar panels typically have the highest costs, which is not a realistic purchase in this situation. Diaw et al. (2017) identified that approximately 21 percent of land in Senegal is suitable and available for solar power projects due to vegetation, hills, residential areas, and railroads. Thus, the available solar power potential in Senegal can be calculated using Equation 2 below.

$$P_{available\_solar} = \Sigma\, I * A * 15\% * 21\% = P_{solar} * 3.15\% \qquad (2)$$

The economic potential was determined by omitting the regions with solar irradiation levels below 6.00 kWh/m^2/day. This was done to maximize the energy production for the lowest cost. If the same solar panel was used in a region that experiences above 6.00 kWh/m^2/day of solar irradiation, the LCOE per kWh will be lower than in a region that experiences below 6.00 kWh/m^2/day of solar irradiation. Additionally, in areas of high solar irradiation more energy will be available for conversion, thus less solar panels and space would be required to meet a production target than in areas of low solar irradiation.

3.1.2 Wind

Electricity from wind is produced through the conversion of kinetic energy into electrical energy using wind turbines connected to a generator mounted on a pole (Tchanche, 2017). Wind power is dependent on the velocity, density, and volume of air in the area of interest. From the definition of kinetic energy, Equation 3 can be derived, where ρ is the density of air, A_t is the rotor swept area of the turbine ($A_t = \pi r^2$), and v is the velocity of air.

$$P_{wind} = \frac{1}{2}\rho A_t v^3 \qquad (3)$$

To determine the power output of the wind turbine, the efficiency of the wind turbine must be considered, as seen in Equation 4. The power coefficient, c_p, represents the ratio of power extracted from the turbine to the total wind power or conversion efficiency. This dimensionless value typically ranges from 0.25 to 0.45. The maximum possible conversion efficiency for a wind turbine is 0.59, it is commonly referred to as the Betz Limit (Kalmikov & Dykes, 2017). The Betz Limit shows that a wind turbine cannot convert more than 59 percent of the kinetic energy of the wind into mechanical energy (Kidwind Science, 2019). Since wind turbines are not all able to work at the maximum efficiency, it is assumed for this paper that the wind turbine used in the potential energy calculations can convert 60 percent of the Betz Limit into electricity. Thus, the wind turbine is able to convert 35 percent (60%*59%) of available wind energy into electricity. This coefficient of power (c_p) of 35 percent falls within the expected range of 35 to 45 percent for a good wind turbine and it continues the trend of calculating a conservative estimate of power potential.

$$P_{turbine} = \frac{1}{2}\rho\pi r^2 v^3 c_p = P_{wind} * c_p \quad (4)$$

The constants used to calculate the wind power potential from the turbine are summarized in Table 1 below.

Table 1: Summary of Constants used in Wind Power Potential Calculation

Density of Air (ρ)	1.225 kg/m^3
Turbine Area (A_t)	4.52 m^2
Power Coefficient (c_p)	35%

The density of air at sea level was implemented in these calculations. It should be noted that the density of air decreases with elevation. The impact of the change in density at higher elevations on wind power would be offset by higher wind speeds. To determine the number of wind turbines that could be installed in Senegal, the same assumption on land availability from the solar power calculation was used. Thus, only 21 percent of the land area in Senegal is assumed to be available for wind turbine installation.

The economic potential was computed by reducing the available area for wind turbine installation. It has been determined that the regions in Senegal with the highest wind speeds are located along the coast, thus the inland regions were omitted from the economic potential as it would be more profitable to install wind turbines in areas with higher wind speeds as it would generate more power.

3.1.3 Biomass

The main sources of biomass energy come from animal, agriculture, and forest residues, as well as urban waste (Karaj et al., 2009). These biomass sources contain energy, which can be released as heat when burned or converted into liquid biofuels or biogas to be burned as fuels.

Due to the availability of data, the biomass energy potential in this paper will be calculated based on agricultural residues only. Agricultural residues are the crop remaining in the field after the main product is collected. The crop residues that will be included in this calculation come from maize, millet, potato, rice, and sorghum crops.

Equation 5 is used to calculate the physical potential from residuals. The calculate the physical potential the following crop characteristics are multiplied: yearly crop production (p), residual energy value (REV), dry ratio (DR), and residue to crop ratio (RPR).

$$P_{biomass} = p * REV * DR * RPR \qquad (5)$$

The yearly crop production (p) is the weight of crops produced annually in kg. The residual energy value (REV) is the energy produced per ton of residuals measured in GJ/ton. This value was found to be 7.9 GJ/ton for maize and 7.5 GJ/ton for sorghum. Due to lack of information available, the residual energy value for the remaining crops was assumed to be 7.5 GJ/ton, as they share similar properties with sorghum. The dry ratio (DR) is used to convert the fresh weight to dry weight of the crops. The residue to crop ratio (RPR) is a conversion factor used to determine the crop residues remaining after crop harvest.

To determine the economic potential of biomass power from crop residuals, the collection rate (CR) and efficiency (E) need to be considered. Since 100 percent of residuals would be virtually impossible to collect, a collection rate (CR) must be taken into account. A collection rate of 50 percent is assumed for this calculation because it is the rate at which residues can be removed that scholars have identified no significant impacts on soil fertility or erosion would occur (Fischer et al., 2007). Additionally, the power plant will be unable to convert 100 percent of the crop residuals into electricity, thus the conversion efficiency must be included. Biomass energy has a high conversion efficiency of 75 to 80 percent for heat or combined heat and power production, whereas for electricity generation the conversion efficiency is only 20 to 25 percent (Biomass Energy Resource Center, 2009). For the purposes of this paper, it will be assumed that the biomass will be used to produce heat or combined heat and power to ensure optimal use of the resource. Thus, an efficiency of 75 percent was assumed for the calculations. Equation 6 was used to determine the economic potential of biomass in Senegal.

$$P_{available\_biomass} = P_{biomass} * CR * E \qquad (6)$$

3.1.4 Hydropower

The production of hydropower requires streams of water to fall from a certain height at a high enough flow rate to rotate the hydraulic turbines (Tchanche, 2017). Theoretical hydropower potential is defined as the total power produced if 100 percent of the mean annual discharge is used (no losses or flow constraints) and the full head of the river is used. The amount of power produced is dependent on the head and flow available on location. It can be calculated using Equation 7 below, where m is the mass flow rate (kg/s), g is the gravitational constant (9.81 m/s^2), and H_{net} is the net head (m).

$$P_{hydro} = mgH_{net} \tag{7}$$

Head is the difference in height from the entry (source of water) and exit point (turbine location) for water in a hydro system. This difference in height is directly proportional to the amount of power produced. The minimum head height is around 2 metres, but a larger head results in more power. The net head is the total head measured at the site multiplied by the efficiency. In this case head losses are assumed to be 10 percent. Thus, net head can be calculated using Equation 8 below.

$$H_{net} = H_{gross} * 90\% \tag{8}$$

The economic potential of hydro power in Senegal was determined by multiplying the physical potential by the system efficiency, η. The system efficiency is the product of the efficiencies of the turbine, drive system, and generator. Based on research, typical efficiencies for a hydro system are 85 percent turbine efficiency, 95 percent drive efficiency, and 93 percent generator efficiency resulting in a total system efficiency of approximately 75 percent (Renewables First, 2015). The economic potential for hydropower can be calculated using Equation 9.

$$P_{available\_hydro} = P_{hydro} * \eta \tag{9}$$

3.2 Electricity Generation Costs

The Levelized Cost of Electricity (LCOE) is a static indicator that is widely used to compare different technologies on a per unit of electricity basis. It represents the average cost to provide electricity over the lifetime of the plant for a given capacity factor. The LCOE is calculated by dividing the sum of all plant-level costs by the amount of electricity the plant can produce after discounting (IEA et al., 2015).

It reflects technology risks but is independent of project risks in different markets. Thus, it is closest to the actual investment cost for electricity production in regulated monopoly markets (IEA et al., 2015). Additionally, for renewable technologies, the LCOE varies by project, technology, and country due to capital and operating costs, technological efficiency and performance, and the available renewable energy resource (IRENA, 2018)

There are several assumptions and limitations with this methodology that must be taken into consideration before comparing technologies. These assumptions and limitations will be discussed in section: 3.2.2 Assumptions and 3.2.3 Limitations.

3.2.1 Methodology

The methodology used to calculate the levelized cost of electricity was taken from the 2015 Projected Costs of Generating Electricity report by the International Energy Agency, Nuclear Energy Agency, and the Organization for Economic Co-operation and Development. In this report, LCOE is defined as the electricity tariff rate required for an investor to break even on a project after paying back all equity and debt investors.

Equation 10 identifies the relationships between the variables, a detailed explanation of these variables can be found in Table 2. The left-hand side of the equation represents the discounted sum of benefits whereas the right-side shows the discounted sum of costs from the start of construction to the end of disassembly, including the discounted value for future waste management costs. It can be seen that the sums of the present value of the discounted revenues and the present value of discounted costs are equivalent, this forms the basis for the LCOE calculation. The equation of the two sides is possible due to two main assumptions that are detailed in the following Section 3.2.2 Assumptions.

$$\Sigma P_{MWh} * MWh * (1+r)^{-t} = \Sigma[(Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t) * (1+r)^{-t}] \quad (10)$$

Table 2: Variable explanations for Equation 10 (IEA et al., 2015)

P_{MWh}	The electricity tariff or the lifetime costs to the supplier for electricity.
MWh	The total amount of electricity produced in MWh, assumed to be constant.
t	The year production sale or cost payment occurs.
$(1+r)^{-t}$	The discount factor for year t (which reflects payments to capital).
$Capital_t$	The total capital construction costs for year t.
$O\&M_t$	The operation and maintenance costs for year t.
$Fuel_t$	The fuel costs for year t.
$Carbon_t$	The carbon emission costs for year t.
D_t	The decommissioning costs for year t, including dismantling and waste management costs.

Since the supplier's lifetime cost for electricity, P_{MWh}, is assumed to be constant it can be defined as the levelized cost of electricity and the electricity tariff rate required for an investor to break even. Thus, Equation 10 can be rearranged into Equation 11 as seen below.

$$LCOE = P_{MWh} = \Sigma(1 + \mathrm{r})^{-\mathrm{t}} * \left[\frac{Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t}{\mathrm{MWh}}\right] \quad (11)$$

Equation 11 is used to determine the levelized cost of electricity over a given lifespan based on the capital, operation, maintenance, fuel, carbon, and decommissioning costs. The entire equation is summed from the start of the construction period to the end of dismantling. It should be noted that the total amount of electricity being produced is not discounted, but the economic value of this electricity is discounted.

3.2.2 Assumptions

Many assumptions are made in this model to harmonize the data to enable comparison between different technologies and locations. The general assumptions made to calculate the LCOE for all technologies will be detailed below. Specific assumptions made for each technology will be described in the corresponding Results section.

To set the LCOE and electricity tariffs to be equivalent as described in the previous section, the following two assumptions were made:

1. The real discount rate, r, which is used to discount costs and benefits is stable and constant over the lifetime of the project. In this methodology, a 3 percent discount rate represents the social capital cost, a 7 percent discount rate corresponds to the market rate in restructured or deregulated markets, and a 10 percent discount rate is used to reflect the investment in a high-risk environment. These given rates were identified to allow for a cost comparison of different technologies in diverse regions.

2. The electricity tariff, P_{MWh}, is assumed to be constant and stable throughout the project lifetime. All output is sold at this tariff, at the assumed capacity factor.

The following key parameters including technology lifetimes, fuel and carbon costs, were assumed and kept consistent as they significantly impact the result of the calculation. If they were not kept consistent, it would be difficult to determine the national electricity generation conditions. For example, if different carbon costs were used for LCOE calculations in a single region it would be difficult to compare results and understand electricity generation costs in the given market.

3.2.2.1 Technology Lifetime

Table 3 identifies the expected construction periods and lifetimes for each technology used. These values were used as the default value in this scenario as national data was unavailable. Longer construction periods correspond to longer technological lifetimes. In practice, these longer construction periods result in a longer period of time before income is generated. This is a key consideration for the investors when deciding which technology to implement.

Table 3: Expected construction periods and lifetimes for each technology (IEA et al., 2015)

Technology	Construction Period	Lifetime
Solar, wind and biomass plants	1 year	25 years
Natural gas power plant	2 years	30 years
Coal and geothermal power plants	4 years	40 years
Nuclear power plants	7 years	60 years
Hydropower	7 years	80 years

3.2.2.2 Costs

Capital Costs

The capital costs were determined as $/kW based on research for the region.

Operation and Maintenance (O&M) Costs

The O&M costs for each plant were assumed to be 4 percent of the installed costs. A variety of studies have indicated ranges for O&M costs between 2 to 6 percent for renewable plants.

Fuel Costs

Fuel costs are specific for each region. They were not used in this paper, as the LCOE calculation for renewables does not require fuel costs.

Carbon Emission Costs

As an explicit carbon price is not stated for Senegal, 30 USD / tonne of CO_2 was used.

Decommissioning Costs

The decommissioning and waste management costs are dispersed over ten years at the end of the lifetime of a plant for all technologies. The remaining equipment and material value for fossil fuel plants is assumed equivalent to tear down and restoration costs, thus resulting in zero net costs for decommissioning. For solar panels and wind turbines, equipment is replaced at the end of its lifetime instead of decommissioned, the value of the new installation is predicted to be 20 percent of the initial capital investment. In this case, national values were not available thus the values in were used.

Table 4: Decommissioning Costs (IEA et al., 2015)

Nuclear energy	15 % of overnight costs
All other technologies	5 % of overnight costs

3.2.3 Limitations

Despite the usefulness of being able to compare different technologies using the LCOE, there are several limitations of this framework that must be taken into account.

Comparing variable renewable technologies, such as solar and wind, with traditional energy sources, such as natural gas and nuclear energy is challenging due to the variable nature of renewables. The electricity variability of renewables impacts the ability to balance the system. Any deficits production must be compensated through other methods of electricity generation. The requirement to constantly balance supply and demand leads to system costs. System costs impact all technologies in terms of grid connection and location. However, within the levelized cost of electricity calculations, only technical system costs are taken into consideration as experts are unable to agree on how much the system costs are as they vary with structure, system setup, and quantity of renewables that cannot be used on demand. Additionally, system costs are sometimes paid for by the power plant developer and sometimes included in the costs for the whole electricity system (IEA et al., 2015).

Another limitation of this framework stems from the LCOE calculation measuring the cost for a technology at plant level. The cost is isolated around the plant indicating that costs resulting from interactions between the power plant and the remainder of the electricity system are not taken into consideration. Additionally, the implications of integrating a new technology into the system are not represented using this methodology (IEA et al., 2015).

In terms of renewable technologies, the LCOE is useful to indicate the cost and competitiveness trends. However, it does not include external benefits to using renewable technologies, such as financial support and government incentives. Renewable technologies lead to the reduction of negative environmental effects, including air pollution and environmental contamination. These technologies also avoid using fossil fuels, which are volatile in price and negatively impact the environment. Unfortunately, these benefits are not represented in the LCOE as they are difficult to quantify. Other potential sources of revenue are also not considered in the LCOE calculation (IRENA, 2018).

4. Results

This section summarizes the results of the electricity potential and cost calculations for Senegal, where the physical potential is the total available resource in the country and the economic potential is the amount of potential that can realistically be captured. The following sections will indicate the results of the calculations and detail any assumptions made.

4.1 Physical and Economic Potential

Table 5 summarizes the results from the physical and economic potential calculations.

Table 5: Summary of Physical and Economic Potentials in Senegal

	Physical Potential Power (MW)	Economic Potential Power (MW)
Solar	2,339,308	22,667.32
Wind	2,634	782.02
Biomass	0.90	0.34
Hydro	5.96	4.47

For reference, 1 megawatt (MW) of power is enough to power one of the following:

- 100,000 light-emitting diode (LED) lights based on regular usage or
- 24,857 refrigerators or
- 9 Nissan Leaf vehicles or
- 2,500 homes based on a global average household electricity consumption of 3,471 kWh per year or
- 15,263 homes based on the annual household consumption in the West African country Nigeria.

4.1.1 Solar

For the solar power potential calculations, it was assumed that the size of area experiencing each Global Horizontal Irradiation Level as determined by Diaw et al. (2017) in Table 6 is a reasonable representation of the actual area. They determined the total area to be 198,588 km^2, which is greater than the actual area of Senegal, 196,712 km^2. This discrepancy occurred during map processing and was explained as a result of excess area at country borders. Additionally, through their map processing they identified that only 21 percent of land in

Senegal is available or suitable for solar power plants due to hills, vegetation, residential areas, and railways. This information was used to determine available area for solar panels.

Table 6: Area corresponding to GHI Ranges (Diaw et al., 2017)

GHI radiation (kWh/m²/ day)	Area (km²)
5.00 to 5.40	0
5.41 to 5.50	148
5.51 to 5.60	8,112
5.61 to 6.00	188,532
> 6.01	1,796

From the results, it can be seen that the total physical solar power potential calculated for Senegal differs from the results identified in Section 2.4.1.1 Estimation of Solar Potential in Senegal from Diaw et al., 2017. Despite using the same initial data, different assumptions were made when calculating the final physical potential. In Diaw et al., 2017, they assumed that 1 km^2 can produce 50 MW of electricity. In this paper, the lowest efficiency of a solar panel and the minimum radiation value was used to calculate a conservative estimate of power potential.

4.1.2 Wind

The data from Ould Bilal et al. (2013) as described in Section 2.3.2 Wind Energy Potential was used to determine the average wind speed in Senegal. The authors measured the average monthly wind speeds at eight different meteorological on the coast of Senegal for a year. All sites studied in this report are located along the coast. To calculate the results for this report, the yearly average wind speeds at each site were averaged to determine the average wind speed in Senegal. These measurements were taken at heights of 12 m and 20 m. To ensure the average wind speed was appropriate to use, the calculated value of 4.37 m/s was compared with the results from the Global Atlas for Renewable Energy as seen in Figure 8 below.

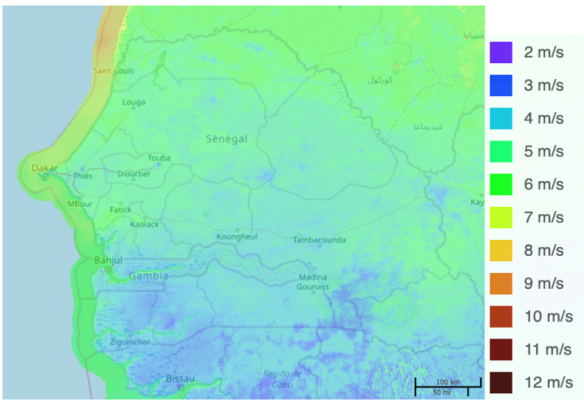

Figure 8: Average wind speed 1km at 50m above ground 2015 (IRENA, 2015)

It can be seen in Figure 8 that across Senegal wind speeds range from 3 m/s to about 8 m/s 50 m above ground, with the majority of locations experiencing wind speeds around 5 m/s. Thus, the calculated average wind speed of 4.37 m/s can be justified as wind speeds increase as the distance from the ground increases.

Before calculating the wind power potential in Senegal, the number of wind turbines that can be placed within the country needed to be determined. To keep the calculations consistent and enable comparison between the different technologies, the available area for solar panels as previously discussed was also assumed to be the available area for wind turbines in Senegal. The optimal distance between wind turbines should be the length of 15 rotor diameters, as stated by a fluid dynamics professor at Johns Hopkins University (Marchetti, 2010).

The diameter of the rotor blade for the wind turbine to be used is the last piece of information required to determine the wind power potential in Senegal. Table 7 below displays the characteristics of the chosen wind turbine, Yellow Sand, based on the recommendation from Ould Bilal et al. (2013). This small wind turbine was recommended for isolated or off grid applications due to its high capacity factor.

Table 7: Chosen Wind Turbine Characteristics (Ould Bilal et al., 2013)

Description of Wind Turbine	Rated Power (kW)	Swept area (m^2)	Cut-in wind speed (m/s)	Rated wind speed (m/s)	Cut-off wind speed (m/s)	Hub height (m)
Yellow Sand	0.3	4.52	3	8	15	12

The cut-in wind speed is the wind speed required for the rotor blades to start turning. The rated wind speed is the wind speed at which the turbine generates electricity at its maximum capacity. The cut-out wind speed is when the turbine shuts down to prevent mechanical damage. Additionally, the rated power is the maximum power that can be produced by a wind turbine. In this case, it is higher than the calculated power output per turbine of 82 W using the given assumptions. Thus, it can be seen that the previously described wind turbine is a suitable choice due to its ability to fit the requirements for the average wind speed and power output as determined for in Senegal based on the available data.

From the calculations in this report, it has been confirmed that there is wind potential across the country. However, further research into the wind characteristics at specific locations and heights is recommended before determining which wind turbine would be able to produce the maximum amount of power for that area. For example, along the coast at higher wind speeds and heights, a larger turbine could be installed thereby increasing wind power potential. This indicates that the wind power potential in Senegal may be significantly higher that the estimate determined in this report.

4.1.3 Biomass

Approximately, 46 percent or 88,680 km^2 of Senegal's total land is used for agriculture (World Bank Group, 2017). In 2016, Senegal produced approximately 5 billion kg of crops, of which crop residues data is only available for 40 percent of total production. Due to the limited data for crop residues, the physical potential determined in this calculation is likely only a portion of the biomass potential in Senegal. The available crop production and residue data is summarized in Table 8 below.

Table 8: Summary of available crop production and residues in 2016 (FAOSTAT, 2019)

	Crops Produced (kg)	**Crop Residues (kg)**
Maize	320,524,000	3,147,985
Millet	606,853,000	7,623,416
Potatoes	67,485,000	125,975
Rice, paddy	863,875,000	11,159,838
Sorghum	153,450,000	3,061,528
Total	2,012,187,000	25,118,742

From the information displayed above, the residue to crop ratio was determined to be 1.25 percent. The residual energy values of 7.9 GJ/ton for Maize and 7.5 GJ/ton for the remain crops were utilized based on data found in Fischer et al. (2007). Along with the residual energy values, a dry ratio of 15 percent and a collection rate of 50 percent, as justified in Methodology Section 4.1.3 Biomass, were used to determine the physical potential of each crop. From the calculations it was determined that the physical potential of rice and millet were the highest in Senegal, 398 kW and 271 kW respectively. This is due to the significant amount of these crops produced in the country. The physical potentials for each crop were added together to compute the total biomass potential in Senegal.

4.1.4 Hydro

To calculate the hydropower potential in Senegal, the flow rate of the prominent rivers must be determined. As can be seen in Figure 9, the rivers with the highest annual flow rates in

Senegal are the Senegal River, the Faleme River, and the Gambia River. These rivers each have a mean annual flow rate between 100 and 1,000 m^3/s, indicating that they have the highest potential for hydropower production in the country.

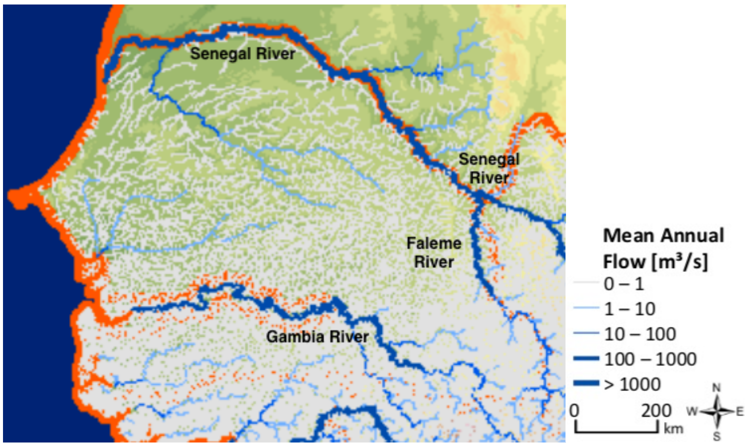

Figure 9: Mean Annual Flow Rates of Rivers in Senegal, where country borders are represented by orange dotted lines (ECREEE & PÖYRY, 2017)

The flow rates used to calculate the hydropower potential in Senegal for each river are summarized in Table 9. For the calculations, it was assumed that 100 percent of the flow of the river and one turbine are used to generate power. This may change depending on the type of hydropower plant installed. For example, a run-of-river hydropower facility, such as the Felou Hydroelectric Plant in Mali diverts a portion of the river through the facility. Additionally, it should be noted that flow rates are seasonal due to varying precipitation levels. With the highest flow rates occurring from August to October each year.

Table 9: Flow rates used for the hydropower physical potential calculation (ECREEE & PÖYRY, 2017)

	Flow Rate (m^3/s)
Senegal River	550
Faleme River	125
Gambia River	175

To obtain conservative estimates in this report, the following details were implemented in the calculation of the hydropower potential in Senegal. Since both the Senegal and Faleme River are located on international borders, only half of the hydropower potential for this river is used in determining the total hydropower potential for Senegal. Additionally, the head for each river was assumed to be 2 metres, the minimum height to produce hydropower, to simplify the calculation. This is the current head height for the Felou Hydroelectric Plant on the Senegal River in Mali. The head height will vary based on the location of the hydro power facility along each river. High head sites would occur in upland locations at the heads of rivers with sloped grounds. Low head sites would occur downstream and often have a higher flow rate due to the merging of smaller rivers (Renewables First, 2015). Thus, a detailed analysis of the topography of each river and potential sites available for construction would be required to produce a more accurate hydropower potential and determine what type of facility to implement. This is beyond the scope of this paper.

4.2 Electricity Costs

Table 10 summarizes the results from the LCOE calculations for solar, wind, biomass and hydropower in Senegal.

Table 10: Calculated LCOE for solar, wind, biomass and hydro power in Senegal

	LCOE (USD/kWh)
Solar	0.173
Wind	0.077
Biomass	0.051
Hydro	0.091

Figure 10 displays the calculated LCOE values for Senegal (blue dot) relative to previously documented LCOE ranges from around the world. It can be seen that the calculated values fall within or just outside historic LCOE values. The LCOE ranges for fossil fuels were taken from historic values and used for comparison. It can be seen that the calculated values are close to or within the LCOE value range for fossil fuels.

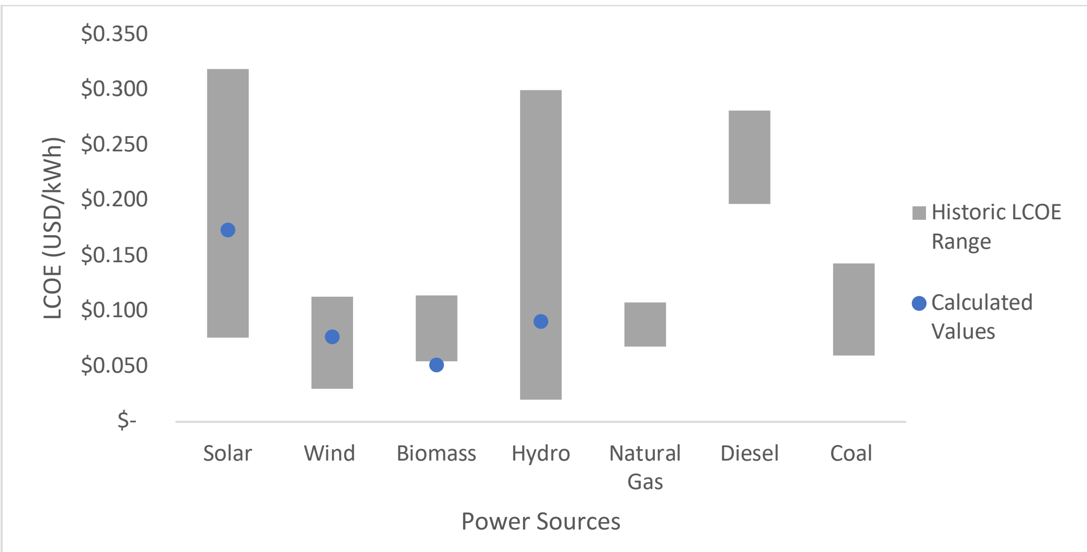

Figure 10: LCOE ranges compared to calculated values

The levelized cost of electricity (LCOE) for renewable technologies in Senegal was calculated using several assumptions. General assumptions for all LCOE calculations are detailed in Methodology Section 3.2 Electricity Generation Costs. Assumptions specific to this scenario are outlined in the following paragraphs. All parameters were assumed constant for the lifetime of the project.

Real Discount Rate

A 10 percent real discount rate, r, is used in these calculations to reflect the investment in a high-risk environment. This was chosen to ensure the results are conservative and reflect the likelihood of investors perceiving Senegal as a high-risk investing environment.

Capital Costs

The capital costs were determined as $/kW based on research for Senegal as seen in Table 11.

Table 11: Capital Costs for Renewable Technologies in Senegal (US EIA, 2019)

Technology	Capital $/kW
Solar	2,671
Wind	1,877
Biomass	4,985
Hydro	3,123

Operation and Maintenance Costs

The operating and maintenance (O&M) costs for each plant were assumed to be 4 percent of the installed costs. Additionally, variable operating and maintenance costs are assumed negligible for the purposes of this report as they are often small for renewable technologies.

Fuel Costs

Fuel costs are specific for each region. For the purposes of this paper, fuel costs are not required for the calculation of LCOE for renewables.

Carbon Emission Costs

Since renewable technologies produce little to no greenhouse gas or carbon dioxide emissions, the carbon emission costs are assumed negligible for the LCOE calculation.

Decommissioning Costs

The decommissioning and waste management costs for each renewable technology is assumed to be 5 percent of the overnight costs.

Electricity Produced

The total amount of electricity produced in MWh for each plant was assumed to be constant over the lifetime of the plant. To ensure the LCOE for each technology was within the range of previously determined LCOE for these technologies, the plant sizes were optimized to reach these values. This was done to identify the most likely plant size required to make the renewable technologies a feasible option in terms of cost. The plant capacities used for the LCOE calculation and the previously determined economic potential are listed in Table 12.

Table 12: Plant capacities used in LCOE calculation

	MWh	Calculated Economic Potential Power (MWh)
Solar	20	544,016
Wind	25	18,769
Biomass	50	8
Hydro	30	107

From Table 12, it can be seen that the chosen plant capacities are only a portion of the available economic potential power in Senegal for solar, wind and hydro power. These plant capacities correspond to existing ones in Senegal, neighbouring countries, and countries that experience similar climate. For example, a 30 MW solar park has been constructed near Dakar, Senegal, Lake Turkana Wind Power project in Kenya has 365 wind turbines and 310 MW capacity, and Felou Hydroelectric Plant in Mali has a capacity of 60 MW. Thus, it is not improbable for the chosen plant capacities to be implemented.

A biomass plant capacity can range from 4 to 350 MW as seen around the world, more specifically a biomass plant in British Colombia, Canada has a capacity of 60 MW. However, it can be seen that the economic potential power for biomass is lower than the plant capacity used in the LCOE calculation. This is due to a lack of availability of data on other potential biomass sources. Using the assumptions previously stated, the LCOE for an 8 MWh biomass plant is quite high at 2.02 USD/kWh and would not be feasible to implement. Before rejecting the possibility of utilizing biomass power in Senegal, all types of biomass and their availability should be analyzed.

It should also be noted that based on the assumptions applied to the LCOE calculations, plants with greater capacities have lower LCOE. However, this may change as the installed and capital costs per kilowatt are adjusted based on plant size.

5. Discussion

The objective of this section is to review the current situation, analyze the available energy sources, identify potential strategies for increasing electrification rates across Senegal using the calculated results, and highlight the benefits of electrification.

The energy demand in Senegal is increasing, but production continues to remain insufficient. From the current population dispersion and lack of rural electrification in Senegal, it is evident that unless another solution is presented, the demand for imported oil and biomass, as well as the deforestation rate in Senegal will continue to increase.

Currently, the majority of available energy in Senegal comes from imported fossil fuels or locally produced biomass. The reliance on imports results in a trade imbalance, negatively impacts the economy, and creates risks in terms of having a stable and secure supply of energy. As a result, Senegal is left exposed to market fluctuations and geopolitical tensions that may occur. In 2013, Senegal’s energy independence rate was 49 percent, but if biomass is omitted from the calculation, the energy independence rate drops to 5 percent (Tchanche, 2017).

5.1 Available Energy Sources

Renewable technologies are becoming a more competitive way to meet electricity generation needs due to a steady decline in costs, especially for solar and wind power technologies. The decrease in costs is primarily a result of technology improvements, an increasing number of experienced developers, and a proven track record of renewable technologies. Technological improvements lead to more efficient technologies, which often leads to a decrease in operating, manufacturing, installation, and material sourcing costs. Additionally, these improvements allow more energy to be harvested from the same resource using the same amount of space. An increasing number of experienced developers and a proven track record of these technologies decreases the risks associated with the project, lowers capital costs, and leads to growth opportunities (IRENA, 2018).

Throughout this paper, the potentials for solar, wind, biomass, and hydro power in Senegal have been highlighted. However, to accurately determine the feasibility of implementing any of the technologies the benefits and challenges for each resource and its associated technology must be analyzed. These benefits and challenges for each potential energy source along with the current energy source, fossil fuels, are summarized in Table 13 below. A detailed discussion of each energy source can be found in the following subsections.

Table 13: Summary of the benefits and challenges of each energy source

	Benefits	**Challenges**
Solar	• Renewable • Can be installed anywhere, from rooftops to the ground • Can be privately owned • Able to power homes and buildings that are off the grid • Highest potential in Senegal • 1-year construction period	• Dependent on location and hours of sunlight • Large number of panels needed to produce a lot of energy • Limited solar activity data available
Wind	• Renewable • Free and always available • Technologies are improving • Associated equipment costs are decreasing • Can be placed near load centers to reduce transmission losses • Lowest determined LCOE • 1-year construction period	• Dependent on location • Local acceptance required • Lack of local knowledge on technologies and benefits • Power output is dependent on wind speeds • Turbines can only be placed in suitable regions • Noise
Biomass	• Not dependent on location • Easily accessible, multiple sources • CO_2 neutral fuel • Favourable climate in Senegal • Help reduce the country's dependence on imported fuel • 1-year construction period	• Significant land required • Potential competition to be faced over land use • Requires access to water and nutrients • Seasonal supply • Collecting residues
Hydropower	• Renewable • Grid stability • Flood control and drought management • Opportunities for irrigation services, water supply • Customizable to location and needs • Longest technology lifespan	• Dependent on location • Increasing evapotranspiration rates leading to the drying up of waterways • High capital costs and 7-year construction period • Negative impact on regional ecosystem • Production of GHGs during construction
Fossil Fuels	• Easily transported • Advanced and efficient technologies for processing • One drilling site can provide resources for significant amount of energy temporarily • Easy to find	• Non-renewable • Unstable prices • Causes air pollution and global warming • May lead to health problems and a decrease in quality of life • Unevenly distributed resource

5.1.1 Solar

Solar power is produced through the conversion of sunlight into energy. In 24 hours, the sun directs 10,000 to 15,000 times the amount of energy to earth than the global population requires. This can produce approximately 1.4 kW/m^2 (over 200 million GW globally) of electric energy annually. Nearly 51 percent of the Earth's most concentrated sunlight reaches Africa, making it a prime location for solar power installations (Diaw et al., 2017).

The most popular solar panel technology is a solar photovoltaic (PV) system, which is able to transform sunlight into electricity (Branker et al., 2011). The global market for PV technology has been growing rapidly over the past decade. Cumulative installed PV capacity around the world has grown from 6.1 GW in 2006 to 291 GW in 2016 (IRENA, 2018). Solar PV systems are a popular solution around the world for rural electrification, where isolated systems are easily installed (Tchanche, 2017).

5.1.1.1 Current Situation

Senegal receives about 3,000 hours of sunlight per year. The solar power potential in Senegal was explored in Section 1.1.5.1 Solar Power. The construction period for solar technologies is typically 1 year with an average lifetime of 25 years. The physical and economic potentials were determined to be the highest of the analyzed renewable sources at 2.34 million and 22,667 MW respectively. The LCOE was determined to be 0.17 USD/kWh, which is the third cheapest option of the renewables studied and within the range of historic LCOE values for solar power. It is slightly higher than the range of LCOE for natural gas and coal, and lower than the LCOE for diesel.

The government does not provide any tax breaks for the implementation of solar energy systems, thus foreign investment has been required to expand this sector (Purdy, 2012). Market growth is dependent on the expansion of related national and international projects as a result of low purchasing power (Africa-EU Renewable Energy Cooperation Programme, 2016). Of the companies currently involved with solar power systems in Senegal, most deal with the installation and servicing requirements for subsidized systems (Energypedia, 2018). Several concentrated solar systems have recently been constructed in Merina, Bokhol, and Sinthiou Mékhé (Tchanche, 2017).

Currently, the unsubsidized market for solar panels in Senegal is small (Energypedia, 2018). The non-profit organization, Solar Village Project, is using a crowdfunding campaign to generate finances for the installation of off-grid solar systems in rural Senegalese villages. They are focusing on electrifying seven villages with a total population of 3,000 and have highlighted how the success of off-grid solar systems in East Africa can be replicated in West African countries, such as Senegal (Pothecary, 2016).

5.1.1.2 Benefits

The benefits of solar power technologies include long life span, an abundance of installation locations, no GHG emissions post installation, and storage ability. Solar panels can last for about 25 years with limited maintenance required. They can be installed virtually anywhere the sun shines from rooftops to fields. After installation, no pollution is emitted during electricity production. The electricity produced can be stored in batteries for use at a later date or used to immediately power buildings and heat water (SEPCO, 2016).

Another benefit of solar power is the ability to generate all the power required for a home or building from a nearby solar panel. This could enable the electrification of regions, especially rural areas, that are not connected to the grid. Additionally, solar panels can be privately owned, and excess energy produced could be sold.

5.1.1.3 Challenges

The ability to produce solar power is dependent on the amount of sunlight and land space available. Challenges are faced in the winter months and cloudy days when access to sunlight is limited. Additionally, a significant amount of space on rooftops or on land is required to produce large quantities of electricity.

Implementation of solar power technologies in Senegal is currently limited due to a lack of data on solar activity. This inhibits the ability to accurately evaluate the solar power potential in potential installation locations (Diaw et al., 2017). Installation costs for solar power vary from country to country, making it difficult to predict the total cost for a project. The differences in costs are due to land costs, presence of government incentives, and labor and manufacturing costs in each region (IRENA, 2018). The average capital cost for solar projects used in this paper was determined to be less than biomass and hydro power plants.

5.1.2 Wind

Wind is a renewable, non-polluting energy source. The construction period for wind farms is typically 1 year with an average lifetime of 25 years. The physical and economic potentials were determined to be the second highest of the analyzed renewable sources at 2,634 and 782 MW respectively. The LCOE was determined to be 0.08 USD/kWh, which is the cheapest option of the renewables and within the range of historic LCOE values for wind power. It is also within the range of LCOE for natural gas and coal, two of the current fossil fuels used in Senegal.

Wind power is produced through the conversion of kinetic energy into electrical and mechanical energy using a wind turbine and generator (Tchanche, 2017). The amount of wind power that can be generated is dependent on the wind resource, the rotor diameter, and the turbine height. Electricity can be generated from wind turbines at a minimum wind speed between 3 to 5 m/s, with maximum power generation occurring at wind speeds between 11 to 12 m/s (IRENA, 2018).

There are two types of wind power: onshore and offshore. Onshore wind power is harvested from wind turbines on land, and offshore wind power is harvested from wind turbines in lakes, rivers, and oceans. Due to availability of data only onshore wind potential is considered in this report. It should be noted that Senegal has a long border with the Atlantic Ocean, where there could be significant offshore wind power potential that remains untouched.

5.1.2.1 Current Situation

Despite evidence of potential, wind energy in Senegal is limited and remains virtually untapped. Multiple wind power projects have been announced but are slow in development. This can be attributed to the absence of reliable wind resource data in Senegal; thus, it is difficult to determine the total wind power potential.

The data used for this report came from eight metrological stations located on the northern coast of Senegal. The locations for these metrological stations were displayed in Figure 7 in Section 2.3.2 Wind Energy Potential. The mean monthly wind speeds (m/s) for these locations are shown in Figure 11 (Ould Bilal et al., 2013).

It can be seen in Figure 11 that the monthly mean wind speeds vary significantly throughout the year which would result in an unstable amount of energy produced throughout the year. With the highest wind speeds for each region in April and May (dry season), and the lowest in September and October (rainy season).

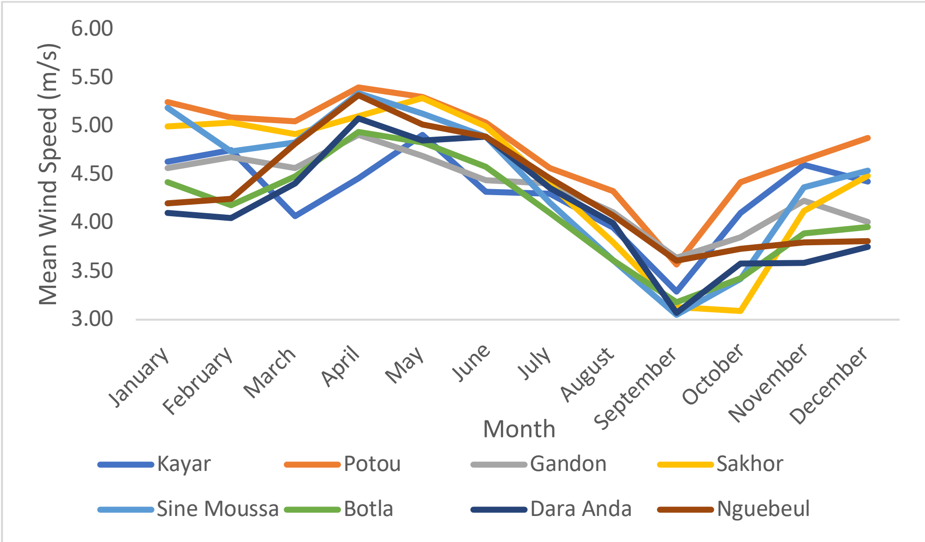

Figure 11: Monthly Mean Wind Speeds in Senegal (Ould Bilal et al., 2013)

All of the locations mentioned above are located along the northern coast of Senegal. This area is considered to be the best location for wind power potential in Senegal. With many remote villages in this region that are not connected to the national grid, it is a promising method to electrify the area. This is evidenced by a recent 481 million USD investment into a 158 MW wind farm north of Dakar. Upon completion the wind farm, as described in Section 1.1.5.2 Wind Power, has the objective to increase grid connections by 15 percent and reduce power cuts currently facing the nation (Lockhart, 2018)

5.1.2.2 Benefits

Wind power is a clean, constant source of energy with a growing global market. An increase in wind power technology efficiencies and a decrease in equipment costs can be associated with the increase in market share (Belabes et al., 2015).

Many countries are currently increasing their wind energy generation capacity by replacing old turbines with newer ones, allowing for an increase in electricity generation without using more space. This can be accomplished due to the use of more efficient turbine designs with larger rotors and taller turbines that are able to reach higher wind speeds. (IEA Wind, 2016). There is also a large selection of wind turbines on the market allowing developers to install the best wind turbine that satisfies the constraints of the chosen location. The competition and continuous innovation in the wind turbine market has resulted in decreasing costs for wind power (IRENA, 2018).

Wind turbines can be placed near load centers to reduce the amount of transmission losses thereby increasing the amount of electricity available to customers. Another advantage of a wind turbine is that the power generated can be used for multiple applications. For example, if wind speeds are too low in the off season to produce electricity, the wind could be used to power water pumping stations instead (Youm et al., 2005). This would be beneficial in areas like northern Senegal, where there is significant agriculture production.

5.1.2.3 Challenges

Wind power is limited by the technological, topographical, economic, and political characteristics of the region. Wind project development in Senegal is limited due to lack of information on resource availability and lack of knowledge on wind power technologies (Ould Bilal et al., 2013). The amount of wind energy that can be produced is dependent on the wind speed and the ability of the chosen turbines to convert the available wind into power. A suitable region for a wind farm cannot be at a high altitude, have a high slope as it would make accessing difficult, be in a protected area, such as national parks, for legal reasons, and near an airport due to safety concerns (Zhou et al., 2011). Additionally, large scale wind power projects require significant financing and government approval to be successful. It should be noted that in terms of capital costs, wind power plants are the cheapest of the renewable technologies analyzed.

Other challenges for wind power projects include noise and local acceptance. Wind turbines can be very loud, and many individuals do not want them in their communities. A study completed by Health Canada identified a relationship between being exposed to wind turbine noise and annoyance. On a more promising note, Health Canada found no evidence of a relationship between wind turbine noise and medical conditions. Additionally, educating locals about the benefits of this technology compared to alternative options may reduce the size of this hurdle (IEA Wind, 2016).

5.1.3 Biomass

Biomass is a renewable source of energy that comes from animal and plant organic material. It stores energy from the sun, which is released as heat when biomass is burned. Energy can be produced from biomass through direct burning or by converting it to biogas or biofuel, which is then burnt as fuel (US EIA, 2018). The solid, liquid, and gaseous fuels from biomass can be used for cooking, heating or electricity.

Bioenergy is the energy produced from biomass. It is a more sustainable, easily exploited, and globally available source of energy (Nzila et al., 2010). Energy can be produced from a diverse group of biomass resources, including urban waste, manure, sewage sludge, agricultural residues, food processing waste, wood, and wood processing residues (Bentsen & Felby, 2012). Solid biomass, including wood and garbage, is burnt directly to produce heat. Biogas is created through the decomposition of food, yard waste, and paper. It can also be produced using a digester machine to process manure and sewage. Biofuels such as biodiesel and ethanol can be used as heat or fuel for vehicles. Biodiesel is produced through animal fat and vegetable oils. Ethanol is created through the fermentation of crops like sugar cane and corn (US EIA, 2018). The amount of energy that can be produced from biomass is dependent on the properties of the chosen feedstock, the biomass to energy conversion process, and the efficiency of the technology that uses the biomass as fuel. The cost of bioenergy is based on having a sustainably sourced supply of biomass feedstock steadily available at low cost (IRENA, 2018).

The construction period for biomass technologies is typically 1 year with an average lifetime of 25 years. The physical and economic potentials were determined to be the lowest of the analyzed renewable sources at 0.90 and 0.34 MW respectively. The LCOE was determined to be 2.02 USD/kWh based on an 8 MWh plant, which is the most expensive option of the renewables studied. For a 50 MWh plant, the LCOE was determined to be 0.05 USD/kWh, which would be the cheapest renewable option and is within the range of historic LCOE values for biomass power. This value is lower than the range of LCOE for natural gas, coal, and diesel. Both values were included in this report because both are considered reasonable options to be implemented. A 50 MWh biomass plant is believed to be feasible due to the significant biomass potential unaccounted for in the potential calculations due to a lack of data on other biomass sources in Senegal. These other sources indicate that the physical potential for biomass energy in Senegal could be significantly larger.

The potential calculations in this paper focus on agricultural residues, which are the parts of a crop remaining after harvest. Often referring to the fibrous parts of crops such as sugar cane, roots, dried fruits and cereals. They are not consumed by humans and have little to no feed value for animals. In Senegal, there has been an increasing trend in the amount of crop residues available, especially grains, as grain production has grown in the last decade (FAO, 2014).

5.1.3.1 Current Situation

Global biomass production comes from wood and wood waste (64 percent), urban waste (24 percent), agricultural waste (5 percent), and landfill gases (5 percent). About 35 percent of primary energy consumption in developing countries, and 14 percent of the total world energy consumption comes from biomass (Demirbas et al., 2011).

Currently, biomass is the most popular energy source in the residential sector in Senegal due to a favourable climate for biomass growth. It is found throughout the country, with regions rich in biomass located in the southern and eastern part of the country. These regions include Kaffrine, Kolda, and Tambacounda. There are many forms of biomass available in Senegal, including firewood, charcoal, and agricultural residues. Firewood is the most popular source of biomass in Senegal and is often used in both urban and rural households, as the main energy source for household chores, such as cooking (Tchanche, 2017).

The exploitation of wood as an energy source has caused deforestation and led to the disappearance of the Senegalese forest area. Approximately 48.5 percent of land in Senegal was covered by forest in 1990, by 2015 this number dropped nearly 6 percent. In this time period, Senegal lost 10,750 square kilometers of forest area or 11.5 percent of the total forest area with the deforestation rate ranging from -0.51 to -0.46 percent per year (World Bank Group, 2017). Figure 12 depicts the change in forest area in Senegal over 25 years.

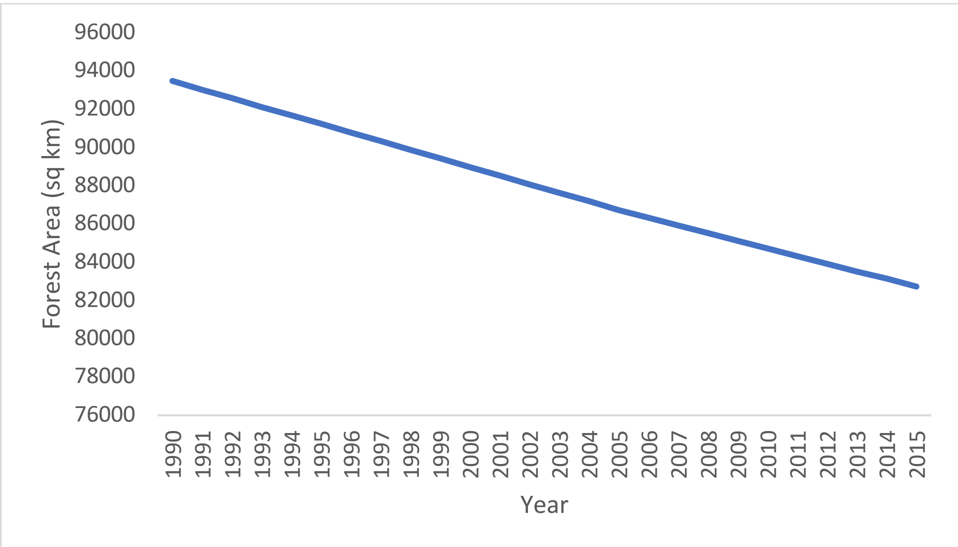

Figure 12: Change in Senegalese forest area (World Bank Group, 2017)

Burning crops for energy may also create harmful consequences with respect to human health, climate, soil and air quality. It is a common way, especially in Africa, to prepare lands for cultivation through burning crop residues after harvest. Countries in Africa have intensive rates of residue burning per hectare of harvested land, with burning patterns increasing at high speeds (Cassou, 2016). Converting land through biomass burning, uncontrolled decay, or deforestation is linked to climate change through the production of CO_2 and other GHG emissions due to the release of volatile, unburnt hydrocarbons. This may also lead to nitrogen leakage and the eutrophication of surrounding water sources. Thus, it can be concluded that current practices are wasting significant amounts of agricultural residues that could otherwise be collected and used to produce energy (Nzila et al., 2010).

5.1.3.2 Benefits

Biomass is a CO_2 neutral fuel as it absorbs the same amount of CO_2 from the atmosphere as it releases in combustion (Demirbas et al., 2011). This would reduce the amount of greenhouse gas emissions produced, which is better for the environment, and improve air quality thereby reducing healthcare costs related to inhaling polluted air.

There are several sources of biomass energy that have yet to be explored in Senegal, including urban waste, and landfill gases. Combined with biomass energy potential from the abundance of agricultural residues and wood residues in Senegal, the dependence on imported fuel could be greatly reduced and a stable energy supply could be created in the country. Due to the variety of biomass energy sources and favourable climate in Senegal for crop growth, biomass energy production is not dependent on location.

Other benefits may include a creation of jobs in the agricultural sector to produce and collect crop residues. Having a processing plant could lead to infrastructure improvements, including road improvements and grid connection in the area. Additionally, the demand for biomass could lead to an increase in income for local farmers (IFC & BMF, 2017).

5.1.3.3 Challenges

The key challenge and limitation in biomass energy potential is land availability. To produce biomass for energy at large scales, a large amount of land is required. For example, one acre of land is required to produce 400 gallons of biofuel, which is enough to power a car 12,875 km, which is just over half the distance an average person in the U.K. drives per year (Walker, 2009). There is also concern that in the future there will be competition with the food industry for the land, as well as the grains and fertilizers required for biomass production. This may become an ethical and social concern related to the priorities of a country. For example, if these lands are used to produce energy, but there is not a sufficient amount of food produced to ensure citizens are not malnourished it would become an ethical and social issue for the country. Additionally, a decrease in the amount of food available would lead to an increase in food costs and may result in the starvation of members of poor families.

To limit the competition with food supply, using agricultural and food residues for biomass energy are one of the most sustainable options for the long term. However, there are multiple applications for the use of agricultural residues, including as animal feed, thus it is not correct to assume all agricultural residue is collected for energy production (Bentsen & Felby, 2012). This is taken into account in the physical potential calculations through the Collection Rate (CR) factor. Another challenge is the availability of water and nutrients which may constrain the amount of agriculture produced each year. Additionally, technologies to convert biomass into a sustainable energy source are at their infancy in many African countries, including Senegal, due to lack of knowledge and economic factors (Nzila et al., 2010). This is reflected by the significant capital costs for a biomass plant. The associated capital costs are the highest of all the renewable technologies analyzed.

Other challenges include collection and transportation issues, as well as a seasonal supply. The collection and transportation of crop residues presents challenges due to high transport costs, lack of storage facilities, road conditions, and being able to collect residues from large fields as they become available at different times. In terms of supply, many crops have seasonal availability. For example, many crops including maize, millet, and sorghum are seeded in May and June and harvested in September and October leading to a maximum availability of crop residues in November and much lower availability in April (FAO, 2014).

5.1.4 Hydropower

Hydropower is a mature renewable technology, with the first hydropower plants constructed in the 1890s (Koch, 2002). It is produced by converting the energy from flowing water to electricity. Despite high installation costs, hydropower is a low cost, flexible, and abundant source of power. Hydropower is the largest renewable energy source on the planet, accounting for 6.7 percent of global energy production (Muise, n.d.).

The construction period for hydropower plants is around 7 years with an average lifetime of 80 years. The physical and economic potentials were determined to be the third highest of the analyzed renewable sources at 5.96 and 4.47 MW respectively. The LCOE was determined to be 0.09 USD/kWh, which is the second cheapest option of the renewables studied and within the range of historic LCOE values for hydropower plants. Additionally, it is within the range of LCOE for natural gas and coal, and lower than the LCOE for diesel.

There are three types of hydropower facilities: run-of-river, impoundment, and pumped storage. Run-of-river hydropower facilities divert a portion of the river through its turbines subjecting it to the variability of water flow rates. It can be done without the use of reservoirs or dams. Impoundment hydropower facilities are the most common, they utilize a dam to generate a large water reservoir, which is then passed through turbines in the dam producing electricity. Pumped storage hydropower facilities are similar to the impoundment facilities with an additional reservoir below the dam. Water in the lower reservoir is pumped to the upper reservoir to produce energy that can be stored for use at a later time (Muise, n.d.).

5.1.4.1 Current Situation

Hydropower is currently one of the most exploited and profitable renewable energy resources used in Senegal (Tchanche, 2017). However, the only hydropower stations in the region, Manantali and Felou, are located in Mali, a neighbouring country. Of which, only 60 MW of the hydro power from the Manantali plant is utilized by Senegal (United Nations Industrial Development Organization, 2016). Research in Senegal has indicated that there are many streams with significant electricity production potential. Additionally, there is potential to produce small hydropower plants for isolated areas at lower costs (Tchanche, 2017).

The flow rates of the rivers are highly variable with the seasons. For example, the flow rate in the Senegal River can be up to 300 times higher in the rainy season than it is in the dry season (Camara & Harrison-Church, 2006). The flow rate in the Gambia River ranges from 4.5 to 1,500 m^3/s, with the maximum flow occurring around October at the end of rainy season (UN Division of Technology, Industry and Economics, n.d.).

Over the years, public opinion on hydropower has changed as a result of increasing awareness of environmental issues and human rights. Every hydro project was previously considered beneficial to the public, however, over time the different advantages and disadvantages have been recognized and must be considered by each individual country before implementation (Koch, 2002). These challenges and benefits are discussed further in the sections below.

5.1.4.2 Benefits

The benefits of hydropower production include energy storage, grid stability, and local benefits. Hydropower facilities have the ability to store energy for long periods of time, from weeks to years, based on the size of the reservoir. This would provide a stable source of energy for Senegal, which could be utilized along with other renewable sources of energy, such as wind and biomass, that vary seasonally. The turbines in a hydropower plant can be controlled to ensure the electricity system operates at sufficient capacity. For example, turbine speed can be increased to generate more electricity if required. Local benefits of hydropower facilities include flood control, drought management, and the potential to create irrigation systems, a municipal water supply, better navigation, and space for recreational use (IRENA, 2018).

Hydropower facilities have the ability to produce large amounts of renewable electricity from a natural resource with insignificant amounts of GHGs. Additionally, hydropower plants can be customized to the location in terms of size and properties, including height of water drop, inflows, and reservoir size (Koch, 2002). The construction of a hydropower plant could also lead to infrastructure improvements like road improvements and grid connection in the area.

5.1.4.3 Challenges

A major challenge facing hydropower production potential in the long term is climate change. Climate change will impact water resources due to increasing temperature and decreasing precipitation. Global warming would lead to the drying of waterways, which would negatively impact the water flow rates and the amount of hydropower that could be produced. Currently, in southern Senegal nearly 85 percent of rainfall evaporates or transpires (evapotranspiration), thus only 15 percent is available to produce runoff. In the central and northern parts of Senegal, the ability to generate runoff from rainfall is reduced to less than 5 percent (ECREEE & PÖYRY, 2017). Projected climate change effects for Senegal are summarized in Table 14. The ranges provided are quite large, this is due to the difference in geographic location and current climate across the country. It is expected that the northern parts of Senegal will experience the most extreme changes in response to climate change.

Table 14: Predicted impacts from climate change 2026-2045 (ECREEE & PÖYRY, 2017)

Temperature Change (°C)	+0.9 – +1.2
Precipitation Change (%)	+2.0 – -9.9
Runoff Change (%)	-2.0 – -29.9
River Discharge Change (%)	-2.0 – -14.9

The direct environmental impact of a hydropower facility is also a challenge due to the pressure placed on the regional ecosystem and the greenhouse gas emissions produced during construction. Concerns arise for the regional ecosystem as a result of damming a river due to wildlife habitat disruption, involuntary displacement of the local community, obstructing fish passages, and flooding land upstream. Additionally, if the dam were to fail it would destroy the surrounding landscape and likely kill anyone located downstream. Construction of a hydropower plant utilizes a significant amount of cement, which contributes to carbon dioxide emissions. It may also require upstream land to be flooded, leading to a loss of upstream vegetation and the production methane as the vegetation underwater decays (Muise, n.d.).

The ability to produce hydropower is dependent on the topographical characteristics of the chosen location. Thus, each hydropower project is designed for a specific location within a specified river basin. Water must fall from a minimum height of 2 metres at a high flow rate to rotate the hydraulic turbines and produce hydropower. Typically, the chosen locations are remote sites located far away from existing transmission networks and infrastructure resulting in higher installation costs (IRENA, 2018). This has resulted in hydropower having the second highest capital costs of the renewable technologies analyzed.

5.1.5 Fossil Fuels

Fossil fuels supply around 80 percent of the world's energy and can be used to meet a variety of needs including transportation, electricity, and heat. They are non-renewable resources that are extracted from the ground. Fossil fuels were formed millions of years ago when animals and plants died and were buried under layers of sediment and rock. Different fossil fuels are formed based on the length of time, temperature, and pressure conditions it faced underground and the organic matter that was combined. The three main types of fossil fuels are coal, oil and gas. Once extracted from the ground, these fossil fuels are burnt for electricity or refined into usable fuel for heating and transportation. The burning of fossil fuels produces carbon dioxide and GHGs (U.S. Department of Energy, 2019).

5.1.5.1 Current Situation

Fossil fuels have traditionally been imported to Senegal. Before the 1980s, all domestically produced energy came from thermal plants. Since the construction of the hydropower plants in Mali, Senegal has been importing renewable energy. As of 2018, thermal energy represented 87 percent of installed capacity in Senegal (U.S. Agency for International Development, 2018). This is only a 3 percent decrease from 2010, where 90 percent of available electricity was provided by thermal plants (United Nations Industrial Development Organization, 2016). Thus, they still import crude oil and consume it in large quantities.

A natural gas power plant has a construction period of 2 years with an average lifetime of 30 years, whereas a coal power plant has a typical construction period of 4 years and a lifetime of 40 years. This is short construction period and long lifetime is beneficial to note given the fossil fuel resources that have recently been discovered in Senegal. These resources were found in Diamniadio, Sangomar, Casamance, and off the Atlantic coast with the potential to create a local supply of fossil fuels for Senegal (Tchanche, 2017).

Senegal's first coal power plant opened in Sendou (600 metres from the Atlantic Ocean) in November 2018, with the objective to supply 40 percent of the electricity demand in Senegal. The plant cost $188 million USD to build and was sanctioned in 2009. There are plans to double capacity from 125 MW to 250 MW through another phase of construction. However, the plant is currently facing backlash from local citizens over air pollution, coastal erosion and general disruption concerns. Complaints have also been issued over the land the plant is built on being taken from locals without compensation (Lockhart, 2019).

5.1.5.2 Benefits

Existing technology and ease of transport are the major benefits associated with fossil fuels. Current technology enables efficient utilization of resources to generate large quantities of energy and allows for plants to be constructed in many locations. Fossil fuels, such as oil and gas, can be easily transported in large quantities through pipes, trucks, and ships due to their liquid form. Additionally, fossil fuels are easy to find with current technologies and one drilling location can provide a significant quantity of fossil fuels for a period of time (Alternative Energy Secret, 2013).

5.1.5.3 Challenges

There are many challenges facing the fossil fuel industry including environmental, social and economic issues. It is widely known that the use of fossil fuels contributes to many negative environmental problems, such as global warming and air pollution (Martins et al., 2018). This has been proven through many scientific studies and the fact that three quarters of human emissions from the past 20 years are as a result of burning fossil fuels (U.S. Department of Energy, 2019). Social issues caused by fossil fuels include health problems, including cancer and respiratory diseases, and a decrease in quality of life. Economically, the cost of fossil fuels and the associated markets are very unstable (Martins et al., 2018).

Fossil fuels are a non-renewable resource being depleted at alarming rates. The global consumption of fossil fuels has approximately doubled every 20 years since 1900 (Alternative Energy Secret, 2013). This raises the issue of how nations that are dependent on fossil fuels for electrification will power themselves in the future when the fossil fuel resources run out. Additionally, fossil fuel resources are unevenly distributed creating energy security concerns for countries that are dependent on fossil fuel imports (Martins et al., 2018).

5.2 Electrification

This section is focused on identifying potential strategies for increasing electrification rates using the calculated results and highlighting the benefits of electrification.

5.2.1 Evaluating the Renewable Technologies

To evaluate the likelihood of implementing the renewable technologies reviewed in this report an evaluation matrix was utilized, as seen in Table 15 below. Each criterion was ranked from 1 to 4, with 1 being the worst option and 4 being the best option. The technology with the highest total score is considered the best option for implementation in Senegal based on the assumptions used and identified throughout this report.

Table 15: Evaluation Matrix for the Renewable Technologies Analyzed

Criteria	Solar	Wind	Biomass	Hydro
Construction Period	4	4	4	1
Plant Lifetime	1	1	1	4
Capital Costs	3	4	1	2
LCOE	2	4	1	3
Physical Potential	4	3	1	2
Economic Potential	4	3	1	2
Location Requirements	4	2	3	1
Independent of Seasonal Change	4	3	2	1
Ease of Rural Implementation	4	2	3	1
Total	30	26	17	17

5.2.1.1 Evaluation Matrix Justification

The evaluation matrix was used to rank the renewable technologies on several factors. The highest scores were given to the technologies that represent the most attractive option for investors for each criterion. The justification behind each ranking can be found in the following paragraphs.

The ideal construction period was considered to be the shortest due to the ability to produce electricity and generate income in the shortest period of time. Thus, solar, wind, and biomass technologies all received a 4 in the evaluation matrix because they have the same construction period of 1 year. The longest plant lifetime was determined to be the most beneficial as it would be able to produce electricity for a longer period of time before it needed to be replaced. This resulted in hydropower receiving the highest score of 4 due to its long lifetime of 80 years. Solar, wind, and biomass were given a 1, as they all have the same lifetime of 25 years.

The projects with the lowest capital costs and LCOE were perceived to be the best option, as less money would be required to generate electricity. The energy sources with the highest physical and economic potentials were considered the best option because they would be able to produce the most amount of energy in Senegal.

The highest score for location requirements was given to the technologies that were flexible in terms of their location. Solar panels can be placed virtually anywhere that receives sunlight in Senegal due to high levels of irradiation in the country resulting in the highest score in the evaluation matrix. The variety of biomass sources that could be used to produce electricity reduces location dependence for biomass projects. However, to convert the biomass into energy a processing plant must be built, which made biomass more location dependent than solar and it was given a 3. Wind power is dependent on wind speeds, which are variable across the country and highest along the coast. This resulted in a score of 2. Hydropower plants can only be located near waterways with high flow rates, indicating it is the most dependent on location of the technologies studied, thus it received a 1.

The seasonality of each resource was also analyzed to determine the effects of the changing seasons and climate on energy potential. The resources were ranked from power output being most affected by seasons (1) to least affected (4). Despite having the ability to store power, hydro facilities are dependent on water flow rates to produce power. The flow rates already vary with the changing seasons and are expected to get lower over time as a result of climate change. Thus, hydropower was determined to be the most affected by the changing seasons. Biomass was ranked second most affected by the changing weather as crop growth is seasonal and the availability of agricultural residues is variable. Additionally, climate change may begin to affect crop production in the future. Wind power is dependent on wind speeds, which are seasonal, however, the lowest wind speeds measured were still sufficient to produce wind power. Thus, it was ranked above biomass and hydro power in terms of the effect of seasons on power output. Solar power was ranked least affected by seasonal change as the irradiation levels across the country are high all year round despite the cloud cover that may occur during the rainy season.

Finally, the technologies were ranked based on ease of rural implementation, this was based on how easy it is to power homes without connecting it to the national grid. Solar power is the best option for rural implementation as it has been proven to power homes off the grid, without access to transmission lines. Biomass was determined to be the second-best option for rural implementation as biomass plants can produce power using a variety of inputs, thus plants can be customized to availability of biomass in a given location. Isolated grids could be used to transmit the power from the biomass plant to nearby homes. Wind turbines were determined to be a better option than hydropower but not as good as solar or biomass technologies due to the distance required between turbines. This large distance between turbines indicates a large amount of space is required for implementation. Additionally, wind power can only be transmitted through the grid or through a combination of solar and wind technologies, which becomes complex and costly. Hydropower was determined to be the worst option in terms of rural implementation as hydropower plants are often located in isolated locations and thus need to be connected to the grid.

5.2.2 Future Scenarios for Increasing Electrification

This subsection will focus on the potential paths that Senegal could take towards increasing electrification rates around the country. Three situations will be analyzed with respect to increasing electrification rates: best case scenario, most likely to occur, and business as usual.

5.2.2.1 Best Case Scenario

The ideal scenario to increase electrification rates in Senegal is to increase the amount of renewable energy produced and improve access to the grid by increasing transmission lines across the country. The strategy to improve access to the grid was not analyzed in this report, as it is beyond the scope of this project, but it would significantly increase electrification rates.

Increasing the amount of renewable energy produced would enable Senegal to increase their energy generation while minimizing their impact on surrounding ecosystems. Globally, the production of renewable energy is increasing due to the positive aspects of using a natural renewable resource and the knowledge that a dependence on fossil fuels is not sustainable in the future. Thus, it would be ideal for Senegal to begin to produce their own renewable energy and reduce their dependence on fossil fuels. Additionally, reducing the countries dependence on fossil fuels would positively impact SENELEC, as its revenue is directly impacted by increasing oil prices. This would give them the ability to invest in alternative energy plants and maintenance for existing assets.

From the evaluation matrix above, it can be seen that solar power has the highest physical and economic potential in Senegal, and the highest total score from evaluation. This indicates that solar power is the most promising method to increase electrification rates, especially rural electrification rates in Senegal. Therefore, the best-case scenario would be for the installation of solar panels both in solar parks and remote communities across the country. Senegal could also further diversify their energy portfolio through a mix of wind, biomass, and hydro power investments. These technologies are all able to produce large amounts of electricity in Senegal but would require access to a grid to power rural locations.

At the moment, many of the suggested strategies are unfeasible due to the high associated costs. These costs can be reduced through government incentives, and foreign investments. Thus, Senegal should immediately focus on minimizing the challenges associated with independent power production and restructuring SENELEC to increase efficiencies. This would increase the attractiveness of investments in Senegal and would directly help electrify the nation.

5.2.2.2 Most Likely

The most likely scenario to increase electrification in Senegal is the expansion of inputs to the national grid. This will likely be done through the continued development of large solar parks and wind farms across the country, as well as utilizing the discovered fossil fuel resources.

Foreign investments will likely continue to have a large impact on the direction of the electrification strategy in Senegal. These investments will probably be focused on harvesting energy from renewable resources. Focus of the electrification strategy in Senegal will remain on increasing the capacity of the national grid before expanding the reach of the grid. Rural communities will likely continue to burn biomass to meet their electrification needs. These needs may also be met through an increase in the usage of other biomass sources such as agricultural residues to produce power. Smaller installations targeting rural communities will also begin to become more prevalent in the near future. However, it will likely take a long time for these small installations to fully electrify the 8.4 million people living in rural locations.

5.2.2.3 Business as Usual

The business as usual case for Senegal would be to continue to import fossil fuels in large quantities and refine them locally, as well as continue burning biomass in rural locations. The use of fossil fuels was not included in the evaluation matrix as it is not perceived to be a feasible option down the road. The negative effects of fossil fuels have previously been discussed in addition to the risks associated with depending on an imported unsustainable resource for the majority of power production in a country. The burning of wood will likely continue in rural locations without access to the grid, contributing to deforestation in Senegal.

Senegal currently imports a small amount of renewable hydropower, recently opened a solar park, and has begun constructing a wind farm. This indicates promising growth of renewable energy in the country. However, this growth has been primarily due to foreign investment, which may be impacted in the future by unstable foreign economies and governments. Additionally, foreign investors in Senegal face many challenges that could impact their electricity output, such as grid instability and technical difficulties. These challenges are negatively impacting the amount of foreign investments Senegal receives and have been addressed by the government as areas they are working to improve.

Currently, electrification strategies are focused on increasing electricity production in Senegal before expanding the grid and electrifying rural areas. Thus, it is likely to be a long time before the entire country is electrified if business as usual continues.

5.2.3 Effects of Electrification

The populations and economies of developing countries are expected to increase in the coming decades leading to an increase in electricity demand. Electrification is required for the economic development of developing countries. Rural electrification has been identified as a key method to reduce poverty and increase living standards in developing countries (Moser, 2013). Having access to electricity presents an opportunity for economic development in rural villages, improving the standard of living through agriculture, education, gender equality, health, and environmental sustainability.

Energy access for agricultural activities can increase crop yield, as it is able to assist in irrigation, harvesting, and after harvest activities. Educational opportunities increase as access to light at night allows for the opportunity to study after the sun goes down, and less time spent collecting biomass, such as wood, for energy production leaves more time to study. Women can utilize the previously used time spent collecting biomass to complete other tasks that can generate income, thereby increasing gender equality.

The general health of the population can be improved by increasing access to medical care and reducing air pollution. As previously mentioned, having access to electricity increases educational opportunities, which could lead to more doctors and expand access to medical care. Electricity would also enable the use of different medical technologies, which would improve the standard of medical care in Senegal.

Additionally, energy is currently produced in rural locations in Senegal through the burning of biomass, such as wood. Burning biomass releases harmful toxins into the air, which leads to indoor air pollution. Thus, a decrease in biomass usage will reduce the number of premature deaths of children and women as a result of air pollution. Lastly, reducing biomass usage will decrease the stress placed on the environment, especially as a result of deforestation (Thiam, 2011).

6. Recommendations and Conclusion

6.1 Limitations

The results of this report are subjected to several limitations. Due to a lack of available data on the natural resources and general costs for labor, land, and maintenance in Senegal, multiple assumptions were made and detailed throughout the report. Despite the assumptions related to the results, the methodology described, and the benefits and challenges associated with the different technologies can be utilized to analyze the implementation potential in any country.

The conclusions and recommendations for future research based on the final results are discussed below. Further data and analysis should be completed before implementing any of the examined strategies.

6.2 Conclusion

The objective of this paper was to analyze the potential energy sources in Senegal. These energy sources were evaluated using their physical and economic potential, as well as their levelized cost of electricity. Potential strategies for increasing electrification in Senegal were reviewed. Two major issues that Senegal needs to address in the future with regards to their electrification strategies have been identified. These issues include how to reduce dependence on imported fossil fuels and how to increase electrification rates, especially in rural areas.

Dependence on imported fossil fuels can be reduced by sustainably exploiting alternative resources and diversifying the energy supply. To sustainably exploit alternative resources caution must be taken to maintain the surrounding ecosystems. For example, biomass can continue to be used as any energy source, but caution should be taken with respect to the amount of biomass harvested to reduce impact on local ecosystems.

Senegal could diversify its energy portfolio through a mix of solar, wind, biomass, and hydro power investments. Based on the analysis completed in this paper, it can be concluded that the best path forward for increasing electrification rates in Senegal is to increase the solar power production. Solar power is able to provide power to the grid and electrify rural communities without access to the grid. Wind, biomass, and hydro power were also proven to have significant potential in Senegal but would require a grid expansion to electrify rural areas.

From the analysis completed in this paper, it was identified that solar power was the best method to increase electrification rates in rural locations without access to the grid. Wind, biomass, and hydro power were also determined to have significant potential in Senegal. However, they would require access to the national grid or an isolated system to distribute power. The levelized cost of electricity for the renewable energy sources analyzed were within the historic range of levelized costs for fossil fuels. This indicates that the costs for renewable energy is similar to historic costs for fossil fuels. Since the benefits of producing renewable energy outweigh the advantages of importing fossil fuels, it is likely that renewable energy will become an important part of Senegal's energy future.

6.3 Next Steps

Further research on this topic should include the collection of data that would enable accurate renewable energy potential calculations. This would be able to confirm the conclusions reached in this paper. Additionally, alternative energy sources and their potential in Senegal should be analyzed. These include offshore wind power and marine energy technologies. It could also be interesting to do research on SENELEC to identify how its inefficiencies are impacting electrification rates and to look for ways to optimize its processes. Reviewing how government policies could be used to promote renewable technologies and shape the energy landscape in Senegal could also be a path for future research.

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