MSc Program
Environmental Technology & International Affairs

The Pathway to a sustainable energy future of Sub-Saharan countries
A case study of the implementation of renewable energy technologies in Senegal

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 5 June 2018

Affidavit

I, **VALERIE HENGL, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE PATHWAY TO A SUSTAINABLE ENERGY FUTURE OF SUB-SAHARAN COUNTRIES: A CASE STUDY ON THE IMPLEMENTATION OF RENEWABLE ENERGY TECHNOLOGIES IN SENEGAL", 58 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Many countries in the Sub-Saharan region and especially in West Africa are among the poorest and least developed regions in the world. In particular, the possibility of access to electricity remains one of the biggest challenges of its population despite its enormous potential for renewable technologies. Therefore, this master thesis examines by means of a case study on Senegal, why the implementation of renewable energy projects in Sub-Saharan Africa is so slowly evolving and establishes recommendation how the Senegalese government can overcome the barriers of renewable energy implementation by appropriate policy measures and financial incentives. First of all, a country overview with data about the current electricity sector and the legal framework in Senegal is presented. Further, the appropriate technologies regarding its renewable potentials are discussed. Next, the opportunities, barriers and solutions for a successful implementation of renewables are presented. It is found that Senegal has already implemented some policy measures to improve the distribution of electricity and the country's energy mix. However, the vast opportunities of these innovative technologies can never be harnessed without the appropriate application of certain legal regulations, suitable financial measures and enhanced technological capabilities.

Table of content

List of Acronyms and Abbreviations

ADB	African Development Bank
AEME	Agency for the Economy and Control of Energy
ANER	Senegalese Renewable Energy Agency
ASER	Senegalese Rural Electrification Agency
BP	British Petroleum company
CDM	Clean Development Mechanism
CO2	Carbon dioxide
CSP	Concentrating Solar Power Devices
ECB	European Central Bank
ECOWAS	Economic community of west African States
EIB	European Investment Bank
FCFA	Communaute Financiere Africaine Franc
FDI	Foreign direct investment
FIT	Feed-in tariff
GDP	Gross domestic product
GEF	Global Environment Fund
GW	Giga Watt
HV	High voltage
IPP	Independent Power Producers
IRENA	International Renewable Energy Organization
kWh	Kilowatt per hour
LV	Low voltage
MV	Medium Voltage
MW	Mega Watt
NGO	Non-governmental organisation
ODA	Official development Aid
OECD	Organisation for Economic Co-operation and Development
PANER	National Action Plan for Renewable Energy
PNUER	The National Rural Electrification Emergency Program
PPAs	Power Purchase Agreements
PPP	Public Private Partnership
PSE	Plan Sénégal Emergent

PUDC	Emergency Community Development Program
PV	Photovoltaic
R&D	Research & Development
RE	Renewable energy
RES	Renewable energy systems
RET	Renewable energy technology
SDG	Sustainable Development Goals
SENELEC	National utility provider in Senegal
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USD	US Dollar
WB	World Bank

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1. Introduction

“As long as the sun shines, the grass grows, the river flows and the wind blows”

- Native American saying

This native American saying underlines the unique advantage of renewable energies in its very core: as long as mother earth exists, and the sun keeps shining, as long renewable energy can be harnessed. Thus; it is striking that Sub-Saharan Africa has the greatest potential for renewable energy but the lowest energy access rate in the world. In addition, the insufficient infrastructure, the lack of health care and education in combination with the rising living standards in Africa bring many challenges with them. To meet these challenges, efficient harnessing of the technology improvements by tapping renewable energy sources for economic development is of utmost importance. According to The Economist (2014), the new innovative energy systems offer African nations the opportunity to jump from the world`s electricity laggard to a leader in renewables – if the governments don’t hold it back.

While the Sub-Saharan countries are struggling in order to adopt and utilise the possibilities this globalized world is offering, developed countries already focus on the next challenge that is ahead of us, climate change. With the announcement of the Sustainable Development Goals (SDGs) by the United Nations, the new era towards a path of sustainable development was celebrated. The outstanding impetus, which promises to fulfil most of the hurdles ahead is *renewable energy* (RE). These technologies offer the benefits of a cleaner environment because of fewer emissions, a more gender-inclusive society by enabling electricity to all, better educational quality through the possibility of studying at night, zero hunger through effective agricultural uses and foremost they ensure access to affordable, reliable, sustainable and modern energy for everybody.

However, when visiting Senegal, one notices that implementation is not easy for economies that are not able to finance themselves, even though of their possible potential. The challenge remains to invest into improvements of their infrastructure and education, while being fully dependent on the import of goods. Even if RE offers many opportunities for developing countries, without cooperation with international actors it is not possible to leapfrog over the hurdles.

Therefore, this thesis aims to investigate the question, *how the Senegalese government can overcome the challenges regarding the implementation of RE by identifying the policy measures to enable a blooming renewable energy sector for all Senegalese people.*

This methodological framework of this thesis was developed during a field trip to Senegal were government officials and entrepreneurs were interviewed and the local environment investigated. In addition, a literature review through relevant academic papers and institutional websites has facilitated the creation of this thesis.

Firstly, this paper will define the term renewable energy and discuss the benefits that are attached to it. Afterwards, it will focus on the difficulties regarding the local infrastructures on the implementation of renewable energies. Secondly, it will take a closer look at the case of Senegal and develop a strategy on how renewable energy technologies can be efficiently and economically implemented. The next chapter investigates the potential of renewable energies in Senegal, in addition to an overview of its current electricity sector and policy framework. After having established the current situation, the barriers, possible business models for RE entrepreneurs and support mechanisms are analysed. Lastly, recommendations for the Senegalese government will be discussed following with the conclusion.

1.1. Overview of the Benefits of Renewable Energies in Sub-Saharan countries

The lack of electricity is one of the main bottlenecks for economic growth and poverty reduction in Sub-Saharan Africa. The access to electric energy increases the economic productivity of a country by enabling the population improvement in their daily life like the ability to work at night or the use of automatic water pumps to raise the productivity of the agriculture by providing food security. Renewable energy offers so many opportunities because it permits the use of various technologies.

According to the International Energy Agency (2018), renewable energy is defined as energy that is derived from natural processes that are replenished constantly. “In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biofuels, geothermal, hydropower and ocean resources, and biofuels and hydrogen derived from renewable resource.” (International Energy Agency, 2018).

In the case of Senegal, RE allows the country to become independent from fuel imports and, therefore, constitutes a reliable and sustainable substitute to traditional energy sources. Furthermore, the use of RE decreases greenhouse gas emissions compared to traditional biomass and coal plants: Thus, renewable energy technologies (RET) do contribute to the third goal of the SDGs by decreasing air pollution and further providing a healthier lifestyle. Besides, RE generates only CO2 emissions during the production and instalment of its respective infrastructure and thus hardly contributes to climate change (Schwerhoff & Sy, 2017). Especially in rural Senegal these technologies may serve as direct substitutes for the collection of firewood which is the traditional energy source used in the country. Therefore, contributing to a sustainable use of forests and ecosystems. Another advantage of the innovative technology of renewables is that they can be implemented in remote, rural areas and deployed in a decentralized way. This is particularly important to the country as it features a widely dispersed population.

The aforementioned reasons on how the implementation of RE benefits the overall population of Senegal, raise the question why RE is not yet extensively diffused in the country. One relevant explanation is that social benefits for a community outweigh the private benefits of investors, i.e. economic gain, by far. Therefore, the country is in need for international organisations that align the needs of a society with the investors incentives (Schwerhoff & Sy, 2017). Subsequently, international financial institutions like the World Bank (WB) and the African Development Bank (ADB) may employ financial aid for RET in Senegal to reduce the bottleneck of energy access and hence trigger the reduction of global inequalities with an extremely high social rate of return.

2. The implementation of renewable energy in Senegal

2.1. Country overview

Figure 1: Map of Senegal (ildado.sn, 2018)

The Republic of Senegal is a country in West Africa, enclosed by Mauritania in the north, Mali to the east and Guinea-Bissau and Guinea to its south. Additionally, it borders The Gambia, which separates its Southern region Casamance. The Republic of Senegal gained its independence from French Colonization in 1960 as the Mali Federation, which only lasted several months. In 1982, The Gambia and Senegal formed a nominal confederation of Senegambia that failed largely in the integration of the two countries and was therefore again dissolved in 1989 and the nations remained constant since. The total area of the Republic of Senegal is about 196 722 km² with a population of 14.5 Mio. and a median age of 18.7 years (Central Intelligence Agency, 2018). The capital of Senegal is Dakar which is located in the west with about 3.52 Mio. Inhabitants (2015). About 44.4% of the total population lives in urban areas with a rate of urbanization of 3.53%. The birth rate was about 36 per 1000 people, about the same as the average of all Sub-Saharan countries (37) but very high compared to OECD countries with a rate of 12 out of 1000 in 2016 (Central Intelligence Agency, 2018). Furthermore, about 57.7% of the population are literate. The two official languages are French and Wolof. About 95% of the population is Muslim, 4% Christian and about 1% of Animist religion.

Senegal is said to be one of the politically and economically most stable countries in West Africa. The unemployment rate is about 48%, but in the age group of 15-24 years it is hardly about 12,4% (Central Intelligence Agency, 2018). Moreover, due to the high unemployment rate the national net migration rate is negative with minor improvements over the last years (Worldbank, 2018). The Senegalese economy is mainly driven by the mining, construction, tourism, fisheries and agriculture sectors where the major export goods include phosphate, fertilizer, agricultural products (mostly peanuts, millet, rice, fish), petroleum refining and gold mining.

In addition, Senegal is a member of the Economic Community of West African States (ECOWAS) which is a regional economic cooperation of fifteen western African countries[1]. The official currency is the Communaute Financiere Africaine francs (CFA) which is also used in 7 other West African states namely: Benin, Burkina Faso, Guinea-Bissau, Ivory Coast, Mali, Niger and Togo. The FCFA has been established in 1945 and has been pegged to the France Franc in order to hinder strong devaluations of the currency and at the same time facilitate the exports to France substantially. In 1998 and in anticipation of the Economic and Monetary Union of the European Union, the FCFA members agreed to peg their exchange rate to the exchange rate of the Euro. Nevertheless, the blind side for presumed monetary stability is that the respective unions monetary policy is being decided externally by the ECB.

Furthermore, the country's GDP per capita in 2017 amounted to 2 700 USD with a growth rate of 6,8% (Central Intelligence Agency, 2018). The average time to start a business decreased from 57 days in 2000 to 6 days in 2016, which indicates that the Government facilitates the environment for entrepreneurs (Worldbank, 2018). Additionally, a majority of

[1] A full list of the member countries to ECOWAS can be found in Appendix 2.

the financial transactions, especially in the countryside of Senegal, are being done using a mobile phone, therefore the mobile cellular subscriptions per 1000 people in 2016 was at an astonishing rate of 98,5% (Worldbank, 2018).

However, the electrification rate in rural areas is under 28%, whereas in urban areas in Senegal it lies at around 90%. The percentage of access of the total population to electricity is 64,3 %, which is the 3rd highest share in the total ECOWAS area (Worldbank, 2018). The only two countries that have much higher electrification percentages are Cabo Verde and Ghana, but both countries also have much higher GDP levels than Senegal. When looking at Graph 2.1[2] it can be observed that Senegal is slightly followed by Cote d'Ivoire and Nigeria, which has the highest GDP of them (Worldbank, 2018). This indicates that Senegal is doing a good job with its total electrification rate when compared to similar countries.

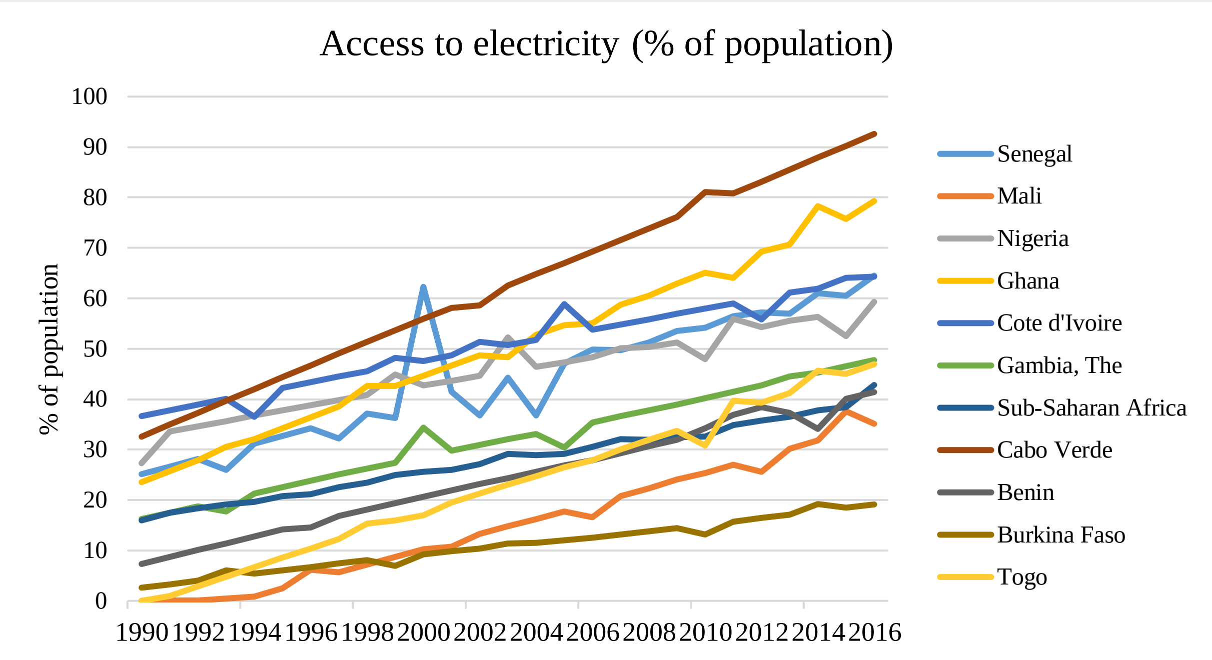


Table 2.1: Access to electricity (Worldbank, 2018)

Though, Senegal remains one of the most stable democracies and hence economies in Africa. Therefore, the country is highly attractive for Foreign Direct Investments (FDI) and Official Development Aid (ODA). According to the definition of the World Bank (2018), foreign direct investment refers to direct investment equity flows in the reporting economy. "It is the sum of equity capital, reinvestment of earnings, and other capital. Direct investment is a

[2] The following ECOWAS countries have been excluded in the table because there electrification rate was too low to be of any significance: Guinea, Guinea Bissau, Liberia, Niger and Sierra Leone.

category of cross-border investment associated with a resident in one economy having control or a significant degree of influence on the management of an enterprise that is resident in another economy. Ownership of 10 percent or more of the ordinary shares of voting stock is the criterion for determining the existence of a direct investment relationship" (Worldbank, 2018).

Looking at Table 2.2 it can be detected that FDI has been constantly increasing over the last 20 years. Even though there were some fluctuations, an overall upward trend can be observed. It is remarkable that the inflow was the highest in 2008, before a decrease of about 150 000 000 $ USD was observed until 2010 (Worldbank, 2018). This slump can be attributed to the financial crisis, when most investors withdrew their money from developing countries due to the instability of financial markets worldwide. Overall, inflow of FDI to Senegal plateaus around 400 million USD $ in 2016, which accounted for 2,6% of its GDP (Worldbank, 2018).

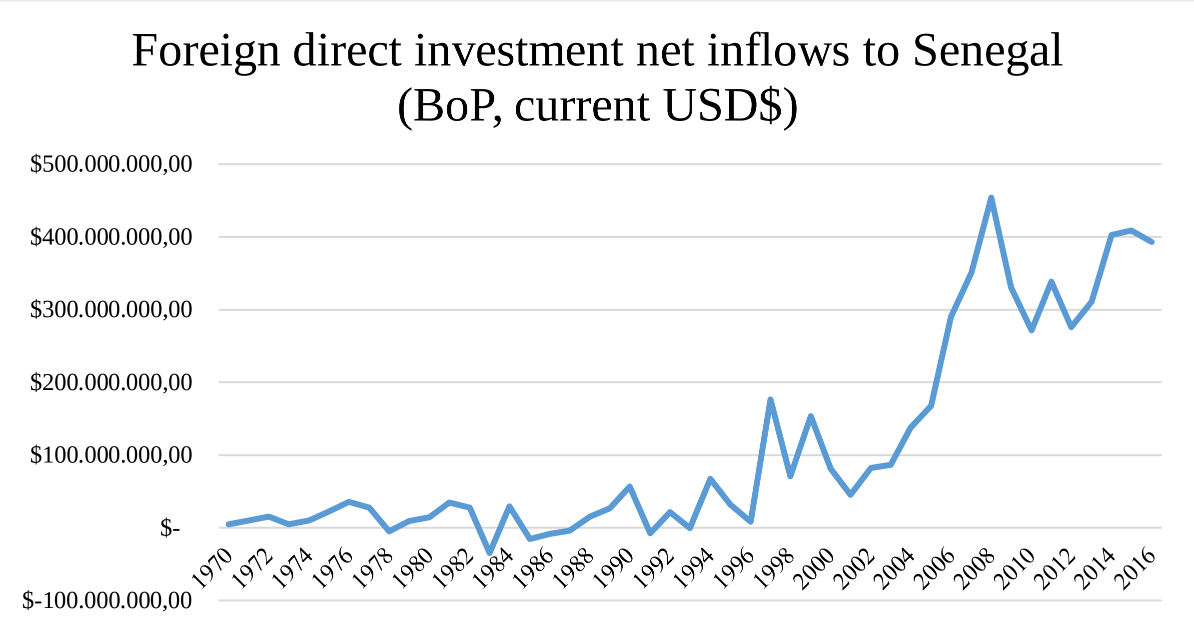


Table 2.2: Foreign direct investment net inflows to Senegal (Worldbank, 2018)

When comparing the net inflow of FDI in Senegal to other sub-Saharan countries in Table 2.3, divided by their respective GDP percentage, it can be clearly observed that the Republic of Senegal achieved exactly the average percentage of all Sub-Saharan countries. Only Ghana experiences a higher inflow of FDI than Senegal, which can be attributed to the fact that Ghana has a higher rate of economic growth and offer a more stable institutional framework which leads to lower investment risks. Noteworthy is the volatility of FDI in the Gambia. The Gambia experienced high investment inflows since the 2000´s, in 2006 it had a net inflow 12,5% of its GDP (World Bank Group, 2018). Yet, the country suffered greatly from the financial crisis in

2008 and the inflow further decreased with the political instability and protests the country experienced in 2015. Concluding, one can argue that political stability is definitely one of the main factors influencing the inflows of FDI. To further increase its inflow rates, the Senegalese government should therefore always prioritize its political and economic stability.

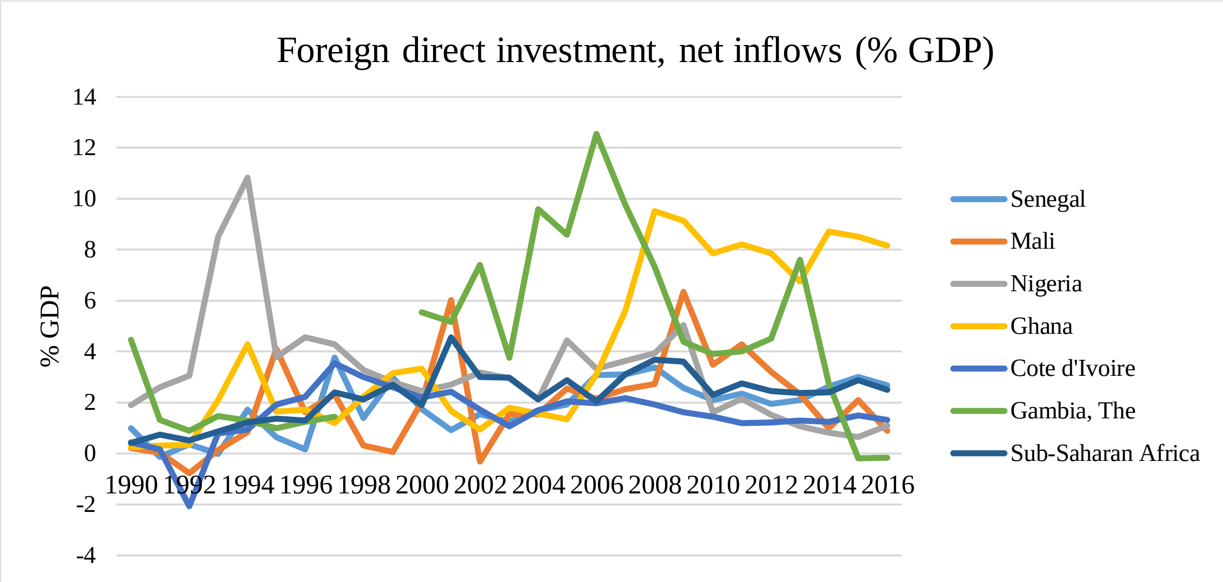


Table 2.3: Foreign direct investment, net inflows (% GDP) (Worldbank, 2018)

2.2. Energy policy framework in Senegal

The electricity sector in Senegal is governed by the Minister of Oil and Energy Sources, Mr. Mansour Elimane Kane, who proposes the general policy and norms to the President of the Republic. The Energy Ministry grants the licenses and concessions provided for by the legal and regulatory framework in accordance with the applicable provisions. Licences and concessions are granted by order with a valid contract by the minister. The independent Electricity Regulatory Commission is responsible for regulating the production, transmission, distribution and sale of electric energy in accordance with the legal and regulatory provisions (Commission de Régulation du Secteur de l'Electricité, 2018).

SENELEC is a public limited company with majority ownership from the government and is the official concessionaire of production, transportation, distribution and sale of electrical energy. In addition, SENELEC is also responsible for the identification, financing and realization of new electricity generating projects. The company is the major player in the electricity sector in Senegal which is mainly due to its monopoly on the transportation and concession ownership throughout the country, except for the interconnected network of

Manantali. Additionally, the framework allows for the participation of independent power producers (IPPs) which are allowed to sell to large costumers. It is bound by electricity purchase agreements signed with independent producers and some self-producing Senegalese industries.

Moreover, the Senegalese Government established three energy related agencies to deal with the most relevant issues in the state´s energy sector.

Firstly, the Senegalese Rural Electrification Agency (ASER) which is an independent agency responsible for providing electricity companies and individuals with the technical and financial assistance needed to support rural electrification initiatives. ASER is developing the electrification programs based on the rural electrification plan defined by the minister of Energy and Oil. The agency is responsible for tenders regarding concessions for new distribution networks in rural areas and investigates about electrification projects by private operators.

Secondly, the National Renewable Energy Agency (ANER) that is responsible for the promotion and development of alternative energies, in all their forms: solar energy, wind energy, biomass, tidal power and small hydro. The agency is researching in the field of renewable energy development, as well as identifying, evaluating and exploiting the potential of available and economically exploitable renewable energy resources in the different regions of the country (ANER, 2018). Furthermore, ANER is participating in the definition and formulation of energy policy, advising the Senegalese Government in the field of renewable energy.

And lastly, the Agency for the Economy and Control of Energy, (AEME) which participates in the implementation of policies in the areas of energy, environment and sustainable development. Furthermore, the agency provides businesses, local authorities, public authorities and the general public with its expertise and advice. In addition, AEME helps to finance and implement projects in the areas of energy efficiency.

Furthermore, there are two relevant independent electricity producers in Senegal, in addition to SENELEC. GTI-Dakar is a private independent producer which signed a contract with SENELEC for the exclusive supply of electricity in the timeframe of 15 years in 1996. It currently operates a 53 MW combined-cycle power plant consisting of a 37 MW gas turbine and a 16 MW steam turbine. The other producer, Ekom-Energie-Manantali is a subsidiary of Eskom South Africa that has signed a contract with the Manantali Energy Society (SOGEM) for the operation and management of the electrical works of the Senegal River. The network operated 5 power plants of 40 MW each and a transmission network with a total length of 1683 km.

2.2.1. National Action Plan for Renewable Energy (PANER)

In December 2015, the National Acton Plan for Renewable Energy till 2030 was launched by the Senegalese Energy Ministry in cooperation with the United Nations Industrial Development Organization (UNIDO), the Global Environment Fund (GEF), Austrian, German and Spanish Development Cooperation, the European Union and the international Renewable Energy Organization (IRENA). The plan has the overall objective to strengthen the share of renewable energy in the energy balance to support Senegal's sustainable development (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015).

The action plan is based on a treaty signed previously by Senegal with the Economic Community of West African States (ECOWAS) in 2013. Also, the national action plan is in accordance with the national development plan "Plan Sénégal Emergent" (PSE) that has been launched in 2012 constituting the benchmark of economic and social policy on the medium and long term until 2035. Thereby, most notably a more equitable geographical distribution of energy services and better articulation of energy with the strategic sectors of development is promoted. This is crucial in order to fight against poverty and preserve the environment, especially through the promotion of clean energies.

The main pillars of the plan are the objectives, policy implications, and scenarios regarding the Senegalese renewable energy and energy efficiency plan.

Firstly, the main objectives of the plan are to (1) ensure the country's energy supply in sufficient quantities, in better conditions of quality and durability at the lowest cost; (2) operate energy diversification to reduce the country's vulnerability to hazards exogenous, especially those of the world oil market; (3) promote the development of renewable energies; (4) broaden people's access to modern energy services by ensuring more equitable distribution of efforts, focusing on disadvantaged regions and vulnerable layers; and finally (5) promote energy management and energy efficiency (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015). In more detail, the new framework is committed to:

- reach a non-biomass commercial energy independence rate of at least minus 15% in 2025, thanks to the contribution of renewable energies and biofuels;
- operationalize the legal, regulatory and institutional framework of the subsector renewable energies;

- obtain, in 2020, a rate of 20% renewable energy in the potential for global electric power utilization.

The following section gives an overview of the policies and measures that have been put into place or planned to directly achieve the stated objectives. The measures can be broadly put into three target categories, namely the increase of renewables towards the energy mix, the increase of rural electrification and a third one including multiple aims.

First, regarding the increase of renewables towards the energy mix, six projects have been conducted in 2017 and 2018, with a total volume of 310 MW, consisting of 150 MW in wind and 160 in solar energy. Further, three hydroelectric plants are planned for 2021 with a volume of 144 MW.

Second, there are three major plans that want to ensure the universal access to rural electrification. The “PNUER” and “PUDC” aim at increasing the rate of rural electrification from 29 % in 2014 up to 60 % in 2017. Most recently the plans have been replaced by a new plan that targets an electrification rate of 100 % by 2025 (Ministère de l’Energie et du Développement des Energies Renouvelables , 2015).

Thirdly, the government implemented several projects with multiple aims. The “Programme national Biogaz” aims to build 10’000 biodigester facilities between 2015 and 2019 and thereby augment the capacity up to 27’500 by 2025. Furthermore, the European Investment Bank (EIB) assists Senegal financially with EUR 100 Mio. to construct a drinking water treatment plant and save thereby 122GWh from 2030 onwards (Europäische Investitionsbank, 2018).

Lastly, the government outlines respective targets for its aims and outlined a strategic strategy on how to achieve them. In Table 2.4 one may observe that Senegal wants to increase its RE share by 2030 to 31 % (including hydro). In addition, as seen in Table 2.5 mini-grids will be further established in rural remote areas, where it will not be feasible to build a national network. Thus, the target is to increase the off-grid renewable energy mix to 26% in 2030 (Ministère de l’Energie et du Développement des Energies Renouvelables , 2015). Remarkably, Table 2.7 with the national targets for solar water heaters, is a small measure but when implemented in 2030 by 80% in all hotels and public institutions, it significantly decreases the energy needed to heat the water otherwise.

Table 2.4 Targets for grid-connected renewable energies	2010	2020	2030
Capacity installed in MW			
Installed capacity of renewable power plants in MW (including medium and large hydro)	68	403	632
Share of renewable energy as % of total installed capacity (including medium and large hydro)	10.90 %	35.60 %	31.80 %
Grid connected power generation (GWh)			
Total electricity generation based on renewable energies in GWh (including medium and large hydro)	253	896	1501
Share of renewable energies in the electric mix in % (including medium and large hydro)	10 %	20 %	23 %

Source: (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015)

Table 2.5 Targets for off-grid renewable energies	2010	2020	2030
Share of rural population served by off-grid systems (mini-grids and stand-alone systems) of renewable energy services in %	2 %	15 %	26 %

Source: (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015)

Table 2.6 Targets for household cooking energy	2010	2020	2030
Share of the population using improved stoves in %	18 %	27 %	32 %
Proportion of charcoal produced by efficient carbonization technologies in %	/	86 %	94 %
Consumption of modern cooking fuels (e.g. LPG, biogas and solar fires) -% of population * LPG	25 %	47 %	64 %

Source: (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015)

Table 2.7 Targets for solar water heaters	2010	2020	2030
Solar water heater for the production of domestic hot water and hot water for industrial processes			
Number of residential homes with installed solar water heaters	/	102000	328000

Share of community health centres, maternities, and schools with solar water heaters (%)	/	40 %	80 %
Share of agro-food industries (using hot water in their process) with solar water heaters (in %)	/	10 %	20 %
Share of Hotels using solar water heaters (%)	/	40 %	80 %

Source: (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015)

2.3. Electricity sector & generation capacities

Senegal's electricity sector is overwhelmingly dependent on heavy fuels like oil and diesel, which both have to be imported. Non-surprisingly, the electricity demand has constantly risen over the past decade and is expected to rise even further in the next years.

Moreover, in 2017, new natural gas reserves have been found off the coast of Mauritania and Senegal. British Petroleum (BP) estimates that the area called "the Tortue field" has the potential of about 15 trillion cubic feet (tcf) of gas, which would be equivalent to all of Africa´s gas production for nearly seven years (BP, 2018). The Senegalese Government has agreed to split the resources and revenues in equal parts with Mauritania, expecting the first commercial drills in 2021 for a period of 50 years. Hence, the Senegalese government plans to transform the current electricity sector in favour of natural gas, phasing out the usage of heavy fuel by the latest in 2025 (Ministère de l'Energie et du Développement des Energies Renouvelables , 2015)

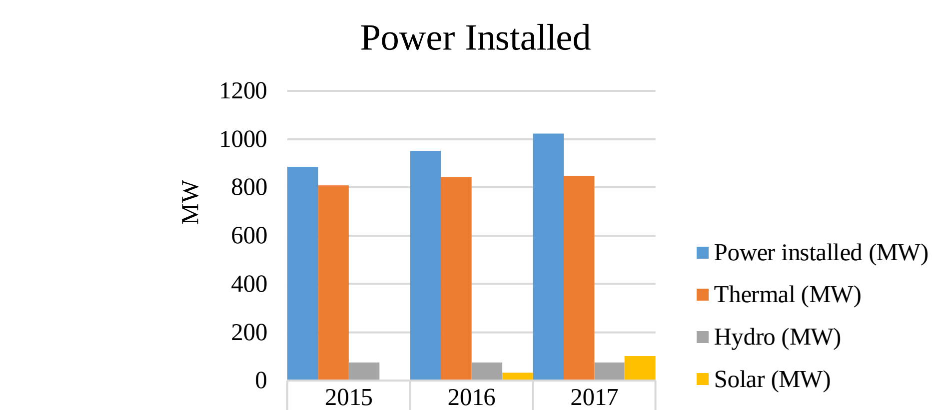
To keep up with the rising demand, the Government has announced in PANER to install 322 MW of renewable energy generation capacity by 2020 (excl. hydro), accounting for about 28.4 % of the total capacity installed. To further increase its electricity access rate referred to in Table 2.1: *Access to electricity (Worldbank, 2018)*, the Government has set targets to achieve universal access in 2025 (Africa EU Renewable Energy Programm, 2018). This will be beneficial for consumers and businesses connected to the national grid which nowadays still suffer from highly unstable and unreliable energy supply. This ultimately leads to black outs and to productivity losses for firms and consequently the overall economy. Hence, to secure a stable access to electricity many firms rely on fuel driven emergency generators.

The total power installed in Senegal by 2017 was 1024 MW (SENELEC, 2018). At table 2.8 shows that within the last 3 years SENELEC has increased the power installed from 886 to 1024 MW. The biggest rise in energy production is due to the newly installed solar plants.

Additionally, during 2018 and 2019 SENELEC plans to feed in another 2x75 MW from solar plants into the energy grid. The country´s generation capacity is expected to reach 1.6 GW in 2030 (Africa EU Renewable Energy Programm, 2018). However, the biggest part of the plants installed will probably be thermal power plants with the usage of gas.

SENELEC operates 11 power plants in Senegal, about 83% (464 MW) of them operate with diesel or gas. In 2015 one plant operating with steam producing 87 MW and one 2 MW solar plant has been installed. Independent, industrial or private energy producers supply their energy to SENELEC through individual Energy Purchase Contracts. Since 2017, these producers operate four diesel thermal plants (298 MW), one coal plant (16 MW) and four solar plants (99 MW).

All of them supply to the interconnected grid of SENELEC, which is mainly concentrated in the western and north-western parts of the country (i.e. Dakar, Thies, St. Louis…). The Non-Interconnected Network comprises the regional centres of Tambacounda and Boutoute (Ziguinchor) and nearly 26 isolated centres distributed between the regions of Kaolack, Tambacounda, Kolda, Ziguinchor, Kedougou and Sedhiou. Additionally, SENELEC has three Energy Purchase contracts with neighbouring countries. Two of them are with Mali for the hydraulic energy generated by the Manantali Dam in the Senegal river basin (75 MW). The third agreement is an energy purchase agreement of the thermal power plant SOMELEC in Mauritania (20 MW).



	2015	2016	2017
Power installed (MW)	886,5	951	1024
Thermal (MW)	809,5	843	848
Hydro (MW)	75	75	75
Solar (MW)	2	33	102

Table 2.8 Power Installed (SENELEC, 2018)

The total electricity production in Senegal is about 3’920.54 GW/h with an electricity consumption of 3’014 GW/h (SENELEC, 2018). In Table 2.9, it is remarkable that in 2015 almost 90 % of energy was based on fossil fuels. When comparing this to table 2.8, it is outstanding that the Government of Senegal has increased the thermal power in the last three years but has increased the power installed of solar energy by almost a 50-fold. Also, in Table 2.9 with the data from the IEA (2018) it is striking that the electricity losses in Senegal are about 17% of the total electricity production. The high losses are a phenomenon all over the sub-Saharan countries according to officials from international organisations. This is due to the fact, that often inhabitants illegally connect themselves to the national grid systems which then lead to disruptions and black outs.

	2015 (GWh)	**% of total electricity production**
Total Electricity Production	3955	
from oil	3307	84 %
from gas	165	4 %
from biofuels	66	2 %
from hydro	342	9 %
from solar PV	4	0 %
from other sources	71	2 %
Losses	**659**	**17 %**
Final Consumption	3371	
Industry	939	24 %
Residential	1097	28 %
Commercial and Public Services	867	22 %
Agriculture / Forestry	19	0 %
Other	449	11 %

Table 2.9: Energy production and consumption in Senegal (iea.org, 2018)

Another, significance worth mentioning for developing countries is the share of final consumption by sectors in table 2.9. In developed nations, like Germany or the USA, the industries have by far the highest electricity consumptions, usually about 50 % of the total country’s consumption. Consequently, it is striking that in Senegal the residential sector derived the highest amount of the total electricity consumption, higher than the industries. This is very common in developing countries and can be explained through the poor economic force of the country, the very low industrialization and the high dependence on the agricultural sector.

In Table 2.10 it is noteworthy that the total electricity production in Senegal has been increasing the last three years which can be interpreted as good sign to keep up to the increasing electricity consumption of its increasing consumers.

	2015	**2016**	**2017**
Total Electricity Production (GWh*)*	3437.58	3598.74	3920.54
Thermal (GWh)	3104.35	3231.74	3502.51
Hydro (GWh)	333.23	360.07	332.21
Solar (GWh)	-	6.86	85.83
Production SENELEC (GWh)	2214.29	2144.45	2139.92
Maximum peak of the network (MW)	533	560	606
Number of clients	1121962	1199155	1332075

Table 2.10: Total electricity production (SENELEC, 2018)

2.3.1. Transmission & Distribution Network Design

As already mentioned, SENELEC is the monopolistic provider on the transmission and distribution of electricity in Senegal. The distribution system comprises a 7,627 km medium-voltage (MV) network at 6.6-kV and 30-kV, a low-voltage (LV) network with a total length of 6,761 km as well as 13 high-voltage (HV)/HV and 3,511 MV/LV (30 and 6.6 kV) substations (Africa EU Renewable Energy Programm, 2018). The transmission network consists of 225-kV and 90-kV lines totalling 6,761 km in length. The HV network supplies the energy to the public, mixed and customer distribution stations. The LV network distributes energy from the MV/LV transformer station to the customer. In Figure 2 the production and transport system is visualized. It is remarkable that the HV line goes from the Manantali Dam in Mali through the north around the border down to the capital city Dakar to transport the energy retrieved the quickest as possible to the biggest cities of the country. The MV lines are concentrated in the western part of the country that also perceives the highest population density. While in the south and south-east it can be observed that there are only very fragmented parts of MV lines which are not connected to the HV line.

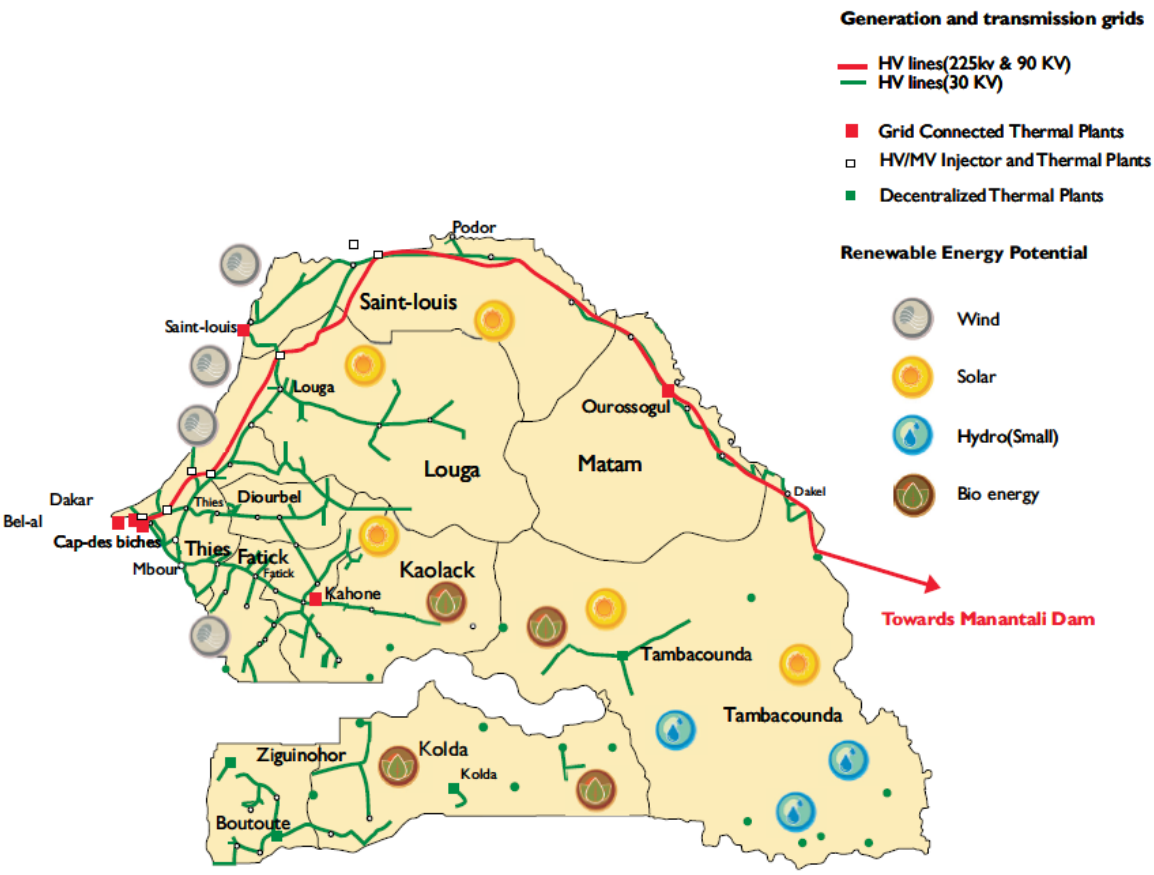


Figure 2: Production and Transportation of electricity *(IRENA, 2012)*

Since the electrification rate still varies strongly in rural areas (namely between 3 % to 73 %) the implementation of the emergency program is more a rebalancing of electrification between departments with a minimum electrification rate by building a medium voltage line.

2.3.2. Tariff Plan & Energy Pricing

From the 1st of May 2017 onwards a new electricity tariff regulation came into effect. It classifies the low voltage clients into three categories: domestic users, professional users and prepaid. Sub sequentially the price of energy per FCFA/kWh is fixed according to three usage blocks.

The per capita electricity use in Senegal lies is about 229 kWh, which is the third most among West African countries (World Bank Group, 2018). The average cost to customers for electricity in Senegal is therefore 101.64 FCFA which are 0,15 € cent. This is about the same price of 1 kWh of electricity in Vienna, Austria. This is very remarkable, because if you compare the income levels of Austria and Senegal with each other it is outstanding that the electricity price is the same. This means that even though the electricity consumption per capita in Austria is 8360 kWh, the Senegalese population pays the same and even has a weaker and more unreliable supply system. This finding has extremely high implications for the Senegalese energy policy. The high prices result from the expensive fuel imported and the reparation works needed and the high cost of imported goods to improve the current grid.

Due to the enormously high costs of electricity to consumers it is impossible for the government to finance new connections or improve the current ones by raising electricity tariffs. In addition, the price of electricity in Senegal has already decreased in the recent years since it was up to 0.18 € cents in 2012. Consequently, it is unbearable to increase the electricity tariff in Senegal because it will immediately result in demonstrations of the population which is already suffering from the high tariff scheme. This brings the policy makers into a vicious circle since it is not feasible to cover the costs of the much-needed improvement of the national electricity network infrastructure through a rise in electricity prices. Therefore, the government has to rely heavily on donor organizations to loan money or other financial instruments (IRENA, 2012).

Tariff Categories (Energy price in FCFA/kw)			
Domestic user (UD)	1st block	2nd block	3rd block
Low Power Domestic Use (DPP)	90.47	101.64	112.65
Medium Power Domestic Use (DMP)	96.02	102.44	112.02
Professional User (UP)			
Low Power Professional Use (PPP)	128.85	135.68	147.68
Medium Power Professional Use (PMP)	129.81	136.53	149.24
Prepayment User			
Low Power Domestic Use (DPP)	90.47	101.64	101.64
Medium Power Domestic Use (DMP)	9.02	102.44	102.44
Low Power Professional Use (PPP)	128.85	135.68	135.68
Medium Power Professional Use (PMP)	129.81	136.53	136.53

Table 2.11: Tariff categories (SENELEC, 2017)

Tariff Option	**1st block**	**2nd block**	**3rd block**
UD-PP	From 0 to 150 kWh	From 151 to 250 kWh	More than 250 kWh
UD-MP	From 0 to 50 kWh	From 51 to 300 kWh	More than 300 kWh
UP-PP	From 0 to 50 kWh	From 51 to 500 kWh	More than 500 kWh
UP-MP	From 0 to 100 kWh	From 101 to 500 kWh	More than 500 kWh

Table 2.12: Tariff options *(Senelec, 2017)*

2.4. Usage & technology of renewable energy

2.4.1. Different types of renewable energy technology

The origin of problems resulting from rather weak national grid network performance and technical instability usually lies with a low availability factor of electricity, huge losses during the transformation and delivering processes and the poor diversification of energy resources. Besides, an increase in population growth and demographic expansion constantly lead to a higher level of electricity demand (Mohammed, Mustafa, & Bashir, 2013). Innovative renewable energy technologies can aid developing countries to overcome these shortages and offer the opportunity to provide electricity and energy services to even the most remotely located and dispersed consumers. Henceforth, this chapter will briefly describe the diverse types of RE and consequently discuss their different strengths, weaknesses and the opportunities they can bring to the Senegalese people.

Biomass energy sources

In the context of this paper, biomass refers to forest tree residues, animal residues, crop waste, agricultural residues, waste paper materials, wastewater and domestic waste. Biomass is the primary source of renewable energy in Senegal and is specially dominated by the heavy usage in the rural areas (see Figure 3). Moreover, many communities depend on forest resources for firewood or charcoal production (Mohammed, Mustafa, & Bashir, 2013), used for household purposes like cooking, drying and space heating. This is attributable to the fact that these are

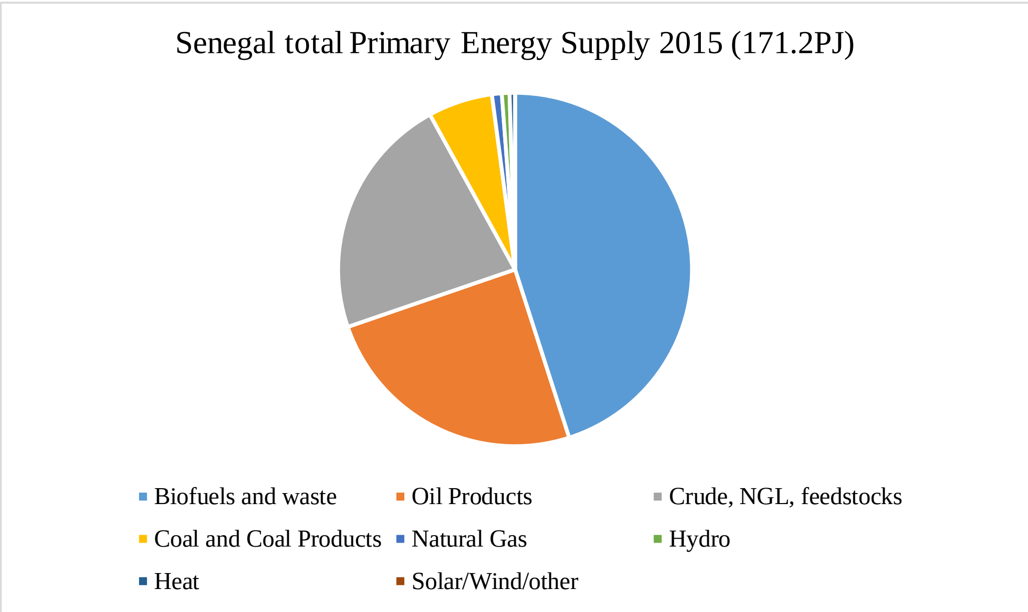


Figure 3: Senegal Total Primary Energy Supply 2015 (IEA, 2018)

the easiest resources collected and available throughout the country, especially for people coming from substandard economic background. Therefore, it is impossible to collect explicit data about its usage since it is a very traditional source of energy and only estimates can be made. However, according to Dasappa (2011), the cereal production and agricultural residues in Senegal are estimated to have a power potential of 41 MW at a 30% availability.

Biogas

"Biogas is a mixture of gases generated from anaerobic digestion of the organic fraction of solid waste" (Mohammed, Mustafa, & Bashir, 2013). Due to its main component of methane it has a very high-quality calorific value and is a very clean source of energy. The biogas production entails the controlling and collecting of different waste substances and then translating them into biofuel production for energy. This process can entail different biodegradable matters like crop waste, animal residue, waste water and so forth. Material for biogas production is abundantly available in Senegal, due to their main production sector of agricultural products. Unfortunately, most of the agricultural residues that could be used are burnt after harvest or supplemented to livestock feed.

The benefit of biogas is that one single biogas plant can be operated for a whole community or enterprise. It is not very economically efficient to install many small biogas plants. Therefore, one of the advantages of biogas is that it serves constantly to a big group of households and is thus a very reliable energy supplier. Even though biogas has this huge advantage which other renewable energy sources do not possess, its implementation is confronted with several challenges.

The reasons for constraining the technology are from various origins. Firstly, a biogas plant is one of the most expensive renewable energy technologies and, therefore not financially affordable for many communities in developing nations. Secondly, biogas plants only operate under very strict conditions that need very advanced technological expertise which is constrained by the human capital shortage in Senegal. Next, the principle advantage of a stable energy supply could also be assessed a disadvantage because the low electricity grid quality in Senegal cannot assure a constant energy outlet. Therefore, a biogas plant has long operating cycles and cannot, due to its technological capabilities, be used as an electricity fill-in technology like PVs. Fourthly, particularly in the rural areas in Senegal a constant water supply cannot be maintained, which is also one of the constant input needs for biogas. Consequently, the biogas potential in Senegal has been by far not exploited. However, if the strategic advantage of biogas is noticed by the governments, it could serve as the perfect renewable substitute to the fluctuating wind and solar energy providers. Hence, governments could focus on the development of village sized biogas plants and offer the required resources for the development to the investors. More importantly, human waste and agricultural waste, such as abattoir refuse are already sparsely used for biogas production in Senegal, although so far only as an energy source for industrial customers and not as an input source to the national grid.

Solar energy

Solar energy is the phenomenon of solar thermal radiation propagated from the sun through a positive enthalpy change in the solar body. In simple terms, it is the conversion of sunlight into usable energy forms. Solar technologies include solar photovoltaics (PV), solar thermal electricity and solar heating and cooling (International Energy Agency, 2018). Solar photovoltaic systems are special solar-energy capturing sensitive devices that convert solar radiation to energy. Meaning that these technologies need power from the sunlight, the output

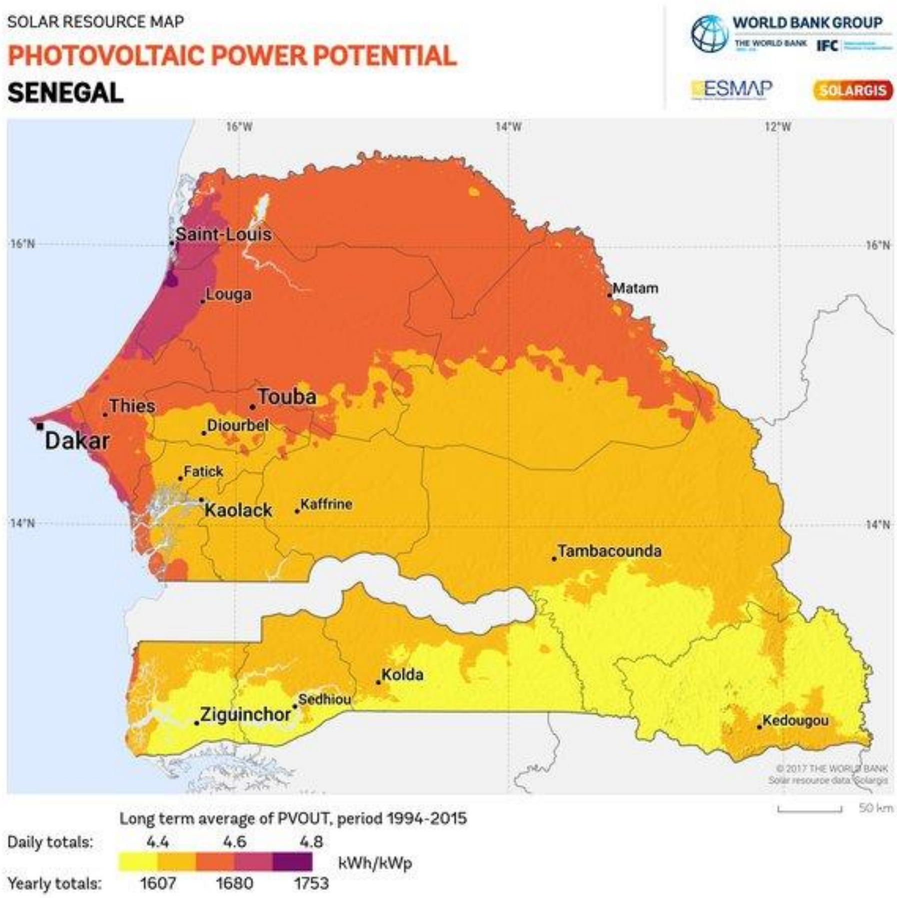


Figure 4: Photovoltaic Potential Senegal (World Bank, 2018)

can be only supplied during the day. Accordingly, during the African monsoon season in the summer months mid-June to Mid-October the PV power output in Senegal is slightly reduced.

Overall, Senegal has an excellent potential to harness solar radiation (Figure 4). In fact, the solar irradiation is above 2 000 kWh/m²/year for Global Horizontal Irradiation across most of the country, with an average global daily irradiation calculated at 5.43 kWh/m²/day (Africa EU Renewable Energy Programm, 2018). The regional differences can be further explored in Figure 4., but the most striking result is that the country has its highest photovoltaic potential in the north-western part which decreases when going south.

Photovoltaic panels have the advantage that they can be manufactured in modules in large plants harnessing economies of scale. This explains why PV systems become more affordable over the years, since their marginal cost curve decreases with an increase in production quantities. Additionally, the technology of PVs made a considerable progress, leading to a better quality and a smaller size of the panels. This allows for a wide range of applications such as from calculators to utility-scale power generation facilities (International Energy Agency, 2018). Due to the high potential and utility of PV panels in Senegal, they can be used for water pumps, water heating systems and other small scale purposed. Particularly, the PV collectors installed on roofs of buildings allow for the energy generation for a variety of household purposes like domestic lightning but also public closed circuit television systems, traffic lights and urban street lights (Africa EU Renewable Energy Programm, 2018). Finally, solar power applications have especially for households many compelling advantages, however, they require a big sum of capital investment. So far, since purchasing power in Senegal is relatively low, PV systems are only rarely bought by private individuals (Africa EU Renewable Energy Programm, 2018). Further, PV technology is very flexible in generation and improves the national grid stability, when there is high demand. Energy from solar systems can be accessed during the day when there is a high demand in energy due to air conditioning.

Other technologies that use the radiation of the sun are concentrating solar power devices (CSP) and solar thermal technologies. Solar heat and cooling technologies produce heat which is then used for hot water, space heating, floor heating or industrial processes (Africa EU Renewable Energy Programm, 2018). The collector type and design regulate the required heat temperature. CSP systems focuse the radiation on a heat receiver which then in turn transforms the heat into electricity. The advantage of this technology compared to PV panels is that is has a built-in thermal storage. This means that CSP technologies continue to transform heat into electricity even at sunsets and sunrise. Concluding, CSP systems should not be seen as a direct competitor but as a complement system to PV technologies, receiving the biggest output when operating both of the technologies at the same time.

Nevertheless, one of the main challenges when implementing solar energy systems is that the energy can only be harvested during sun hours, i.e. during the day, whereas at night when the households need energy for household appliances it cannot be accessed.

Another shortcoming of solar power is that the fluctuation of electricity supply to the weak grid network may lead to over or under capacities which can further lead to blackouts. This problem can be solved with the employment of battery storages for the surplus electricity that permit that the power can also be used at night. Yet, the usage of batteries further raises the costs of solar systems.

Due to its high potential, solar energy certainly has to be included in the national power generation mix in Senegal. The government recognizes the outstanding value of solar energy and has already commissioned two solar plants. Taking into account the currently high price for fossil fuel, the Senegalese Government makes some serious efforts to diversify its energy mix. In the last two years 4 solar plants have been built with a total power installed of 89.5 MW (SENELEC, 2018) all of them in corporation with independent power producers (IPP). Until the end of 2019, 4 new plants with a total sum of 165 MW are planned. All of them are located close to the western coast of Senegal where the highest population density is found.

Wind energy

Wind energy is the other major renewable energy source with a potential to meet the rising energy demand of the world and guarantee the security of the global energy supply. The harvesting of wind energy is one of the oldest electricity generation technologies next to hydropower. In rural areas, wind energy application plays a very important role for electricity generation.

Looking at Figure 5, however, one must realise that the wind potential in Senegal is very limited. At 100m height the potential is solely in the coastal region above 200 W/m² from Dakar to St. Louis, with an overall mean power density for the windiest 10 % area is 190 W/m² (World Bank Group, 2018). The average wind speed in Senegal is about 5.78 m/s which is just above the required threshold of 5m/s to harvest the wind. These findings indicate the wind potential in Senegal remains rather limited. Nevertheless, during the winter months in 2018, the first wind generators with an installed power of 50 MW will be launched with the corporation of an independent power producer (IPP) near Taiba Ndiaye. The project will be installed in three phases of 50 MW each from 2018 to 2020 (SENELEC, 2018).

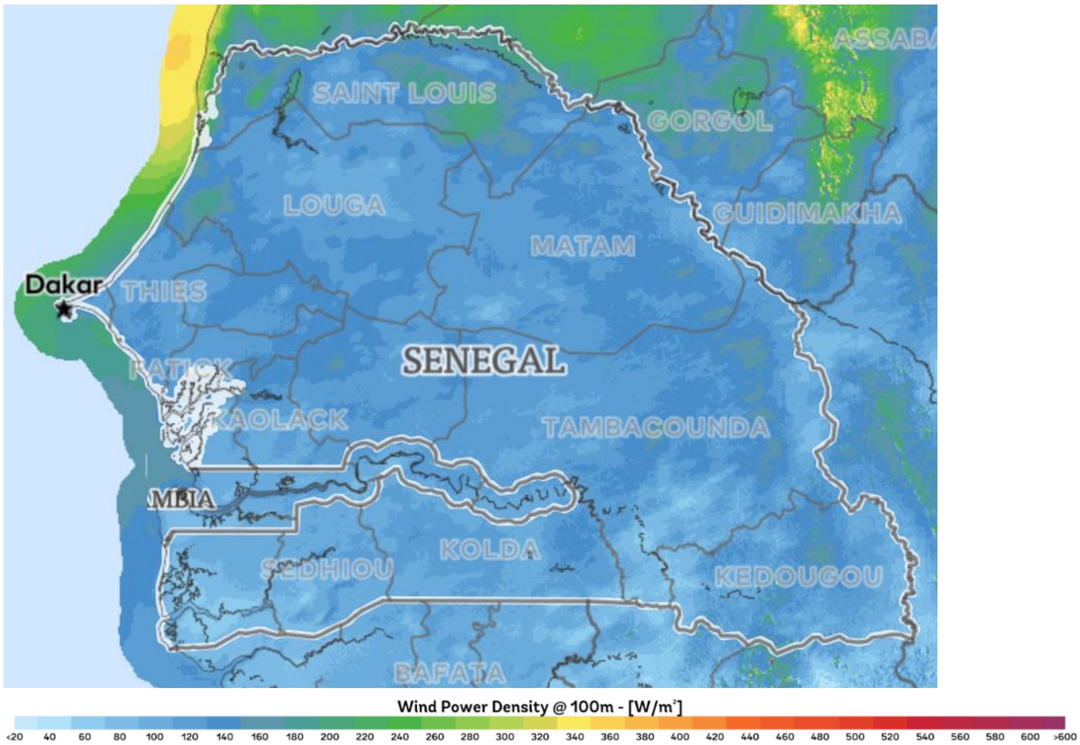


Figure 5: Power density of Wind in Senegal. (https://www.globalwindatlas.info/area/Senegal,

Hydropower energy

The Senegal River which borders Senegal, Mauritania and Mali has a very high hydroelectric potential which is estimated to be about 1200 MW (Africa EU Renewable Energy Programm, 2018). Including the Gambia rivers, Senegal accounts for a total of 1400 MW hydropower opportunities. All these technologies are nowadays still underdeveloped. Schwerhoff & Sy (2017) claim that 92 % of Africa's hydropower potential is not yet exploited. Currently, only about 260 MW are exploited by the Manantali Dam which is located within Mali. Since Senegal is not able to operate a hydroelectric power plant on its own, it is in negotiations with Mali, Gambia and Guinea for future shared projects. In 2019, a 48 MW shared hydro plant with Guinea is supposed to start operating. By the end of 2025, 4 more co-shared plants are foreseen with an additional total amount of 270 MW (SENELEC, 2018).

When taking a look at Figure 2: "Production and Transportation of electricity" it can be examined that even though there many possible implementations of RE in Senegal, the highest potential bears solar energy. This is due to the fact that solar energy can be easily installed in a decentralized way, in remote areas as well as urbanized ones. In addition, small PVs have an enormous cost advantage, especially when taking into account the small income in Senegal. However, the functionality of PV systems bring also challenges to the already weak grid systems. The hurdles can be overcome with battery storage systems or smart meters. Consequently, even if the potential is the highest for solar energy, it is high advisable for the government to invest into a diverse energy mix since this ensures the most balanced and reliable supply of energy.

3. Energy Strategy in Senegal: Opportunities, Barriers and Solutions

3.1. Opportunities & Barriers

Senegal offers all the main opportunities for fruitful renewable energy projects: Firstly, very high potential of renewable energy sources, secondly, high energy prices in local energy markets and thirdly, growing demands due to future economic and population growth (Budzianowski, et al., 2018). In addition, Senegal has a high availability of domestic resources, a very high potential to reduce their import bills by decreasing the purchase of fossil fuels, green job creation and socioeconomic development including a reduction in poverty and improvement of sanitation (Budzianowski, et al., 2018).

Indeed, the modern age brought possible solutions to facilitate the development of RE systems in rural areas. Innovative payment systems for electricity such as mobile phones for small purchases by employing net metering and prepaid meters may solve many issues. The opportunities RE carry for developing countries are widely known. Foremost, they address the bottom of the pyramid by enabling the rural populations an access to energy.

So far, this thesis has broadly analysed why RE systems are of such utmost importance to the future of Senegal. However, the question arises - why are they not already implemented?

Many scientists have already prophesied in the beginning of the 2000s that renewable energy technologies will be used by developing countries to leapfrog industrialized nations. Although Senegal has in recent years developed a renewable energy policy and has so far installed some renewable projects, it has been far away from the renewable energy phenomenon that was once predicted for almost all African countries.

The reason for the missing investment into RE in Senegal can be explained by the concept of risk and return. The higher the risk, the higher the return, and the more likely the failure of the project. Therefore, due to the low investment rates, it can be argued that an investment into RE in Senegal is from the investors perspective not attractive enough. Most likely because the return is too low and does not pay off the risk involved. Also, the large gap of additional energy generating capacity originated from the currently very low electricity supply in Senegal as well as the very strong growth both in terms of population and in economic terms.

Hence, international organisations or climate funds installing and financing pilot projects cannot increase the capacity significantly adjusting for the countries fast growth rates (Schwerhoff & Sy, 2017). Therefore, a ramping up in international financing is certainly required to improve the current energy shortage. Moreover, the risk that deployment of RE faces, should be specifically targeted by policies so it can be sequentially mitigated or even removed over time. In the next paragraphs, this paper will focus on the last-mentioned deployment challenges organisations face when implementing RES in Senegal. First of all, the barriers will be categorized and thereafter the main barriers which Senegal faces will be further elaborated upon. Afterwards, further barriers which are frequently named in the literature will be shortly presented and applied to the Senegalese context combined within the context of Senegal

Firstly, the two main types of barriers can be differentiated into techno-economic and non- economic barriers. *Techno-economic* hurdles are associated with the direct costs of RET compared to fossil fuel technologies, given the internalisation of all external costs and ideal framework conditions (Müller, Brown, & Ölz, 2011). *Non-economic* barriers relate to factors that either prevent deployment altogether (no matter how high the willingness to pay) or lead to higher costs than necessary or distorted prices. The main challenges when implementing RE in Senegal are non-economic barriers. Foremost, the challenges of insufficient human capital availability, the weak institutional framework, financial hurdles and feeble technology diffusion are the main barriers investigated.

- *Human capital*

A very common problem all over Africa is the lack of skilled workers and the absence of managers with a solid business education. This "brain drain" phenomenon signified by the emigration of individuals with a high human capital level, can be attributed to two reasons. Due to political instabilities, economic insecurities and no bright prospects, Africa has witnessed an enormous wave of emigration in the last decades. Citizens which had the opportunity to gain a higher education in the past, were attracted by higher wages, relatively better working conditions and greater availability of job opportunities to emigrate into other countries. According to Budzianowski et al. (2018), around 60 000 professionals left Africa between the 1985 and 1990s.

The other reason for the absence of skilled personal was the failure of the public educational system which lead to a low literacy rate. Nonetheless in the last decades, most developing nations have issued nationwide educational programs with the help of industrialized countries in order to counteract this paradigm. However, the issue of human capital development still remains an enormous challenge. Fortunately, the Senegalese government has recognized this shortcoming and is currently investing a larger share of its budget in basic and higher education. Nowadays, about half of Senegal's population can read and write with a sharp increase over the past years because of a massive extension of the educational programs. Yet, even though the educational opportunities are improving, it is still not sufficiently increasing for the fast-economic growth of the country.

According to all interview partners, the lack of well-educated and skilled workers is still one of Senegal's main problems. Especially, in the sector of renewable technologies the lack of skilled engineers is a big cost factor because the capable engineers have to be hired from industrialized countries with developed nations salaries, leading to much higher costs for developing nations. However, the education of an entire generation takes time and the respective fruits will not be reaped overnight. Therefore, for developing nations to fully utilize their population's potential the respective countries must patiently wait for the outcome of their policies and then offer their graduates a decent perspective in their country of origin. This perspective in the job market can range from better working conditions, a higher job guarantee, financial security to a motivating environment.

- *Institutional framework*

To harness the potential of renewable energy a high quality institutional framework with appropriate legal and regulatory conditions is needed. Experience has shown that the success of renewable energy projects is largely dependent on the existing government policies.

Mohammed et al. (2013) argue that policy issues are one of the major barriers to financial access and market development. In Senegal, the general framework is already in place and well-functioning, but it needs adaption to the challenges that RES comes with. For instance, it is legally impossible as an individual household in Senegal to sell your energy surplus obtained by a photovoltaic panel on your rooftop to the national grid network. Therefore, individuals investing in PV technologies for their households can only benefit from their investment through their own use of the produced electricity, but do not have the opportunity to sell their surplus. This makes PV systems not very attractive from a financial point, since the national electricity tariff is cheaper than investing in solar energy.

During the authors field trip to Senegal, an Interview partner from SENELEC confirmed that the government is currently working on new policies to enhance RES (SENELEC, 2018). The country set a target to achieve 20% of solar energy in the country's energy mix by 2025 According to the interviews, the providing law should be issued the latest by the end of 2018. Additionally, the decentralisation of the regulatory powers as indicated in the national decentralisation process is currently under discussion (IRENA, 2012). Furthermore, legal enforcement towards the quality of national policies should be enforced. Government policies should be targeted to strengthen the private sector's involvement and the entrepreneurial efforts. The current very tight regulatory framework in the electricity sector does not leave a lot of room for entrepreneurial development. To increase the attractiveness of foreign direct investment in this sector Senegal has to improve its institutional reliability for example by guaranteeing confidence between the private and public actors (Thiam D. R., 2011).

- *Financial barriers*

One of the main obstacles when implementing renewable energy projects is often not the technical feasibility but the absence of low-cost products and especially long-term financing vehicles in emerging and developing countries (Karekezi & Kithyoma, 2003). When talking about financing one has to consider that most RE technologies are not affordable to a bigger part of the population. Usually, RETs have high costs due to imported components from industrialised countries which cannot be manufactured locally. Since fossil fuel energy is already in place, the first RE productions sell the output at a very high cost to the consumers. In addition, as already mentioned above, the lack of skilled human capital makes projects even more expensive.

Another big issue regarding the implementation of renewable energy in Senegal is the financing of the respective projects. In every interview and conversation, officials mentioned the need for a higher level of financial resources. The Senegalese government tries its best to create conditions to attract foreign direct investments, as well as to encourage multinational banks to support private initiatives in the energy sector. According to Haselip et al. (2014), interest rates are relatively high in Senegal, which negatively influences the investment rates of the private sector, especially those of SME´s. In addition, local and multinational banks demand a short loan-repayment period in order to reduce their business risk while lending loans with higher maturities. This process acts as a major barrier in the renewable energy sector in particular since the return on investment in infrastructure projects like the RE sector do have a long-term investment horizon (Haselip, Desgain, & Mackenzie, 2014). While interviewing local entrepreneurs this notion was confirmed.

Most interview partners suggested that banks in general are quite ignorant to the small businesses sector as they perceive the risk of the lending activities without a notable credit history and insufficient collateral to be too high. Therefore, microfinance institutions could kick-start innovative business models to cope with this restriction and at the same time respond more flexibly and timely to local needs. Overall, the literature suggests that there are multiple key issues why SME´s do encounter difficulties in acquiring affordable loans.

Concerning the renewable energy market, companies have a high financial risk since the subsidized low electricity tariffs do not allow the immediate payoff of the initial investment. Additionally, a model needs to be developed which ensures that these modern technologies provided to consumers (also below the poverty line) do offer affordable energy prices while safeguarding the remaining industry to stay sustainable. Hence, there are several conditions that investors have to take into account while investing into the renewable energy sector in Senegal and that might turn a possible attractive investment into a very unattractive one.

Furthermore, it was observed that the recent economic crisis of 2007/08 has triggered foreign investors to withdraw their funds primarily from developing countries in order to increase their liquidity in their countries of origin. This had a tremendous effect on many emerging and developing countries' economies. At first those economies turned out to experience a recession as FDI was drawn out with serious implications on the host countries economic stability. The increased macroeconomic volatility led to political instability in several African countries. Further, the lack of investments destabilised some of the African currencies that were not linked to the Euro and had an impact on the major macroeconomic indicators.

Most notably, the foreign demand for elastic products that are easy to substitute and often produced in emerging and developing countries dropped significantly leading to a wave of mass unemployment and economic stagnation. The same was true for the renewable energy sector, where the supply of funds was abruptly stopped, and most infrastructure projects were being cancelled or delayed. The Senegalese population suffered these adverse effects as well but luckily the government remained its stability. Hence, the Senegalese government should increasingly strategize about how to regulate high capital movements in order to secure the stability of their economic and political system. This includes increasing the attractiveness of infrastructure with significantly longer investment horizons of up to several decades to foreign investors and to the domestic market.

- *Bureaucracy & Transparency*

Originally, it seems like RE projects and political actions are in a win-win relationship with many mutual benefits for developing nations. However, as pointed out by Ikejema et al. (2017) there might be a difference in the strategic outlook of the projects. Whilst the population is interested to solve their energy issues in a sustainable manner, some politicians bear the perception that RE projects must demonstrate their party´s fulfilment of campaign promises or support their pleas to their financial beneficiaries, thus presenting an agency problem (Ikejemba, Schuur, Van Hillegersberg, & Mpuan, 2017). The agency problem is a well-established economic theory identifying a conflict of interest between two parties. This conflict arises when the agent (in this case a politician in Senegal), who is supposed to perform a task on behalf of the principal's (the population of Senegal) best interest, acts on behalf of its own interests instead. For example, the population expects from their Energy Minister the improvement of the national electricity network, but he instead spends the money on gas explorations because of its alignment with an international drilling company.

Slow administrative processes and corrupt authorities are also significant hurdles that need to be overcome by entrepreneurs. According to Ikejema et al. (2017) the definition of transparency is "not merely the absence of opacity, but also the active pursuit of clarity in how public projects are designed and implemented". Conflicts of interest are common in RE where political influence is pervasive and usually translates into authority and decision-making power embodied in public sector officials (Ikejemba, Schuur, Van Hillegersberg, & Mpuan, 2017).

Bureaucracy and long waiting times when starting a new business are known to suffocate any entrepreneurial spirit in a country (Amankwah-Amoah, Egbetokun, & Osabutey, 2018). In addition, there might be high corruption costs involved in administrative offices which can delay the project and subsequently raise the extra costs. According to transparency international, Senegal ranks at place 66 of 180 countries in the corruption perception index for 2017, with a total score of 45 out of 100 points (Transparency International, 2018). Almost all the participants in the interviews agreed that corruption is a big problem in Senegal, even though no information could be given as to in which of the RE implementation stages corruption was the most influential to the outcome. Except one interview participant, who denied any response at the mentioning of corruption; proofing that the extent of corruption infiltrating the projects is very high. It has to be highlighted at this point that all the interview candidates were government officials or working for international organisations implying a certain bias. The absence of any transparency measures and inclusive stakeholder participation in the implementation of new projects, already suggests many opportunities for mismanagement.

- *Technology adoption & Underdeveloped infrastructure*

The benefits of renewable technologies can only be harvested if they are properly employed and then spread across the country. Meanwhile, there are many circumstances of African nations missing important infrastructure. Governments should not initiate the transition from old outdated technologies to new ones, but instead capture the new smart technologies directly. The advantage is that the population immediately has access to modern technology which facilitates the shift from poverty to prosperity. Moreover, technologies that improve existing methods and build on already established industries are more likely to be successful (Karekezi & Kithyoma, 2003). However, due to other constraints (for instance: financially, legal, etc…) it may not be possible for citizens to gain independence to the access and generation for energy to use. In addition, the lack of technical expertise on the regional level leads to a low uptake of new technologies as they are more complex. Likewise, grid integration constraints and deficient assessment of available renewable resources are also major risks.

Due to these barriers, the private sector is holding back potential investments into RET. Therefore, the adoption of RE is mainly implemented by development banks with ODA funds or NGO’s that work closely with the government. This has the benefit that the political and financial barriers are solved, however, there is a lack of appropriate technology adoption and training of local professionals. Although, most of these public projects are quite successful upon implementation, the missing link between the community and the appropriate technology is sometimes fatal. When a technological component needs to be repaired and the local technical personal is not able to do so, the production process halts. This leads to a delay of either several weeks till the new component or a skilled worker arrive or can even stop the whole process if the government cannot monetarily afford to repair it.

With projects implemented in PPP or with private investors on the other hand, the possibility of this problem is very low since every delay in production does ultimately lead to a reduction of the respective revenues from operation. More detailed, the private sector will implement a project only if its technological feasible and all the risks of losses are minimized. Therefore, entrepreneurs would make sure that the production does not come to a halt and invest properly into the training capabilities of their workers, ensuring a proper adoption. Additionally, the private sector will rapidly diffuse its technology and repeat their best practices, once successful. This leads to a much faster diffusion rate around the country and higher economies of scale, compared to projects by the Government and NGOs. Thus, for the success of RE entrepreneurs should be motivated by the policy makers to take risks and capitalise RET.

Another technical barrier is the underdeveloped infrastructure which cannot assure a permanent energy delivery, due to grid problems and capacity issues. This hurdle mainly centres around the flexibility of the energy system, for instance the power grids capacity to absorb RE.

These are the main barriers to the implementation of renewable technology which were discovered during the research in Senegal as well as in the academic literature. Other hurdles often mentioned in the literature include:

- *Cultural aspects & social challenges* like insufficient knowledge about the availability and performance of RE as well as lack of awareness and resistance to change (Thiam D. R., 2011),
- *Market aspects* that mainly concern inconsistent pricing structures, unstable currency markets, subsidies for fossil fuels, market power and the failure of taking social and environmental costs into account,
- *Low Intra-African collaboration and trade, and*

- *Environmental barriers* such as environmental impacts, catastrophes, geographical disadvantages etc.

However, all these challenges to renewable energy development are interlinked within each other. Non-economic barriers, for instance political instability, can also translate into economic barriers. The financial, market and economic barriers are all intervened with each other as are the others. Hence, when one hurdle is surmounted, the other one becomes apparent. The degree of interlinkage of different barriers can be observed in Figure 6 (Müller, Brown, & Ölz, 2011).

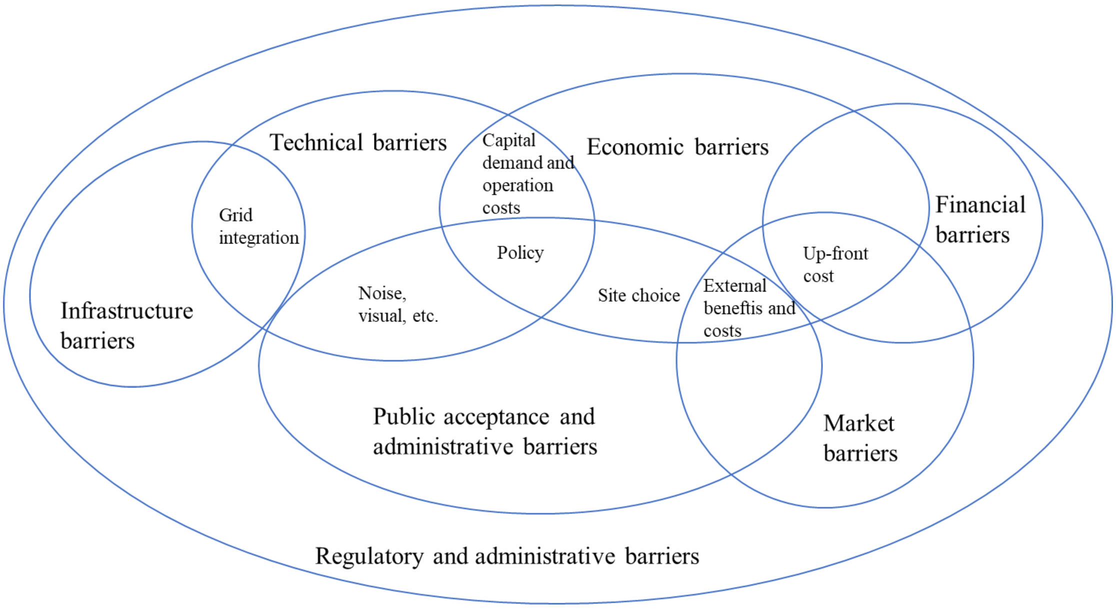


Figure 6: Connection of different barriers *(Müller, Brown, & Ölz, 2011)*

Due to these connections, it is obvious that one government policy may affect many different barriers. Therefore, it is reasonable for governments to look at the interlinkages of the different hurdles and investigate the possible outcomes of their measures. Additionally, the timing to overcoming the hurdles is of utmost importance. It is not feasible for Senegalese policy makers to decrease the financial barriers for the investment into RE through e.g. subsidies, when the technical barrier of a stable grid connection to feed in RE is not ready yet. Therefore, the government has to prioritise their current hurdles and then investigate which policy should be released the first. This finding also indicates that policy makers cannot expect an immediate effect of new policies, since the barriers are so deeply connected with each other that solving one barrier does not lead to the solution of the overall problem.

Some of the hurdles that were mentioned can be solved by a so-called bottom up approach and others by a top down. The missing human capital can only be overcome with the right government support, while technological diffusion can also commence through entrepreneurs developing adapted innovations to the countries issues. All these hurdles can however, be solved with a top-down approach, meaning that the incentives are decided at the highest hierarchy of a population pyramid, namely the government of the country and are then performed from the top till the outcome reaches the bottom of the pyramid, (the poorest population). The top-down approach has the advantage that it is most efficient because it is very autocratic in its decision process and is decided by a few people and then immediately implemented. However, it is also a quite undemocratic process since it is mostly decided by the most powerful people without considering the desires of the rest of the population. In contrast, the bottom-up-approach ensures that the poorest socio-economic group of a nation starts incentives to change but because there are more people involved in a revolution from the bottom up, it takes much longer till it reaches the top then vice-versa. The best approach is a combination of top-down and bottom-up, where they both meet in the middle. Therefore, the next section will focus on the most efficient business models for the renewable energy sector that have the best opportunities to revolutionize the Senegalese energy sector from the bottom upwards.

3.2.Business Models for renewable energy enterprises

Enhancing entrepreneurship is considered as a crucial part when overcoming the challenges of renewable energy implementation. Throughout the history, small entrepreneurs have managed to change a whole sector with their innovative approach. This is also possible regarding renewable energy in developing countries. To achieve the best of both worlds, governments should look out for opportunities to facilitate the operating environment for entrepreneurs as well. Hence, the following investigates the best business models suitable for renewable energy entrepreneurs in developing countries, whose impact on the renewable energy sector will be further discussed.

First, the term business model for renewable energies is defined. As one can see in Figure 2.5 a business model consists of four major pillars: the product, the costumer interface, the infrastructure management and the financial aspects. The product describes the core of a business and the value proposition the company offers to the market. The customer interface clarifies which customers are targeted, how the company delivers the product or services and how the customer relationship is maintained (value creation). The infrastructure management defines a company's logistical approach and network that the firm needs to deliver the created value. The financial aspects address the revenue model and the cost analysis (value capture) (Engelken, Römer, Drescher, Welpe, & Picot, 2016).

A good business model is dedicated to a value proposition, creation and capture and acts as the interface between a firm's development and the market (Budzianowski, et al., 2018). The term "value creation" is defined as how a business designs and executes its motivation and revenue generation for designing and delivering products and services to users (Gabriel & Kirkwood, 2016). If they are used correctly, they may be a disruptive innovation if new products services or markets are created and do as a matter of fact challenge the status quo in a pre-established industry.

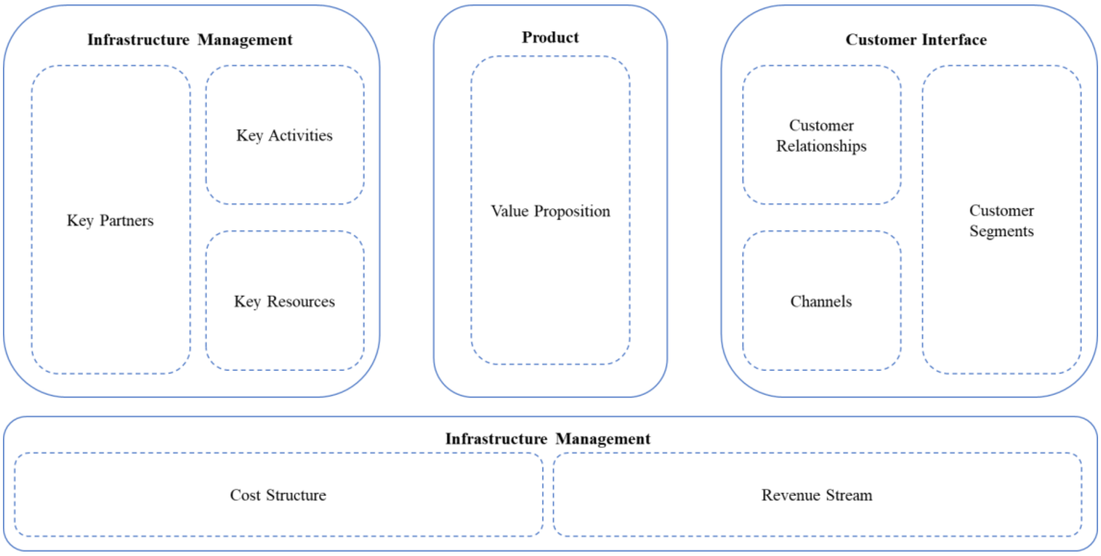


Figure 7: Business Model Canvas (Osterwald et al. 2010)

In RE projects, suitable business models support the overcoming of the barriers and facilitate the adaptation of conventional energy business models of utilities to innovative ones that are competitive on the market (Budzianowski, et al., 2018). An attractive business model is supposed to enable market price oriented renewable energy harvesting and decrease the costs for governments due to economic incentivization. Furthermore, a business models promotes to exploit synergies within economies to accelerate value creation. For a successful project implementation, a RE company should be governed by its business model to establish many partnerships with different stakeholders. A business model analysis describes how the enterprises in the renewable energy sector in Senegal are integrated in the respective market. Furthermore, it offers a framework for comparison between different models for understanding which business models may be better suited to overcome the predetermined hurdles.

According to Gabriel & Kirkwood (2016), entrepreneurs are enablers of the uptake of RETs and recognized as important early adopters which actively promote the need for RET products and services. Since entrepreneurs are risk takers that enable disruptive technologies and institutional change they are especially needed in developing countries to trigger a change to the predominance of the fossil energy industry. Accordingly, developing countries need strategies to motivate the participation of SMEs and microenterprises in order to spread RET. It has been identified that renewable energy entrepreneurs provide supply and maintenance of small-scale technologies and systems, including solar lights and solar home systems as well as provision of microfinance and other financial tools (Gabriel & Kirkwood, 2016). In the research of Gabriel & Kirkwood (2016) three main types of business models in the renewable energy sector in developing countries were found: Consultants, Distributors and Integrators. Each of the three types have their own characteristics in the 4 pillars of the business model canvas and are each triggered by different institutional frameworks.

- *Consultants*

Consultants are the most often reoccurring business model in Africa. They are usually characterized by the small number of employees at a relatively young age (Gabriel & Kirkwood, 2016). Usually, they are the first stage models for entrepreneurs since they have very low overhead costs and are solely based on the knowledge of their employees. The value preposition they offer to their customer is evolved around the provision of advice on their renewable energy loads, system designs and sizing (Gabriel & Kirkwood, 2016). However, they do not implement the systems they recommend but have the available network in place to find suitable technicians for the installation. Also, after they have consulted their customers about their energy needs, their customers are satisfied, and they will no longer require their services. The difficulties of entrepreneurs working as consultants experience the biggest challenges when looking for support by creditors and investors and the overall ease of the business environment in their respective country.

- *Distributor*

A business model built up like a distributor is focusing on the import, sales and delivery of renewable energy products (Gabriel & Kirkwood, 2016). They either operate a shop where they offer their products, or they deliver to their customers. Sometimes they are the implementing partners of consultants that recommend their installation services. The enabling factors to build a distributor enterprise are that the regulatory environment in their operating country is very supportive of their business approach. Most of the time the country has a widespread lack of energy infrastructure which offers the company many customers. Another encouragement for distributors are subsidies and tax concessions by the country to facilitate the spread of RET.

- *Integrator*

Enterprises built upon the Integrator model are a combination of the other two models and differentiate themselves by their bigger size and their longer time in business (Gabriel & Kirkwood, 2016). Integrators design, create and implement large-scale renewable energy systems on behalf of international organisations or communities (Gabriel & Kirkwood, 2016). Since their customers are mainly organisations, they get barely in touch with the end users of their solutions. This approach is not so common in Africa, probably by virtue of the absence of easy financing tools and very specific policies.

The three above described business models do not replace each other but rather shift from one to the other as business activities grow. Therefore, they may rather be seen as different life cycles stages for entrepreneurs. The relationship appears to be a three-step evolution of renewable energy businesses since is starts with the youngest and smallest and ends with the biggest and oldest. Furthermore, because of many commonalties between entrepreneurs of consulting and distribution businesses, their relation can be described as bidirectional and overlapping, before progressing to an integrator model (Gabriel & Kirkwood, 2016).

Consultants ←→ Distributors → Integrators

(Gabriel & Kirkwood, 2016)

Entrepreneurs developing a consultancy business tend to use their knowledge and experience as products and to exploit whatever start-up fund to finance them. When given the right governmental support and environment they may be able to gain additional capital to import and distribute the RET and further enhance their capabilities to become a distributor business. For distributors to become Integrators they need to acquire international funding experiences as well as governmental aid for renewable energy systems which allows them to develop and establish large-scale systems which are suitable for bigger communities (Gabriel & Kirkwood, 2016). According to Gabriel & Kirkwood (2016) most consulting businesses operate in Africa because the continent has the lowest ease of doing business and the entrepreneurs are therefore stuck to the consulting model due to the challenging country context. Additionally, the lack of accessing credit and the lack of protection for investors makes it hard for the entrepreneurs to grow. Hence, entrepreneurs in the consulting phase demonstrate the need of better government support to grow and to develop their network on the respective markets. Thus, it can be argued that promotive renewable energy policies are more relevant for larger businesses that operate in the supply and installation sector than for small service-oriented businesses. In addition, integrator businesses have higher start-up costs hence they need to access to more formal financial sources. That's why they are rather concentrated in regions with a rewarding institutional framework. According to the findings of Gabriel & Kirkwood (2016) the more renewable energy policies and government interest, the more of an encouragement of entrepreneurs to develop integrator businesses. In addition, when governments want to scale up their RE production to meet their targets, they employ rather large integrators which offer faster and bigger solutions. This analysis suggests that countries with less favourable conditions may not only give rise to lower levels of renewable energy businesses but also that these countries need smaller, simpler, more adaptive business models (Gabriel & Kirkwood, 2016).

Hence, in Figure 8 one can observe how the proposed relationship between country characteristics and types of businesses are interlinked. The policy recommendations resulting from this relationship are that governments can encourage more Integrator businesses with a more favourable institutional and regulatory framework. Moreover, if governments in developing countries with none or rather few energy policies pursue a more active approach combined with the interest of a higher share in RE, it facilitates the shift for consultant entrepreneurs to become integrators. Indeed, since there are many consultant businesses on the market in Senegal there is a high potential for them to once grow into larger scale distribution and installation activities (Gabriel & Kirkwood, 2016). The advantage of small scale renewable energy business models is that they can be tested on their feasibility on the market and then be replicated around the country in numerous times (Engelken, Römer, Drescher, Welpe, & Picot, 2016).

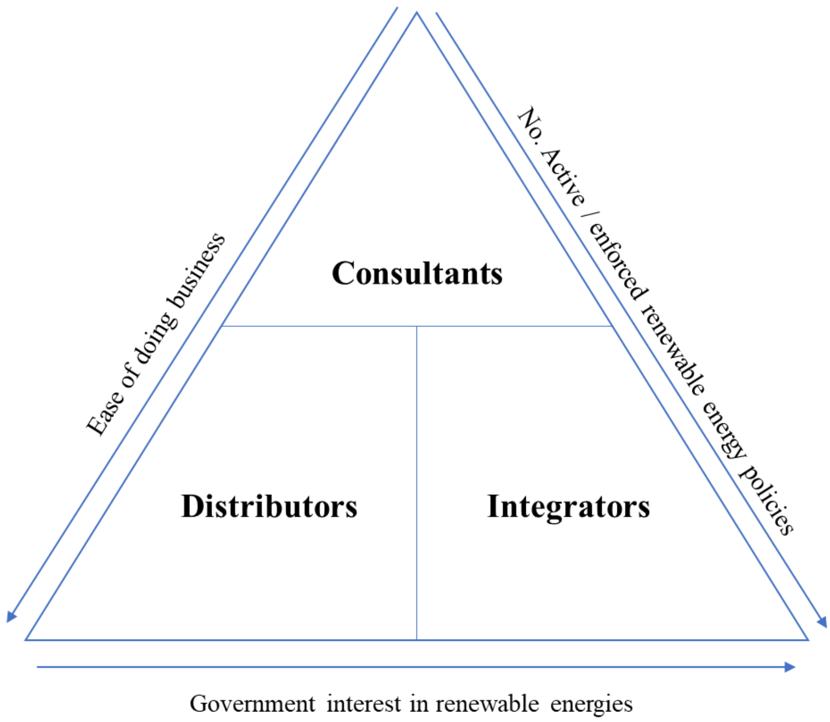


Figure 8: Business models pyramid (Gabriel & Kirkwood, 2016)

3.3. Policy suggestions & support mechanisms

To alternate the current business environment and stimulate the technical change in the energy industry in Senegal towards renewable energy, the government needs to install supporting policies to harness the benefits of RE. According to Thiam (2011) there are two types of mechanisms governments used to promote renewable technology: "Economic" or/and "Command and Control" instruments. The economic instruments can include many different forms like tax policies, subventions and tradeable permits (Thiam D. R., 2011). This thesis will thoroughly discuss the economic and financial instruments in the next chapter whilst the command and control mechanisms will be briefly outlined in the following paragraph. However, economic and command control instruments achieve the highest effectiveness when they are implemented in combination.

The command and control initiatives are regulations or standards normally issued by the government to promote renewable energy. The preference of one of these tools should be made accordingly to the country's priorities regarding environmental protection, economic development and socio-economic structure (Thiam D. R., 2011).

First of all, an overall improvement of energy governance is needed as it enables the more efficient allocation of resources and involvement of institutional and political actors. This in turn motivates local stakeholders like consumers and producers for example to get involved with the planning of the projects. Furthermore, the involvement of stakeholders helps to minimize the local constraints and further adds socio-economic characteristics to the whole processes that would have been otherwise overlooked. This is of utmost importance since particularly in Senegal the gap between rich and poor is very wide, and an involvement of both classes is vital for the success rate of a project.

- *Renewable obligation*

A renewable obligation is a set production target of RE during a fixed time period by governments (Thiam D. R., 2011). The providers of renewable electricity production can subsequently make an offer to the government and compete with other suppliers. In the end within a certain bidding period, the government choses the cheapest supplier. After the selection procedure, a contract is set up with the fixed price guaranteeing the payments. However, for an effective use of this instrument, as with all contracts trust and reliability between the contract parties is required. The investor has to be sure that the contract does not lose its validity when the next government comes into effect and cannot be influenced by public power. Thus, the renewable obligation is barely used in Senegal because investors from developed countries do not like to rely on the government's security.

- *Public Private Partnerships (PPPs)*

  PPPs are a very good option for large RE project in developing countries. They are a form of subsidized borrowing which has the advantage of leveraging public funds and of protecting investors from governmental risks like political instability (Schwerhoff & Sy, 2017). According to the IRENA report (2012), PPPs should be given highest priority when implementing energy programmes because they have the benefit of mobilizing public actors as well as private ones.

Nevertheless, projects should only be supported as PPPs when they offer better value for money then public-sector provisions, meaning that if margins are too high they expand into higher energy prices as well (Africa Progress Panel, 2015). Therefore, policy makers should take this into account and scrutinize the private-sector returns. Many different PPPs are already established in Senegal, however one has to take into account that they only make sense above a certain investment sum. Small scale projects are usually not implemented through PPPs because they are just too minor to go through such a long bureaucratic process.

- *Tenders*

Tenders or auctions mobilize investors to invest in RE assets with long-term incentives from the government (Budzianowski, et al., 2018). Tenders rationalize energy markets and governments can use them appropriately to shape their energy market accordingly. In spring 2017 Senegal has already set up a tender system for RE projects. However, since all the tenders have to be approved by the ministry it slows down the process of implementation. In addition, they hinder the implementation of small scale regional projects, which bear a too small sum of financial costs to enter a tender system and hence make it financially unfeasible to build up small scale projects. Therefore, one could think about a minimum threshold for a project which would be distributed without a tender system, where the bureaucratic cost clearly outweighs the benefits. In certain rural areas, electrification concessions are awarded to bidders in a competitive tender to increase the electrification rate, which have been proven quite successful to date (Africa EU Renewable Energy Programm, 2018).

- *Incubators*

Another very important incentive are Incubators. Industrialized countries have a long history of Research and Development (R&D) and therefore high potential for the harnessing new technologies. Developing countries may counteract through a set-up of incubators in their country where know-how, business development consulting and financial incentives are introduced to renewable energy start-ups. Many of the world leading disruptive technologies have been developed in incubators like the CD or the USB stick. Further, there is the opportunity to set up non-profit incubators in cooperation with multilateral donor organisations. Those can additionally work on topics like education and social integration.

3.4. Possible investment models & financing

When comparing costs of fossil fuel and RE plants with each other it is important to differentiate between social and private costs. Social costs are costs that are borne by the entire society that are indirectly affected (Schwerhoff & Sy, 2017). In the case of RE and fossil fuels, social costs for renewables are much lower since fossil fuels bear externalities like the costs of environmental pollution. These external costs are particularly important in Africa because they usually impact the lives of the entire society and predominantly its poorest inhabitants. Thus, it is a legitimate reason for international organisations to decline fossil fuel projects and invest in RE sources due to their lower social costs (Schwerhoff & Sy, 2017).

There are many great differences between the investment profiles of generated energy by fossil fuels or renewable energy. Fossil fuel energy production plants like diesel generators or coal plants, are relatively cheap to set up but they require high recurring costs as fuel (or coal) need to be purchased constantly. Thus, the private costs which are the direct costs the investors have to bear are much lower for fossil fuel energy. In the case of Senegal, both fuel and coal need to be imported and the government has to pay the global market price. In comparison, RE plants are very expensive to set up but the energy source is mostly for free, so that only maintenance and operation costs are recurring (Schwerhoff & Sy, 2017). RE projects in Africa face high risks especially in the early phase that deter their financial standing. Consequently, it depends on the investor to decide which energy source they rather invest in.

In Senegal it is typically the government and accordingly SENELEC investing in the energy generation. However, they can only borrow money at the market at high costs and are, therefore, naturally inclined to favour investments with low interests like the fossil fuel energy generation (Schwerhoff & Sy, 2017). Furthermore, capital markets are not very well developed in sub-Saharan countries and domestic enterprises or governments can simply not stem the required sums needed for RE development. Moreover, the government needs to scale up their economic incentives first so that RE market matures to facilitate the market entry of further RE enterprises (Budzianowski, et al., 2018).

Before analysing the cost of RE, the different types of RET have to be separately financially analysed. Biomass, geothermal energy and hydropower are already at the price range of fossil fuels and have the lowest costs of RE (Schwerhoff & Sy, 2017). In addition, they all face social and natural constraints like the lack of availability of land. Therefore, analysts estimate that the highest potential for an increase of RET in Africa evolve around solar and wind power. These two resources have become increasingly cheaper over the past year and are very suitable for developed countries. Unfortunately, the production costs are still much higher than those of fossil fuel-based energy. Furthermore, since RET requires a bigger initial investment, investors may experience higher financing costs in the early phase, which can be fatal for any kind of project.

3.4. Financial instruments for governments to promote RE

As discussed earlier in the business models section, regions with the most favourable and supportive regulatory environment facilitate more integration businesses (Gabriel & Kirkwood, 2016). Additionally, not only the lack of regulation but also the high start-up costs of renewable projects are another major disadvantage when compared to fossil fuel-based energy. Therefore, it is of utmost importance for politicians to establish the right financial incentives, so investors are willing to focus on renewable energy. However, the government may also take into account that people living in rural areas are willing and able to pay for beneficial reliable energy services (Thiam D. R., 2011). Besides, policies should enable and encourage open and direct lines of communication between renewable energy consulting firms and local governments to improve their impact on the local communities. Furthermore, multilateral negotiations between governments could help to establish best practice approaches on how financial barrier can be overcome.

Of course, the availability of financial resources will always play a major part when implementing renewable energy projects, but it is important to find the means to make RES in developing countries profitable through the right support incentives. As mentioned before, the selection of financial instruments must always be guided by the policy priorities of the nation and each instrument has its own upsides and downsides. However, the policy makers should also aim to reduce the non-economic barriers to enable the most fruitful environment for both investors and project managers. Lastly, it should not be forgotten that the investor’s decision where to invest is always guided by his expected profits.

- *Feed-In Tariffs (FIT)*

The most commonly applied performance-based support mechanism is the well-known feed-in tariffs (FIT). The tariff guarantees a certified purchase by the national electricity utility provider at a certain fixed price per kWh during a certain time. (Müller, Brown, & Ölz, 2011) (Thiam D. R., 2011). Usually, the feed-in-tariff is determined by the government and reflects the price of electricity in kWh that the national utility firm pays to the renewable energy producer (Thiam D. R., 2011). The agreement between the national electricity provider and the energy producer is usually signed over a long period, like 20 years. A long timeframe is of utmost importance to the investor since it grants him the assurance that his investment will be paid off. The FIT is fixed between the two contract partners over the entire time period (sometimes adjustment to inflation is agreed on though). New contracts are only set up when new plants start to operate. The FIT replicates subsidies provided to producers that make up the difference between the cost of renewable energy produced and the current (fossil fuel) electricity price. Additionally, the full capacity of the RE system has to be taken into account when calculating the tariff.

Therefore, FITs reduce the investment risk and if implemented correctly even encourage further investments. So, it is a very common instrument to insure the investor that their long-term investment in a RE project is guaranteed by the government through a reliable electricity purchase contract. Consequently, programmes have been established for a feed-in premium system where utilities commit to purchase the electricity at the market price and the above-market costs are carried by multilateral or bilateral public-sector funds (Müller, Brown, & Ölz, 2011). This measure encourages the decentralization of renewable technology in isolated and remote areas where the grid connection remains unsustainable (Thiam D. R., 2011). FITs are used in countries where the government's objective is to promote renewable energy, but the budget is constrained, and costs are minimized through the help of fixed price feed in laws (Thiam D. R., 2011). For instance, FITs and their premium programme have already been successfully implemented in Germany and Denmark. However, regarding grid integration constraints, the FITs need to be adapted, e.g. special power purchase agreements (PPAs) (Müller, Brown, & Ölz, 2011). Nevertheless, FITs can be regarded as quite effective and are feasible for countries with an aggressive policy towards RE. Unfortunately, they are rather costly and thus are more suitable at the early phase of RE projects to trigger the investors interests (Budzianowski, et al., 2018). In addition, FIT have been criticized for resulting in higher electricity prices for consumers because there is no incentive for project developers to cut the costs of the supply chain, manufacturers or contractors (Frankfurt School; UNEP Centre/BNEF, 2018). This led to a shift that governments now prefer auctions or tenders for RE projects.

- *Power Purchase Agreements (PPA)*

PPAs are directly linked to FITs because most FITs are concluded through the use of PPA. Power Purchase Agreements (also called electricity power agreement) are signed between two parties. On the one hand the state-owned electricity utility and the other hand the privately-owned power producer (World Bank Group, 2018). The PPA is the principal agreement that defines the revenue and credit quality of a generating project and fixes all the commercial terms between the two parties. (Wikipedia, 2018).

- *Risk Insurance*

As already mentioned, in Senegal as in other developing countries there is a quite concerning risk for political or economic instability that decreases the investment attractiveness level of a country. Therefore, in order to improve their creditworthiness policy makers can mitigate this issue by providing international or public insurances to the investors. However, the validity of these insurances may also be highly questionable

- *Donations & subsidies*

African governments are discouraged to use donations or subsidies for RET. Donated equipment or excessive capital cost subsidies are said to destroy markets (Budzianowski, et al., 2018). In addition, consumers will then wait for donations than rather pay for renewable energy services. It is widely known that free initiatives and gifts from developed countries to developing countries are not well maintained by their users since they have no market value in their view. Therefore, it is important that governments consider their cultural and social considerations and adopt the projects to their socio-economic surrounding.

- *Microfinance*

Microfinancing is especially important for consultant business models and all other small-scale start-up enterprises. It is one of the main opportunities for small enterprises to expand their business models and to expand their market to new customers (Engelken, Römer, Drescher, Welpe, & Picot, 2016). In addition, microfinance banks can use their local market knowledge to the sales channel for renewable energy business models (Engelken, Römer, Drescher, Welpe,

& Picot, 2016). As shown from previous studies in India, especially woman tend to have an increased repayment rate of the outstanding loans. This is because women are in general more risk averse and secondly do mostly have more experience while budgeting the cost of the households. Empowering women would make perfectly sense from an economical view but also raise gender equality and, thereby, reduce the fertility rate. Reducing the population growth rate would lead to a higher capital accumulation per inhabitant and therefore possibly to higher investments into other productive sectors like health, education or infrastructure. Hence, also the RE sector would profit from this measure.

- *Soft loans or concessional loans*

Usually these loans are funded by regional development banks (Schwerhoff & Sy, 2017). Due to guarantees by state members the recipients have access to very low interest rates which can then be passed on the investors (Schwerhoff & Sy, 2017). These instruments facilitate small scale investors to access financial benefits without a high risk involved. Therefore, they may be an important measure to empower Senegalese SMEs and help them make the shift from a Consultant business model to an Integrator model.

- *Tax on fossil fuels*

Tax on fossil fuels is a possibility for governments that really prioritize the shift from fossil fuel energy to RE, however, this will not be very effective in Senegal. Due to their shift to an energy industry focused on gas and their low-income structure, especially the lowest bottom of the pyramid would be affected by a fossil fuel tax. Including the high dependency on fossil fuel of the Senegalese population nowadays, an increase in energy prices could be of immense disadvantages for the country as a whole. Nevertheless, when an economy is already further developed a tax on fossil fuel is said to facilitate a quicker shift to RE.

- *Clean Development Mechanism (CDM)*

The clean development mechanism is a useful tool for developing countries to get their clean energy projects funded by industrialized countries (Chirambo, 2016). It is one of the flexible mechanisms defined in article 12 of the Kyoto Protocol to provide emission reduction projects that generate certified emission reductions units that can then be traded in emission trading schemes (UNFCC, 2018). These emission reductions can then be traded and sold and used by developed countries to meet a part of their emission reduction targets. This mechanism stipulates the main income for the UNFCC Adaption fund, which was established to finance adaptation projects for sustainable development to developing country parties in the Kyoto Protocol. It is not quite clear how the CDM mechanism will look like under the Paris Agreement but the UNFCC assures on its website that the lessons learned and the knowledge gathered through the instrument will be further developed in Article 6 of the Paris Agreement (Chirambo, 2016). However, the CDM helped to finance over 8000 projects in the most vulnerable countries to climate change and gives the countries the choice on which technology projects should be realized (Karekezi & Kithyoma, 2003).

Concluding, the elucidated financial incentives are the major opportunities for the government to overcome the big barrier of the more expensive RE initial start-up cost compared to fossil fuel generated energy. However, once the electricity sector has fully adopted to the renewables it will evolve further by itself without costly incentives from politicians.

3.5. Findings & Recommendations

To successfully achieve the government targets for the diversification of its renewable energy mix for a sustainable development in Senegal, the obstacles, challenges and risks of a transition towards RE have to be addressed. In Table 3.1, the hurdles which were identified in this thesis along with the sector that is involved are once again summarized.

	Obstacles	**Challenges**	**Risks**
Institutional and Regulatory	• Deficiency in the application of laws and regulations • Lack of Incentive and regulatory measures • Governance problem of the RE sub-sector	• Application of laws and regulations to boost renewable energy • Involvement of the private sector • Implementation of the repurchase rate (feed-in-tariff)	• Slowness in the implementation of projects (solar, wind, biomass) • Difficulty in creating the RE Market
Financial	• Price of the technology still expensive for certain population (especially in rural area) • High cost of maintenance	• Financing mechanism for access to RE solutions • Mobilization of investments • Subsidy and financial incentive • Private sector involvement	• The profitability of solar projects • Sustainability of RE sub-sector projects

Technical	• Available energy dependent on the sites • Difficulty in Transport some systems (e.g. wind turbine, blade size) • Maintenance problems • Injection into the SENELEC network • Impact of strong penetration of intermittent sources (solar and wind) in the public network	• Feasibility study of projects with implementation (solar, wind) • Expertise of technology • Implementation of smart grids technologies (metering, communicating, storage of electricity, inverter market models and controllable loads, etc.)	• Security risks associated with self-installation without respecting standards • Land, availability of space or plots (solar) • Deforestation (biomass) • technical problems, in particular for network operators

Table 3.1: Summary Obstacles, Challenges and Risks of RE in Senegal *(Ministère de l'Energie et du Développement des Energies Renouvelables , 2015)*

Firstly, to solve the issues of the deficiencies in the institutional and regulatory framework the following recommendations for the government are suggested:

- Enhance the PANER programme by defining specific targets for each region of Senegal according to its potential of RE
- Promote incentives for regional politicians, communities and entrepreneurs to implement RE programs and sustainable use of energy
- Creation of regulations to launch necessary measures for the financial promotion of RE (e.g. Development of a regulatory legislation for FITs)
- Reduce bureaucratic and administrative hurdles by establishing more transparent public institutions
- Decentralization of the regulatory powers to enhance fast decision making in the rural areas
- Formalize the legal status and framework for PPPs and IPPs
- Enable of a pleasant business setting so SME´s can evolve further
- Create an environment to support the collaboration between the private and public sector

Secondly, after implementing all these necessary measures, developing countries have the urgent need of financial aid by foreign investors. To attract these investors accordingly, policy makers may pursue the following endorsements:

- Provide guaranteed Feed-in Tariffs to attract private investors
- Enable the private sector access to microfinance institutions to trigger the development of small SMEs

- Exploration of potential funding measurements in cooperation with multilateral/bilateral organisations
- Subsidize PV technologies in rural areas and micro-grids to enhance their local socio-economic development
- Invest into the research for technological advances targeted to the Senegalese energy sector
- In a later stage, tax fossil fuel to reduce emissions and to trigger a fast change towards RE

Lastly, to ensure a lasting and efficient shit towards RE, the technical capabilities need to improve through:

- Apply feasibility studies to ensure the building of RE at sites with the biggest potential
- Develop capacity building programmes to strengthen the technical human resource competences
- Increase of the national infrastructure to facilitate the logistics of RET to remote areas
- Improve the national electricity network to reduce the losses and increase its efficiency
- Implement smart grid solutions in rural areas instead of connecting to the national grid
- Invest into the research and use of innovative technologies like smart meters or battery storages to support the grid in over/under capacities

Concluding, three factors are of utmost importance when launching future energy policies: the ecological sustainability, the competitiveness and the supply reliability of RE projects. The continuing and functioning energy supply is the minimum requirement for every energy policy. Furthermore, the competitiveness of the energy sector and the resulting profitability is of high significance for individual consumers and industries. If the prices are too high, the customers cannot afford it and the local industry will suffer. Therefore, it is important to make sure that the national energy sector is competitive with neighbouring countries. Finally, energy production should result into the smallest as possible emissions, which are obtainable through the increasing use of RE.

When having applied this framework to the energy sector of Senegal, the energy policy goal triangle in Figure 9 is developed. To increase the Sustainability of the future energy policies the government have to ensure an increase of RE in the national energy mix, they should reduce their losses of the network so emissions from energy production can be saved and an increase of overall energy efficiency should be pursued. The reliability of the energy sector is dependent

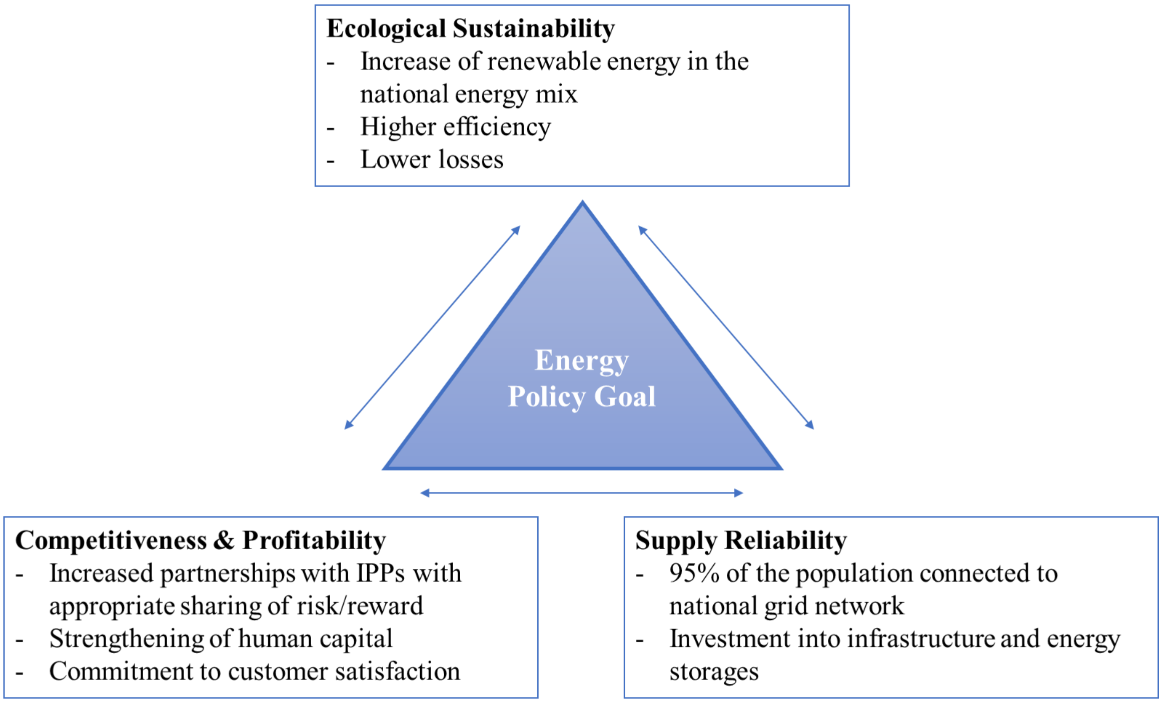


Figure 9: Energy Policy Goal Triangle

on investments into the infrastructure and energy storages as well as raising the electricity access rate of the whole population to 95%. Lastly, to ensure the profitability of the energy sector the government should further establish partnerships with IPPs to ensure the appropriate sharing of risk and reward. Additionally, the technical capabilities of the staff have to be constantly committed and the customers have to be satisfied with the price quality ratio of the national energy network. When these polices are taken care of appropriately, the Republic of Senegal has the chance to further develop their economy and the possibility to leapfrog other countries.

4. Conclusion

In a first step, this work established the reasons why a shift to RE energy is of such significance for all countries worldwide. To fulfil the Sustainable Development Program of the UN till 2030 and finally help the developing world out of its gap, a new modern pathway is needed. Thus, the technologies of RE are an important tool when pursuing socio-economic development on all levels. The benefits of efficient use with renewable sources to produce energy are affecting all levels of a society. Not merely, the increase of access to energy is important for a population but also the impact this has on their life quality. RE brings many advantages with them when compared to fossil fuels: less emissions, lower dependency on fuel imports, easy accessibility and high level of decentralization. Nevertheless, when taking a look at the sub-Saharan energy sectors it is evident that the social benefits for a society, do not outweigh the higher costs of the investors and hence still lead to a lower implementation rate.

In Chapter 2, the background of the state of Senegal was elucidated and the economic and political circumstances of the country were outlined. The importance of a needed higher access rate to electricity has been underlined by various country statistics. In addition, the current FDI state of the region has been shown, which were needed for further findings. Especially the institutional and regulatory aspects have been introduced and their shortcomings discussed. In particular, the National Action Plan for Renewable Energies of Senegal was highlighted, and the respective targets visualized. Furthermore, the current energy situation of the country was established and the production numbers compared to other economies, pointing out the good starting conditions for the Senegalese Republic. In Addition, the new tariff scheme of Senegal and the implications for its consumers were further discussed. Lastly, the biggest part of the chapter was to outline the potential of renewable energies in Senegal while introducing the different types of technologies. The various potentials of different regions and the accordingly contrasting uses of the technologies were one of the main findings. It has to be taken into account that every technology has different advantages or disadvantages. Therefore, it must be highlighted that the best approach would be a balanced energy mix of all renewable energy but the highest potential and quickest implementation for Senegal lies definitely within Solar energy.

The next chapter focuses on the opportunities, barriers and solutions that are encountered by the private sector when investing or consulting Senegal on RE. The field research suggests that biggest hurdles entrepreneurs in the RE sector in Senegal encounter are human capital, institutional barriers, lack of financial incentives as well as weak transparency and slow technology adaption. In addition, the underdeveloped infrastructure of the energy sector as well as cultural aspects need to be taken into consideration. Many problems in these categories were introduced which offered a broad overview of the issues that are encountered in the daily life of entrepreneurs in developing countries. Another aspect of importance is that all the barriers which were identified in this thesis are all tightly connected with each other.

This needs to be taken into account when setting goals to overcome the hurdles of the energy sector.

The private sector is an important tool for fast economic development that work even in a challenging environment. Therefore, different business models for renewable energy entrepreneurs where identified which are needed to overcome the gaps of the current energy dilemma. It is remarkable that according to Gabriel & Kirkwood (2012), mostly consultant enterprises and not distributors or integrators are established in the African markets. The findings indicate that this phenomenon is most likely attributed to the weak regulatory framework in these countries. This is of huge significance on a policy level since the shift from one business model to another can be easily facilitated by the right incentives from government targets. When the most successful entrepreneurs become Integrator businesses, the country also benefits because these companies will have a higher impact on the local energy infrastructure compared to the other two. Hence, the importance of the private sector has to be considered when establishing future policies.

On a policy level, the most useful support mechanisms for RE for the Senegalese market have been identified. Most of these tools were or are still in use in Senegal. However, it has to be pointed out that they are not always fully implemented into the country's regulatory framework. In addition, the complementing financial incentives were elaborated on, which are suggestions that mostly are not applied yet. Hence, these suggestions are unfortunately rather limited because of the missing link to a real successful implementation and can therefore solely be seen as possibilities to attract investment into the country. Although, according to PANER (2015) the Senegalese government is already working on the establishment of Feed-in tariffs for RE.

In the last section, the findings of the previous sections were combined visualized and recommendations for a successful implementation for RE projects in Senegal further considered. The propositions were focused on three main areas of this thesis: institutional and regulatory framework, technical and financial. Several recommendations for policy makers were developed by taking into account the findings of all sections. In particular, it is important that these suggestions are not implemented after each other, but they promise the fastest diffusion of RE when they are applied in a combination. Finally, an energy policy triangle was developed which highlights the most important steps by policy makers for the future development of the energy sector in Senegal.

Consequently, this thesis has investigated the energy sector of sub-Saharan countries, in particular Senegal and established an approach how the current challenges of a successful renewable energy implementation could enable the population the long-awaited access to total national grid connection while offering a high-quality energy service. When this goal is achieved successfully and sustainably, the republic of Senegal can finally focus on the development of its industries and might even manage to leapfrog developed nations, while increasing their prosperity and minimizing their environmental impact.

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6. List of tables

7. List of figures

8. Appendices

I. Appendix Map of Sub-Saharan countries

Source: aphg2015mhs.wordpress.com [accessed on April 29th 2018]

II. Appendix List of ECOWAS member states

Benin

Burkina Faso

Cabo Verde

Cote D'Ivoire

Gambia

Ghana

Guinea

Guinea Bissau

Liberia

Mali

Niger

Nigeria

Senegal

Sierra Leone

Togo

III. Appendix Summary of relevant Interviews during field trip

1. Interview with an official from SENELEC in charge of “big production projects of RE”
2. Interview with the director of promotion and cooperation of ANER
3. Interview with the representative of UNIDO

Note from the Author:

I conducted 5 interviews overall, which all lasted between one and one and a half hours. The officials I interviewed were: the representative of Senegal to UNIDO, the director of SENELEC for renewable energy, the director of renewable energy of the National Agency for Renewable Energy (ANER), the head of the department for biogas research from ANER, and the director for microgrids from the Rural Electrification Agency (ASER). However, all of them were very interesting only the first 3 were very relevant for my research, but I still conducted the interview with them because I did not know beforehand what additional information they might give me. For the interviews I prepared about 20 questions about the topic each in French and English, but since they were all experts in different fields I could not develop a questionnaire but had to do research for each interview individually.