Draft Pre-Feasibility Report for implementation of solar pumps scheme in Togo

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1. Executive Summary

- Togo is one of the **largest agriculturally rich nation in Africa, with agriculture accounting for 41% of its GDP.**
- Togo is among the world's largest producers of phosphate. Togo's carbonate phosphate reserves account for more than 20% of the export earnings.
- **Hydropower and Thermal** constitute of Togo's total installed capacity for electricity generation. Togo imports two-thirds of its electricity from Nigeria and Ghana.
- According to USAID, Togo only has a 35 percent access rate in terms of electricity, with one million households across Togo living without electricity. In 2017, the Government of Togo launched a presidential initiative called "CIZO" with an aim to increase rural electrification to 40% by 2022, and achieve an electrification rate of 100% by 2030.
- **Togo aims to generate 50% of its electricity using solar energy in 2030**. The International Finance Corporation, a Power Africa partner, is supporting Togo's off-grid efforts.
- A total of 100,000 households will be equipped with solar kits in 2020 and approximately 550,000 households by 2030. The solar kits are designed to include a mobile phone, USB charger, solar panel and a battery for energy storage. Additional options would be solar kits for profit, such as solar pumps, freezers, etc.
- With approximately 10,000 boreholes identified in Togo, the **demand for solar pumps is approximated at 4000-5000 by 2030 by Lighting Global.**
- In the Northern part of the country, the GHI values vary between 5.4-5.6 kWh/m^2 while in the Southern part, it lies between 4.7 - 5.2 kWh/m^2. The average solar insolation in the country varies between 4.8 – 5.7 kWh/m^2/day.
- In March 2019, the **Government of Togo introduced subsidies to Togolese households to help with the cost of off-grid solar power systems**.
- The indicative analysis indicates that implementation of solar pumps is feasible with a payback period of around 3-5 years depending upon the irrigated area and crop type. This presents significant opportunity for up scaling the efforts to increase the penetration of solar based irrigation.

2. Introduction

Togo is one of the smallest countries in West Africa. The economy of Togo is majorly governed by agriculture, phosphate mining, and trade and transport. After slowing to 4.4% in 2017 due to political tensions and a sharp fiscal contraction, Togo's economic growth escalated again in 2018 to 4.7%. This recovery was mainly driven by the rebound in the extractive industry, and the continued expansion of the agricultural sector. On the other hand, the economy benefited from the growth fueled by an increase in private investment, which in turn benefited from an improved business climate with lower costs and faster sales and transfer of properties.

The agriculture sector accounted for approximately 40% of the country's GDP in 2018. The economy of Togo relies heavily on both commercial and subsistence agriculture, providing employment to approximately 65% of the labor force. Cocoa, coffee, cotton, and other agricultural products contribute to roughly about 20% of export earnings, with cotton being the most dominant cash crop.

Togo is among the world's largest producers of phosphate. Togo's carbonate phosphate reserves account for more than 20% of the export earnings. However, production has dropped from an annual 5.4 million metric tons in 1997 to 800,000 metric tons in 2010, mainly due to corruption and mismanagement. Production increased again to 900,000 metric tons in 2013, making Togo the fifth largest producer in the world. The mining industry has the potential to develop into one of Togo's most significant economic sectors, with the country being the world's fourth-largest phosphate producer. Togo's estimated 60 million metric tons of phosphate reserves would significantly boost the mining industry. [1]

According to USAID, Togo only has a 35 percent access rate in terms of electricity, with one million households across Togo living without electricity. The Government plans to bring the number up to 40 percent by 2022. Of the 225 MW installed capacity, thermal contributes approximately 158 MW, whereas Hydropower provides about 67 MW. However, this installed capacity accounts for merely one-third of the total electricity consumption of the nation, thus, forcing Togo to import the majority of its electricity from Nigeria and Ghana.

In order to address the poor access rate, the Government of Togo introduced Project CIZO in 2017, an initiative achieve an electrification rate of 100%. Through Project CIZO, the Government will extend its reach to three million households that currently do not have access to electricity, thus, providing electricity to its entire population of 7.5 million.

Until 2016, Hydropower was the only existing renewable form of energy in Togo. Under Project CIZO, the Government aims to address 50% of the country's energy needs in 2030 through solar power.

Sl. No.	Parameter	Units	Value
1	Total population	Nos.	7.6 Mn
2	Population in rural areas	%	60%
3	National Electrification rate	%	35.81%
4	Rural electrification rate	%	7%
5	Thermal installed capacity	MW	158.1
6	Hydro installed capacity	MW	67.1
7	Importation rate of electricity	%	58.35%

Table 1: Country Statistics- Togo
Source: World Bank

1 https://www.bti-project.org/en/reports/country-reports/detail/itc/TGO/

In March 2019, the Government of Togo introduced subsidies to Togolese households to help with the cost of off-grid solar power systems. This subsidy will cover the high installation cost of the solar systems, with the objective to increase the adoption of solar home systems. UK based company BBOXX won a tender to provide electricity to 300,000 households that do not have connection to the national grid using solar kits. A similar tender was given to a company named Soleva in August 2017. Under this program, the Government will provide monthly vouchers to households operating a BBOXX or Soleva system to finance the system. A total of 100,000 households will be equipped with solar kits in 2020 and approximately 550,000 households by 2030. [2]

2 https://www.africanews.com/2019/03/03/togo-subsidises-off-grid-solar-panels-to-ease-access-to-electricity/

3. Geography

A small country of nearly 7.5 million people, Togo is nearly 100 kilometers wide, and situated between Ghana and Benin. From its 51 km coastline on the Gulf of Guinea, Togo extends northward for about 515 km between Ghana and Benin, and it shares boundary with Burkina Faso in the north.[3]

Togo comprises of more than 30 ethnic groups and various local languages. The country's geography is diverse, and its natural assets include land resources and rainfall patterns that are highly favorable to agriculture, significant phosphate and other mineral resources, and a natural deep-water port of nearly 17 meters that is unique in the sub-region.

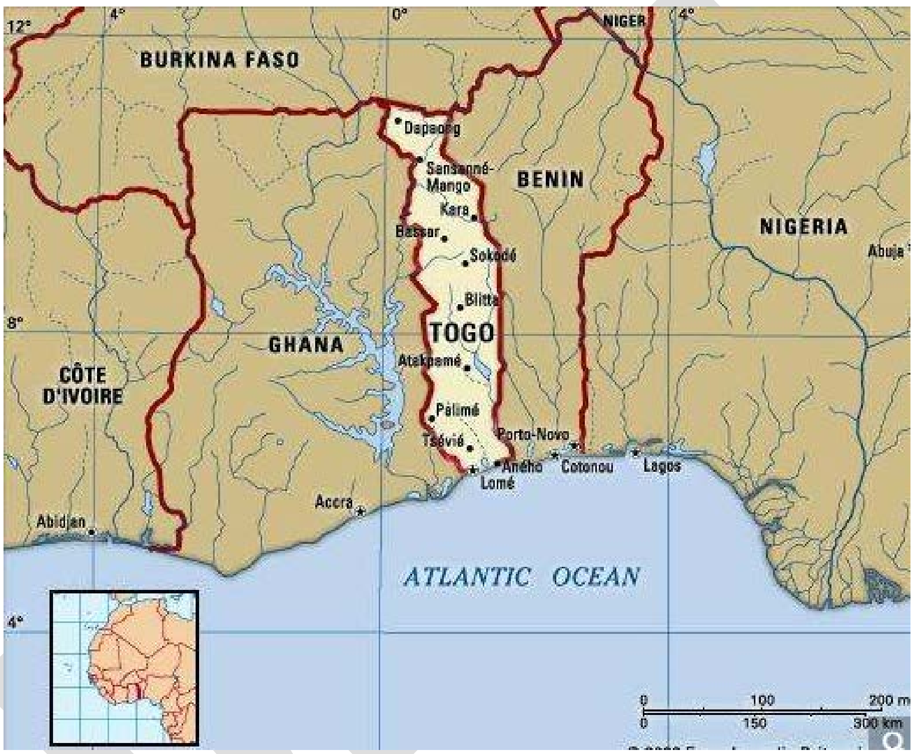


Figure 1: Map of Togo
Source: Britannica

Togo has a total of six geographic regions. The narrow coastal region of the nation consists of low-lying beaches, which are backed by shallow lagoons, the biggest one being Lake Togo. Post this coastal region lies the Ouatchi Plateau, with an inland stretch of approximately 32 km, and an elevation of about 200 to 300 feet. This region consists of *terre de barre,* a reddish, leached, iron-bearing soil.

The northeast region of the plateau comprises of a tableland, whose highest elevations ranges from 1,300 to 1,500 feet. Mono River and its tributaries, including the Ogou, and other smaller rivers drain this tableland. The west and southwest of the tableland consists of terrain that gradually rises toward the Togo Mountains, also known as the Togo-Atakora Mountains. These mountains are spread across the central

3 https://www.britannica.com/place/Togo

region of Togo, from the south-southwest region to the north-northeast region. They origin in the Akwapim Hills of Ghana, and end in Benin, where they are known as the Atakora Mountains. Standing tall at 3,235 feet, Mount Agou, also known as Baumann Peak), is the highest mountain in Togo.

The northern part of the Togo Mountains comprises of the Oti River sandstone plateau. This savanna region is drained by the Oti River, one of the main tributaries of the Volta. Further in the north are the cliffs of Dapaong that are rich in granite and gneiss.

Although savannas form a major part of the Togo landscape, agricultural expansion, a source of income for 60% of the population, has greatly changed land cover in all parts of the country. In 1975, savannas covered 70 percent of Togo, and cultivated areas were mainly found around urban settlements and along the major roads. Between 1975 and 2013, agriculture increased by 14,000 sq. km., or 266 percent. Togo's 7 percent annual expansion rate over this time period ranks as the highest in West Africa. [4]

Coastal erosion is a major challenge faced by the Government of Togo. Togo land and beaches are being worn away by the wind and the waves, and this is destroying approximately five to ten meters of shoreline every year. In select locations, approximately 25 meters of shoreline gets affected over the same period. This phenomenon not only affects the shoreline, but also has a drastic impact on infrastructure, such as roads, buildings, vegetation, etc. which may have been growing on it. Nothing remains.

In order to address this issue, the Togolese Environmental Department and the World Bank have commissioned projects to limit the damage caused by coastal erosion. Facilitating the construction of physical structures that can withstand the effect of wind and waves, and encouraging local communities to actively defend their shoreline are some of the key initiatives taken up by the Government of Togo.

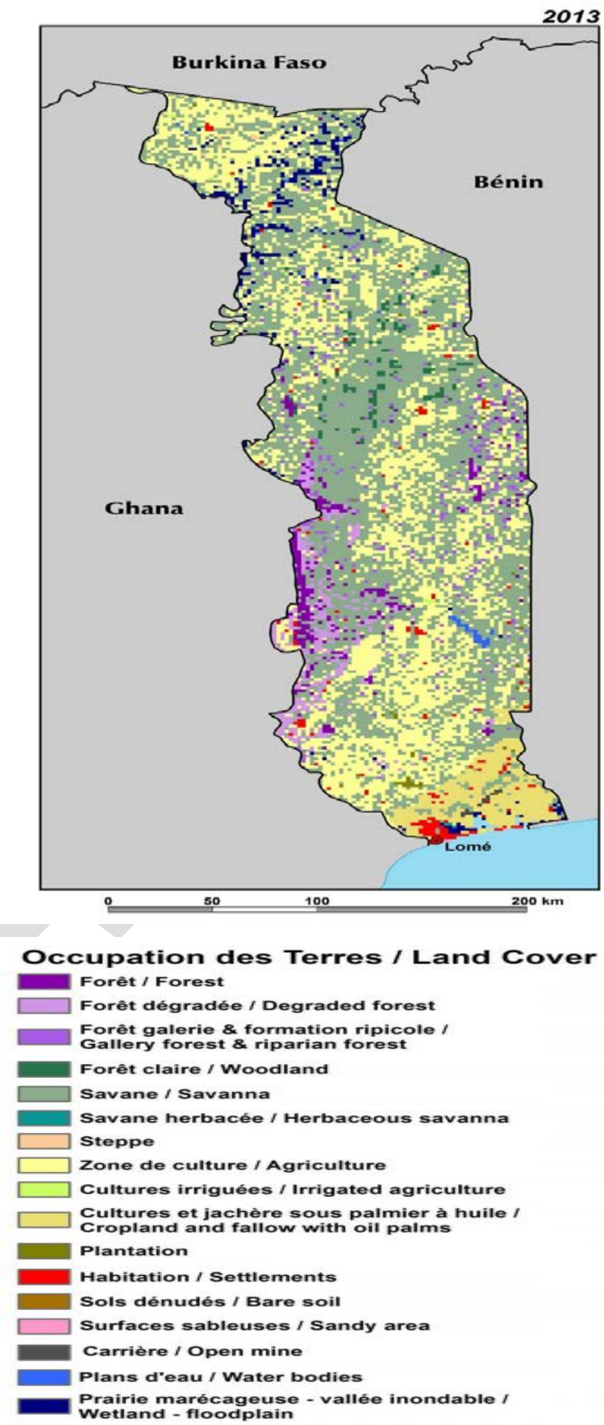


Figure 2: Land Cover of Togo
Source: https://eros.usgs.gov/westafrica/

4 https://eros.usgs.gov/westafrica/ecoregions-and-topography/ecoregions-and-topography-togo

4. Climate and Rainfall

Figure 4: Map of Togo
Source: Britannica

In Togo, the climate is humid and tropical, but it experiences less rainfall than most of its neighboring countries along the Gulf of Guinea. Togo experiences a dry season in winter and a rainy season from May to October in the northern region. The central part of Togo experiences monsoon season from April to October. In the southern area, there are two rainy seasons, the first one from March to early July, and the second one from September to October.

From the Sahara to the humid southern coast — West Africa can be subdivided into five broad east-west belts based on the climate and the vegetation of the region. These are known as the bioclimatic zones of Western Africa such as the Saharan, Sahelian, Sudanian, Guinean, and Guinean-Congolian, shown in the map (Figure-1) below. Northern Togo falls in the Sudanian climatic zone and experiences one rainy season. Woodlands and savannas are in abundance in the north. Because of the open canopy in this region, it is exposed to dry Harmattan winds and is prone to drought. The southern part of Togo falls into the Guinean climatic zone, and it has two rainy seasons. The Atacora mountain range spreads across central Togo, with more wooded landscapes, and a few isolated remnants of dense tropical forest.

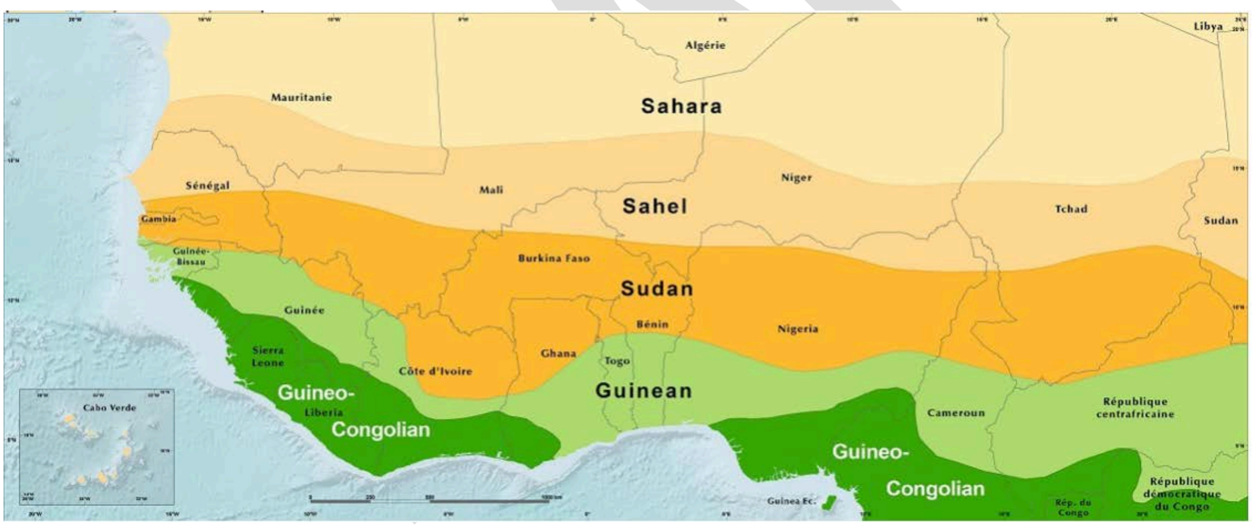


Figure 3: Bioclimatic Regions of West Africa
Source: United States Geological Survey (USGS)

The central-north region of Togo experiences hot and dry winter, sometimes the temperature can reach up to 40 °C, and in the night the temperature can fall to 10 °C or below. In Savannes region the hottest month of the year is March, with an average temperature of 31.44 °C and August is the coldest month, with an average temperature of 25.48 °C. In Kara region the hottest month of the year is March with an average temperature of 29.84 °C and August is the coldest month with an average temperature of 24.66 °C. In Central region the hottest month of the year is March with an average temperature of 28.62 °C and August is the coldest month with an average temperature of 24.16 °C. In Plateaux region the hottest month of the year is February with an average temperature of 27.14 °C and August is the coldest month with an average temperature of 23.64 °C. In Maritime region the hottest month is March with an average temperature of 28.38 °C and August is the coldest month with an average temperature of 25 °C.

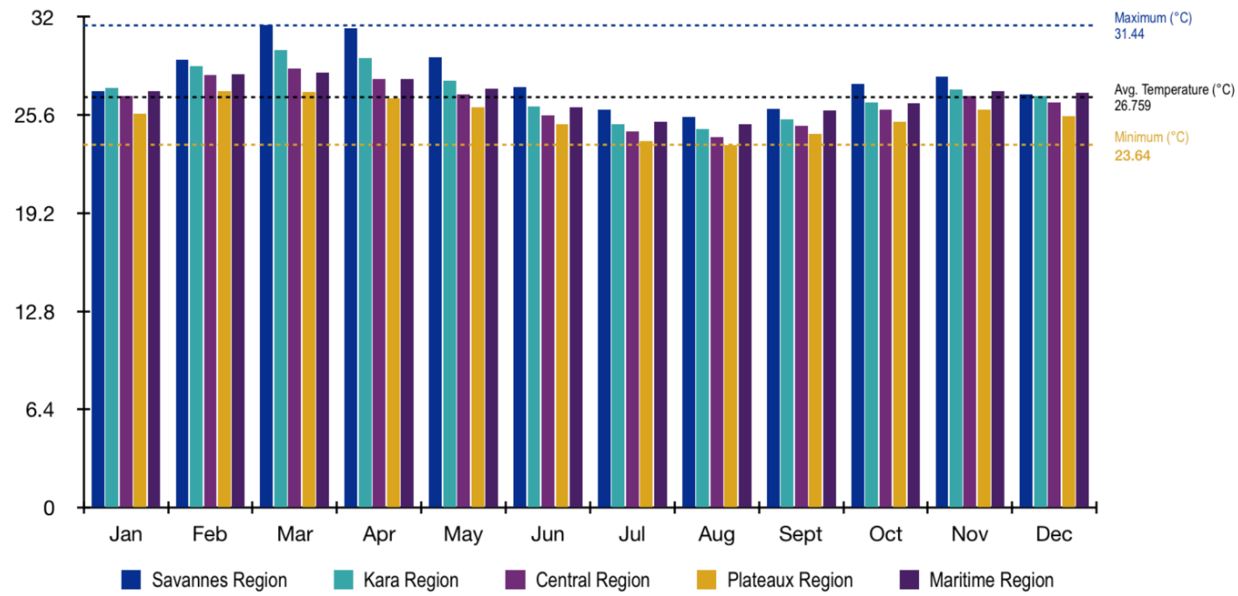


Figure 5: Average Temperature of Togo

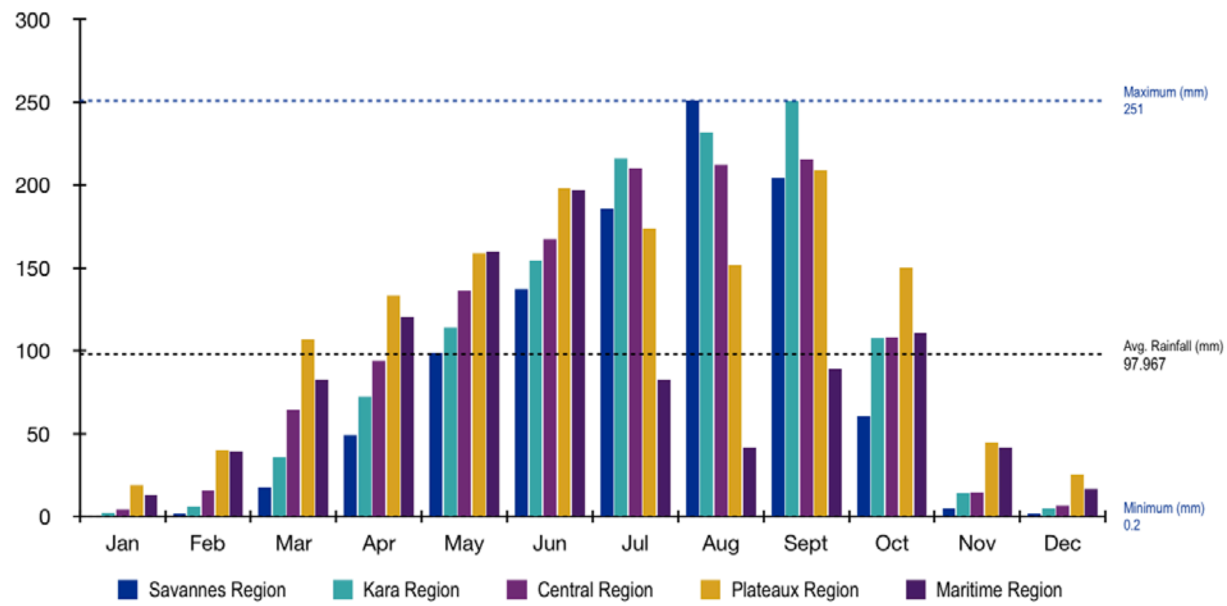


Figure 6: Average Precipitation/Rainfall of Togo
Source: climate-data.org

The rainfall pattern of Togo's 5 geographical regions depict that Togo receives approximately an average of 1175 mm/year of rainfall. Savannes region receives the highest rainfall in August with an average of 251 mm and the lowest rainfall in January with an average of 0.2 mm. Kara region receives the highest rainfall in September with an average of 250.6 mm and the lowest rainfall in January with an average of 2.2 mm. Central region receives the highest rainfall in September with an average of 215.8 mm and the lowest rainfall in January with an average of 4.4 mm. Plateaux region receives the highest rainfall in September with an average of 209 mm and the lowest rainfall in January with an average of 18.8 mm. Maritime region in general receives the least rainfall compared to the other regions. It receives the highest rainfall in June with an average of 197 mm and the least rainfall in January with an average of 13 mm. All in all, Maritime's weather is humid as it is closer to the coast.

5. Soil

In the northern part of Togo, the clay-rich Lixosols are a common occurrence, which generally reflects the stable geological conditions and natural savannah vegetation. Lixisols occur in a tropical climate, comprising of a dry season, on old landscapes. Their age and mineralogy have resulted in low levels of plant nutrients and a high erodibility over time, making agriculture viable only through frequent fertilizer applications, minimum tillage, and careful erosion control.

The Togo Mountain chain in Togo consists of Leptosols, shallow soils that form over hard rock. These soils have a very shallow profile depth and often contain large quantities of gravel. They typically remain under natural vegetation and are highly susceptible to erosion, desiccation, or waterlogging, depending on climate and topography. Leptosols are equally distributed among high mountain areas, deserts, and boreal or polar regions, where soil formation is limited by severe climatic conditions.

The southern region of the Togo Mountains consists of Plinthosols for the major part. These typically form over gently undulating landscapes. These soils consist of a sub layer that is rich in iron mixture of clay minerals, mainly kaolinite and silica, which hardens into ironstone concretions upon exposure to sun. This sub layer, known as plinthite, is impenetrable, and this, along with the fluctuating water table that produces it, restricts the use of these soils to grazing or forestry.

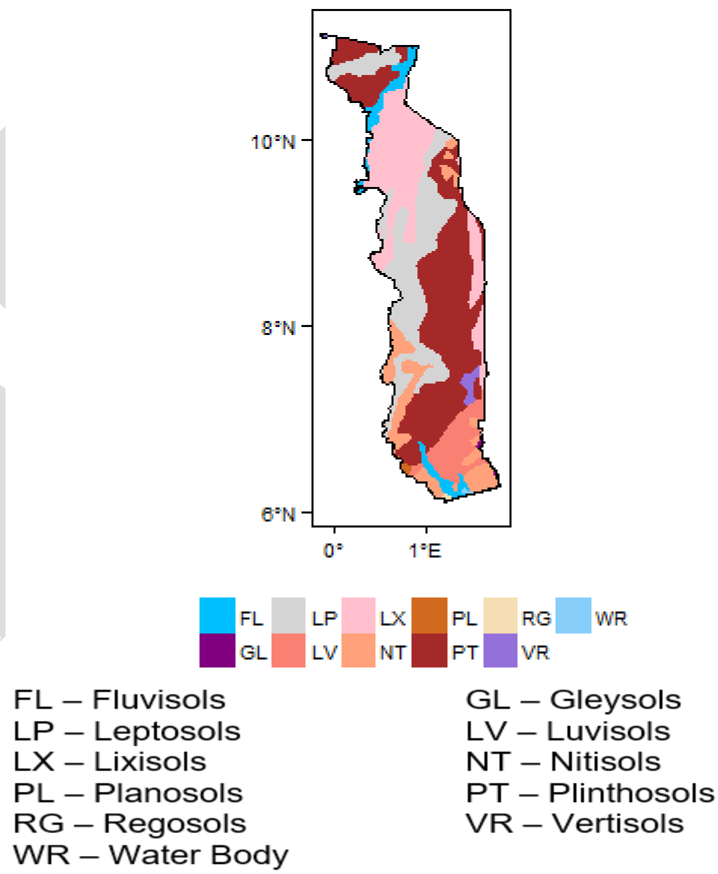


Figure 7: Soil in Togo
Source: British Geological Survey

Nitosols are common along the low-lying coastal plain in the southern part of Togo. These soils form on alluvium and are used for the production of sorghum, maize, yam, millet and various leguminous crops including groundnuts, beans and cowpeas.

The valley of the River Oti in the north and the River Zio in the south consists of fluvisols. Fluvisols typically occur on level topography that is flooded periodically by surface waters or rising groundwater, as in river floodplains and deltas and in coastal lowlands. They soils are good for cultivating dry land crops or rice, and for grazing in the dry season.

6. Agriculture and Irrigation in Togo

The economy of Togo is dependent on commercial and subsistence agriculture, both, with majority of the population practicing subsistence farming. Cocoa, coffee and cotton are the cash crops of the country and generate approximately 40 percent of export earnings. Additional products prevalent in Togo are maize, beans, fish, cassava, livestock, millet, rice, sorghum and yams. Togo has favorable agro-climatic conditions, and is the only country with natural deep water port in West Africa. This makes Togo a major hub in the sub-region and facilitates its trade with other countries.

Togo

Cereal Production

	2013-2017 average	2017	2018 estimate	change 2018/2017
		000 tonnes		percent
Maize	800	855	887	3.7
Sorghum	284	276	277	0.4
Rice (paddy)	147	141	146	3.6
Others	38	30	30	0.0
Total	1 269	1 301	1 339	2.9

Figure 8: Cereal Production for major crops
Source: FAO

Of the total land area of Togo, approximately 44 percent is used for cultivated crops and two percent for permanent crops, such as fruit- and nut-bearing trees.

In 2018, Togo encountered favorable weather conditions, resulting in an above average production of 1.3 million tonnes of cereal crops. Production of maize, the main staple cereal, is estimated at about 887 000 tonnes, nearly 4 percent above the previous year's level and 11 percent above the five-year average.[5]

According to Economic Intelligence Unit, the economic growth of the country is expected to be around 5.2% in 2019. The favorable moisture conditions will yield better outputs in 2019. Following a timely onset of seasonal rains, plantation of maize (main season) in the southern region was completed in April and harvesting is expected to begin in

August. The plantation of rice, millet and sorghum crops is ongoing for harvest from October. The cumulative rainfall in April suggests a favorable scenario for the development of the existing plants.

5 http://www.fao.org/giews/countrybrief/country.jsp?code=TGO

Grazing conditions and water availability for livestock are expected to be better as compared to the previous months in major natural reserves of the country.

Despite the tangible role of agriculture, the enormous agricultural potential that gives promise for agriculture to take lead in the country's economic growth and livelihood improvement has not been adequately exploited. Only 25% of the arable land in Togo is exploited, **which signals high potential for agricultural expansion.**

Togolese agriculture is predominantly rain fed. No definitive statistics are available on the methods used in agriculture, however, several sources suggest that surface irrigation is the only form of irrigation that is practiced in certain parts of the country. Certain parts of the country also use drip and sprinkler irrigation. Agriculture and livestock use mainly surface water and, marketing gardening is usually practiced using groundwater.

The three main basins of Togo are as follows:

- Volta Basin, which drains the main rivers, Oti, Kara, Mô, approximately 26 700 km 2 to the northwest
- Mono basin, which drains the main rivers, Mono, Anie, and Amou, approximately 21,300 km2 to the southeast
- Lake Togo basin with rivers Zio and Haho.

With 32% of the population living below the poverty line, major efforts need to be made towards sustainable agriculture practices in Togo. The key constraints of the agriculture sector are as follows:

- Inefficient output-coping strategies, resulting in low productivity and weak integration with upstream and downstream activities, thus limiting economic potential
- Lack of processing industries
- Inadequate research and development, limiting adoption of new technology
- Limited funding for agricultural water development
- Natural factors such as variable climate and poor soils.

The productivity of Tologese agriculture is highly susceptible to climate change.

According to the Togolese Ministry of the Environment and Forestry , in the dry savannah of northern Togo, a West African country, the wet season, which spanned six months in the 1970s, has reduced to five or four months nowadays. 6 Consequently, on the one hand, a substantial amount of rainwater falls within a short period causing flooding, while, on the other hand, frequent dry spells in the wet season lead to crop failure. In addition, there is no rainfed agricultural activity during the dry season in northern Togo because of a lack of rainfall.

6 www.mdpi.com/journal/water

7. Cropping Pattern

Rain-fed agriculture is predominant in the country; from the onset of rains, farmers cultivate crops whose cycle permits harvesting before the winter begins. When the rains arrive, farmers grow rice. When the rains end, gardens are developed, which allows the production of vegetables. Market gardening also uses well water.

According to a report by USAID in 2008, **approximately 17% of the country is forested, of which, 90% consists of natural forests and 10% plantations.** The Guinean savanna, an area of dry forests, comprises of the most extensive vegetation cover. The main crops that grow in this area are maize, sorghum and cassava. The second largest area of land cover in Togo is the Sudanese savanna, which lies in the extreme northern part of the country. This area consists of parts of forests. The arable crops that are cultivated here are cereals, such as maize, sorghum, millet, and rice, and legumes such as peanuts, beans and soya beans. A part of the savannah Guinean region consists of semi-deciduous forests, where the main crops are maize, coffee, cocoa and cassava.

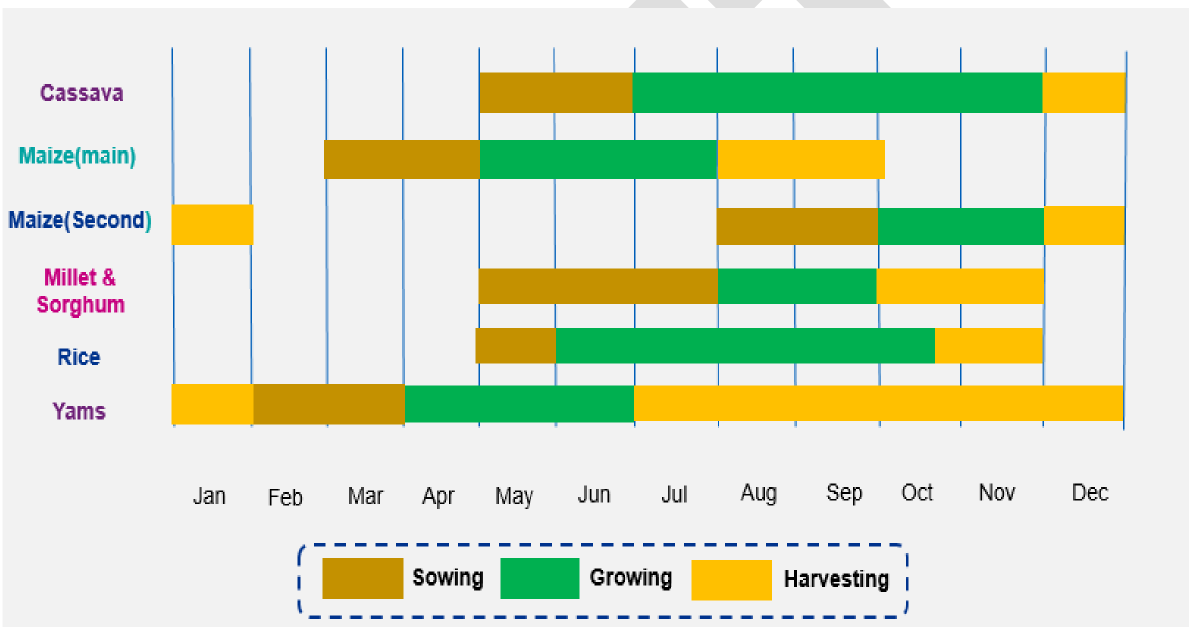


Figure 9: Cropping pattern for major crops;
Source: FAO

8. Background to solar water pumping in Togo

Until 2016, Hydropower was the only existing renewable form of energy in Togo. In 2017, the Government of introduced the CIZO project, under which, it aims to address 50% of the country's energy needs in 2030 through solar power.

In March 2019, the **Government of Togo introduced subsidies to Togolese households to help with the cost of off-grid solar power systems**. This subsidy will cover the high installation cost of the solar systems, with the objective to increase the adoption of solar home systems. UK based company BBOXX won a tender to provide electricity to 300,000 households that do not have connection to the national grid using solar kits. A similar tender was given to a company named Soleva in August 2017. Under this program, the Government will provide monthly vouchers to households operating a BBOXX or Soleva system to finance the system. A total of 100,000 households will be equipped with solar kits in 2020 and approximately 550,000 households by 2030. [7]

The solar kits are designed to include a mobile phone, USB charger, solar panel and a battery for energy storage. Additional options would be solar kits for profit, such as solar pumps, freezers, etc. With approximately 10,000 boreholes identified in Togo, the demand for solar pumps is approximated at 4000-5000 by 2030.[8] This initiative showcases a promising future for solar pumps in the country of Togo.

A number of projects are being implemented by The World Bank, African Development Bank, and other agencies for improving the efficiency of irrigation. The details of these projects are given in the table below.

Funding Agency	Implementing Partner	Funding Amount (USD)	Project Title	Project Description
African Sustainable Energy Fund (SEFA) (hosted by African Development Bank) Union Togolaise de Banque (UTB)	• Government of Togo • Ministère des Mines et de l'Énergie du Togo • The Tologese Rural Electrification and Renewables Energies Agency (AT2ER)	SEFA: $975,000 UTB: $4 million	CIZO Project (2017-2030	The Government of Togo, through a tender process, awarded BBOXX and Soleva a contract to implement 500,000 of its solar home systems in the country by 2030.The project will be based on the PAYGO model in remote rural areas, which will use mobile payment technologies. The Government of Togo will provide subsidies to people who will install BBOXX or Soleva systems, by providing vouchers to finance the installation of the system.
World Bank	• General Secretariat of Ministry of Agriculture	Total Cost: $44.90 million	Togo Agricultural Sector	The objective of the Agriculture Sector Support Project is to rehabilitate and reinforce productive capacities among

7 https://www.africanews.com/2019/03/03/togo-subsidises-off-grid-solar-panels-to-ease-access-to-electricity/

8 https://www.lightingglobal.org/wp-content/uploads/2018/12/Togo-Electrification-Strategy-Short-EN-Final.pdf

Funding Agency	Implementing Partner	Funding Amount (USD)	Project Title	Project Description
	• Government of Togo • Ministere de l' Agriculture de l' Elevage et de l Hydraulique • Ministere de l'Economie et des Finances	Commitment Amount: $ 9 million	Support Project (2011-2020)	targeted beneficiaries across selected value chains, and foster an enabling institutional environment for the development of the agricultural sector, in the recipient's territory. There are three components to the project. The first component of the project is promotion of strategic food crop, export crop and freshwater fish production. This component is to support three productive sub-sectors through improved productivity and value-added of key commodities chosen for their growth potential and poverty reduction impact. The second component of the project is recovery of the livestock sub-sector. This is to provide emergency short term support to rehabilitate small ruminant and poultry production. The third component of the project is support for capacity building and sector coordination. This is to enable the institutional setup implement sound agricultural investments through National Agriculture and Food Security Investment Program (PNIASA), while preparing for the transition to a sector wide approach in the future.[9]
African Development Bank Group	Ministère de l'agriculture, de l'élevage et de la pêche (MAEP)	$129.6K	PROJECT DE TRANSFORMATION AGRO-ALIMENTAIRE AU TOGO - ZTA TOGO (2019-Present)	The overall goal of the Project is to contribute to reducing poverty in rural areas, reducing demand for food imports and promoting agro-industrial development to transform the national economy. Specifically, the project will create a conducive environment for private sector investment in agribusiness, build the capacity for competitive value addition to agriculture, and strengthen linkages between production, processing and commercialization in targeted commodity value chains through the right mix of public and private investments. Agricultural productivity will be increased through world class operational management of the agro-industrial park,

9 http://documents.worldbank.org/curated/en/942291468310172998/Togo-Agricultural-Sector-Support-Project

Funding Agency	Implementing Partner	Funding Amount (USD)	Project Title	Project Description
				modern and climate-smart production practices for large and small producers, effective input distribution systems, IT-based technical support to producers, improved postharvest handling and secure contractual arrangements with output markets.[10]
International Fund for Agricultural Development (IFAD)	Minister of Economy and Finance of the Republic of Togo; IFAD	$ 35 million	Shared-risk Agricultural Financing Incentive Mechanism Support project (ProMIFA) (2018-2024)	ProMIFA will facilitate sustainable access to financial services tailored to smallholder farmers and micro, small and medium-sized agricultural enterprises so they can develop their activities and gain access to markets.[11]

Table 2: Funding Initiatives for Togo

10 https://www.farmersreviewafrica.com/smallholder/2019/02/08/togo-and-ifad-partnering-for-improved-financial-services-and-job-creation-for-rural-people/

11 https://www.afdb.org/en/projects-and-operations/project-portfolio/p-tg-aa0-009/

9. Solar pump Technology Overview

A PVP (Photo Voltaic Pump) typically consists of the following main components:

1. **Photovoltaic array:** An array of photovoltaic modules connected in series and possibly strings of modules connected in parallel.
2. **Controller:** An electronic device which matches the PV power to the motor and regulates the operation, starting and stopping of the PVP. The controller is mostly installed on the surface although some PVPs have the controller integrated in the submersible motor-pump set:
   - DC controller: usually based on a DC to DC controller with fixed voltage set point operation.
   - AC controller (inverter): converts DC electricity from the array to alternating current electricity often with maximum power point tracking.
3. **Electric motor:** There are a number of motor types: DC brushed, DC brushless, or three phase induction and three phase permanent magnet synchronous motors.
4. **Pump:** The most common pump types are the helical rotor pump (also referred to as progressive cavity), the diaphragm pump, the piston pump and the centrifugal pump. Some years ago there were PVP models on the market that operated with batteries and a conventional inverter. However it was soon realized that the cost savings on the pump did not make up for the overall substandard efficiency and the higher maintenance cost due to battery replacements. Instead it became clear that it is more economical to rather store water in a reservoir than electricity in a battery bank.

There are currently three pumping configurations commonly utilized in Africa:

- **DC drive with positive displacement pumps**. This consists of four pump technologies: Diaphragm pump driven by brushed DC motor, Helical rotor pump driven by brushless DC motor, Helical rotor pump driven by surface mounted brushed DC motor, Piston pump driven by surface mounted brushed DC motor
- **AC drive powering a submersible induction motor/centrifugal pump unit**
- **AC drive powering a three phase permanent magnet synchronous motor**. This category consists of: Positive displacement helical rotor pump, Centrifugal pump

The above technologies have specific features which make them suitable for particular applications. Some of the other key technology terms useful for understanding the functioning of a solar powered irrigation system are described in detail as per the table below.

Term	Description
Array Voltage	Some of the pumping systems have high array voltages. This has the advantage that the array may be further from the borehole without significant voltage drop (dependent on cable size and current). Array positioning may be important where there is potential for theft.
DC Motors	DC motors reach efficiencies of up to 80% and are therefore significantly more efficient than sub-kW three phase motors which have efficiencies in the region of 60% to 65%.
Brushless DC Motors	This combines the high efficiency of DC motors with low maintenance as opposed to brushed DC motors which require regular brush replacement (approximately every one to two years – head and quality dependent).
Three phase permanent magnet motors	This similarly combines the high efficiency of permanent magnet motors with low maintenance.

Term	Description
Positive displacement vs. Centrifugal pump	Positive displacement pumps have a better daily delivery than centrifugal pumps when driven by a solar PV system with its characteristic variable power supply. This is due to the considerable drop in efficiency of the centrifugal pump when operating away from its design speed. This is the case in the morning and the afternoon of a centrifugal pump driven by a PV array, unless that array tracks the sun (which is why centrifugal PVPs effectiveness improves more with a tracking array than a positive displacement PVP). The efficiency curve of a positive displacement pump is flatter over a range of speeds. However the efficiency of positive displacement pumps decreases with the shallowness of the borehole (the constant fixed friction losses become a more significant part of the power it takes to lift water). Therefore it is not surprising that both Grundfos and Lorentz use centrifugal pumps for applications where the lift is less than 20 to 30m but switch to positive displacement pumps for deeper wells.
Diaphragm pump	The diaphragm pump is used for pumping small volumes of water from 100/120m depth. The pump needs regular maintenance (diaphragm replacements, cleaning). If the diaphragm breaks the motor chamber gets wet. The pump can run dry.[12]

Table 3: Key technology terms in a solar powered irrigation system

12 Ministry of Mines and Energy (Namibia), UNDP, GEF

10. Experience and Perceptions

1. **Theft**: This is a problem for both PVP and diesel pumping but very costly for the PVP systems due to the main portion of the capital cost being vested in the solar PV modules.
2. **Variable water demand:** Diesel pumps can pump water on demand. PVPs do not have that flexibility. A hybrid system such as solar diesel would present an attractive solution, however at a higher cost.
3. **Supply security:** PVP is considered to have less redundancy, is more difficult to repair and is susceptible to lightning strike. Diesel pumping has a more solid service infrastructure and is considered more reliable. The hybrid pumping solutions would improve supply security.
4. The diesel system is considered more flexible (flexible in moving a diesel engine to another borehole).
5. Diesel fuel is part of an existing infrastructure and the owner is able to do the minor service on the engine himself. PVP technology requires knowledge of mechanics, electrical and electronics thus making the user/operator dependent on specialized service which is often only available in Windhoek.
6. PVP are perceived to pump insufficient water.
7. **Corrosion** is a problem for both diesel and solar pumps.
8. The environmental impact of diesel pumps includes carbon emissions, possible borehole contamination, and threat to borehole sustainability. PVPs can be seen as a resource protection if it is designed for the maximum sustainable yield of the borehole.
9. The operation of PVPs is quiet.
10. PVPs are perceived to be expensive.
11. Many users on commercial farms combine the need for starting the diesel pump the opportunity for inspecting fences, checking on livestock and other farming activities. However, if a PVP is used then the frequency of these trips over the farm decrease[13].

13 Ministry of Mines and Energy (Namibia), UNDP, GEF

11. Recent Solar Pumps Uptake and Pricing

Information to be furnished by Togo NFP (if any)

12. Feasibility Analysis

The feasibility of a solar powered irrigation system depends on a wide array of factors ranging from geographic parameters such as temperature, rainfall, water table depth to site specific parameters such as cropping pattern, land size, planting date, irrigation technique etc. Any feasibility analysis of a solar powered irrigation system would involve both the technical feasibility and the financial feasibility. The technical feasibility would analyze the site specific conditions to determine whether such system can be installed considering the different technical aspects such as solar irradiance, size availability, panel size, tracking systems, water table depth etc. The technical feasibility would also provide recommendations on the ideal pump size and type considering the dynamics of the site. Once technical feasibility for a given system is established, the costs involved and the expected returns are calculated using financial feasibility analysis. The below figure summarizes the interplay of various parameters involved in technical and financial feasibility analysis.

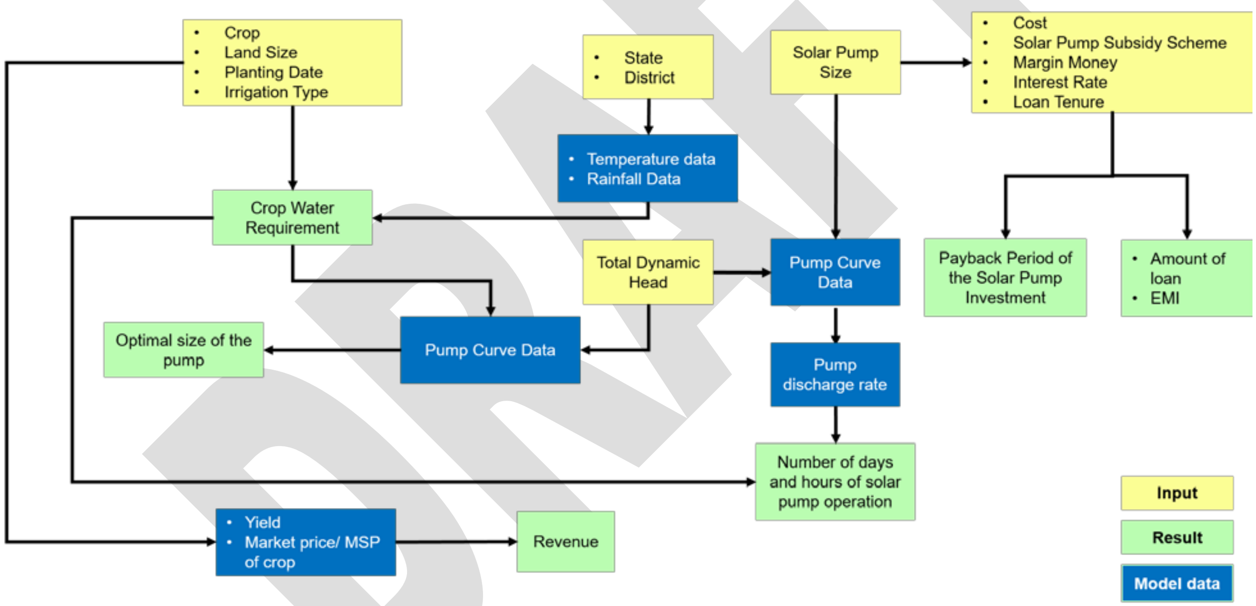


Figure 10: Factors involved in feasibility analysis of a solar powered irrigation system

12.1 Technical Feasibility Analysis

12.1.1 Solar Irradiance

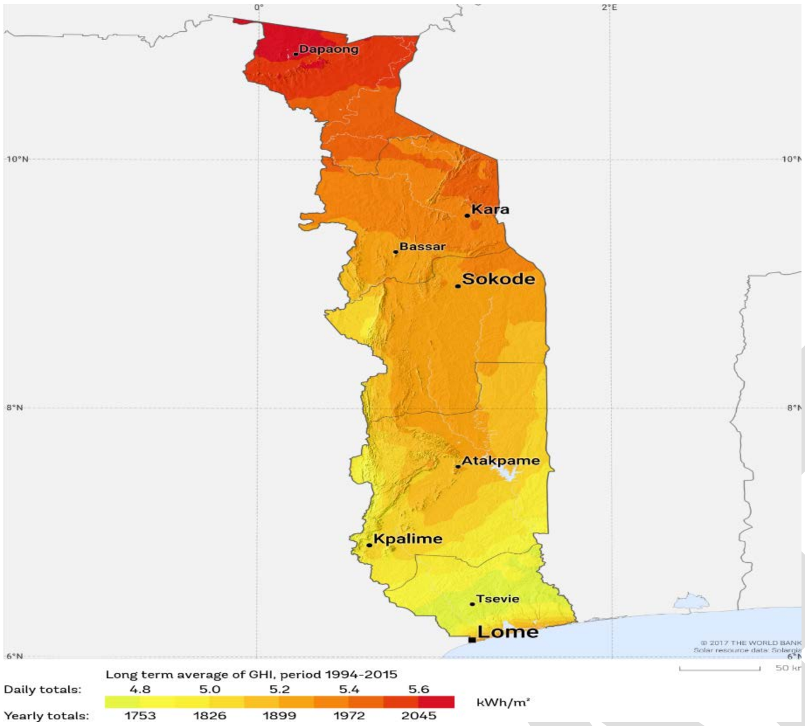


Figure 11: Global Horizontal Irradiance of Togo
Source: Global Solar Atlas, World Bank Group

The efficiency of solar panels and consequently the solar energy output depends on three factors: the intensity of the solar radiation flux; the quality and the operating temperature of the semiconductor in use and the operating temperature of the semiconductor cell. Though the two latter factors may somehow, in one way or the other, be altered and improved; the intensity of the solar radiation flux however, to a great extent, is simply a given natural resource. The actual level of solar irradiance depends on the latitude and local climatic conditions. Annual solar irradiance, for instance in northern Europe is different from that noted within the sub-Saharan region. Figure shows the long term global horizontal irradiance over Togo. As clearly indicated from the figure, the Northern part of the country, particularly in the warm desert area, the GHI values vary between 5.4-5.6 kWh/m^2 while in the Southern part, it lies between 4.7 - 5.2 kWh/m^2. The average solar insolation in the country varies between 4.8 – 5.7 kWh/m^2/day. The value signify great potential for development of solar technologies in the country owing to the abundance of solar insolation available throughout the year. The utilization of solar energy can further be increased by utilization automatic/ manual trackers to ensure maximum absorption of solar irradiance by the panel surface.

12.1.2 Water Table Depth

The water table depth in Togo varies based on the type and productivity of main aquifers. The aquifers can be classified as low to high productivity, low to moderate productivity, moderate to high productivity, low to moderate productivity, very low to high productivity and low productivity. The table below summarizes the water table depth for the various aquifers.

Aquifer Productivity	Water table depth
Low to high productivity	15 m to 40 m
Low to moderate productivity	10 m to 150 m
Very low to high productivity	10 m to 300 m
Low to moderate productivity	10 m to 30 m
Low to high productivity	40 m to 400 m
Low productivity	4 m to 60 m

Table 4: Water table depth at various levels of aquifer productivity

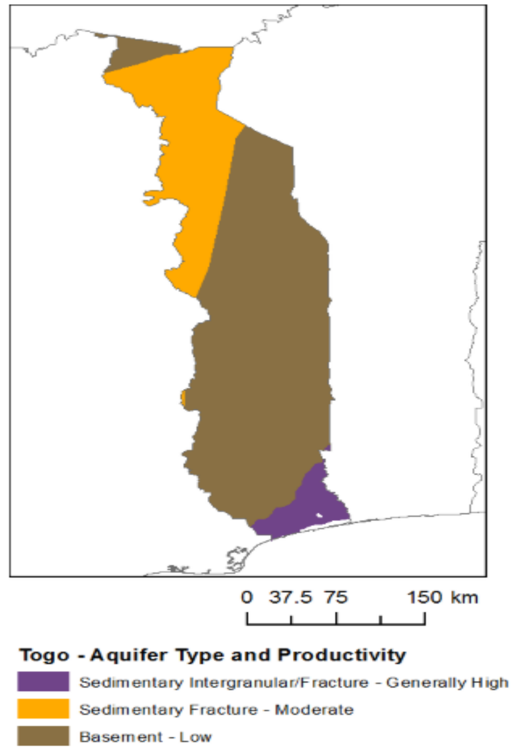


Figure 12: Hydrogeology of Togo
Source: British Geological Survey

12.1.3 Pump Location

The pump should be located in an enclosed room called a pump pit or a pump house. Surface pumps are not water proof and need to be kept away from water and protected from environmental conditions to prolong their lifetime and reduce maintenance requirements. Distance between the pump and the PV panels should be kept to a minimum to reduce voltage drop in the cables. Increased distance causes harmonics and would require a harmonics filter to avoid damages to the pump and the inverter/controller.

12.1.4 Pump Sizing

Oversizing would incur unnecessary costs, and under sizing would lead to insufficient performance. This is why each component needs to be properly designed and sized to meet the specific requirements of the project. It is the only way to guarantee reliability and system durability, and achieve the desired performance. Similarly when sizing a solar system, it is recommended to use the 'worst month method'. By sizing the systems for the month with most adverse conditions in the year, it will be ensured that water supply will be enough for all the other months. The worst month in the year will be that in where the gap between the energy required to supply water and the energy available from the Sun is higher. In case the daily water requirement is the same all the year round (meaning too that the energy required is the same all the year round since pump will run for the same number of hours any day), the worst month will be that with least solar radiation (for example, July for the case of Khartoum)[14].

14 Sun-Connect News

12.1.5 Water Demand

Water demand is the major factor affecting the size of the pumping system. For solar systems it is calculated as a daily consumption rate (m^3/day). The storage capacity is the volume of water that need to be stored to ensure sufficient and continuous supply of water to end users. Storage tanks usually range in a volume of between 1 to 5 days of daily water requirements, depending on the location and the usage patterns

12.1.6 Total Dynamic Head

[15]The total dynamic head is a very important parameter of a solar pumps which determines the various head losses that the pump must overcome. It is a summation of the suction head, discharge head and the friction losses. The total dynamic head and the desired flow rate of the system are applied to the pump performance curve, which is used for proper pump selection based on required electrical power input and optimum efficiency.

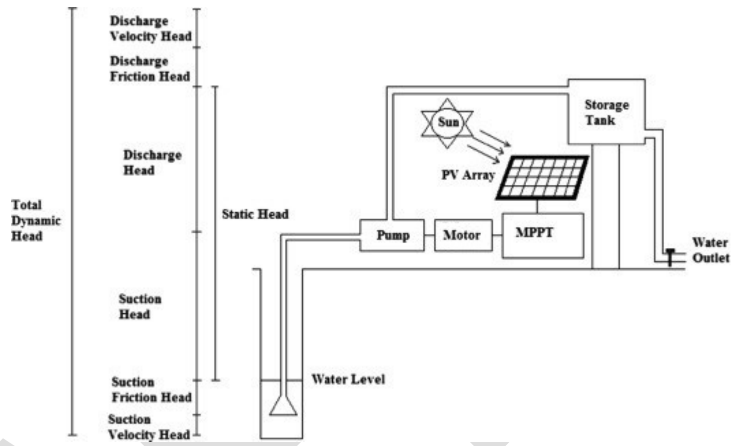


Figure 13: Total Dynamic Head of a solar pump

15 ScienceDirect.com

12.2 Financial Feasibility Analysis

12.2.1 Payback Period Analysis

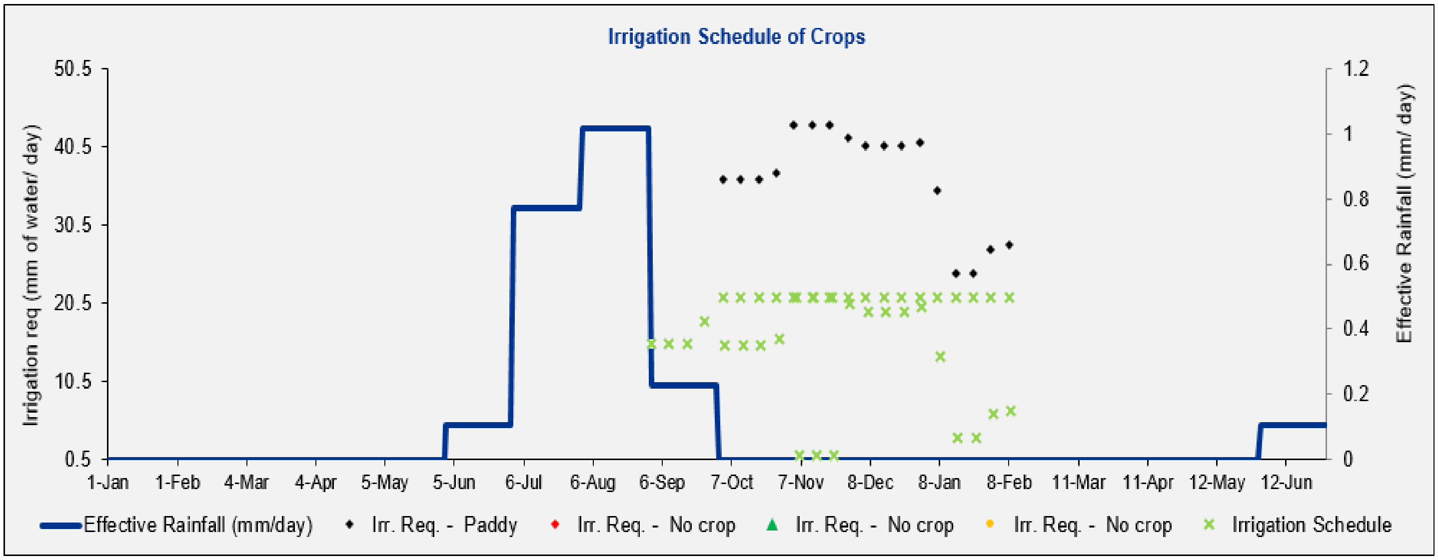
Indicative Inputs

S.No.	Particulars	Unit	Value	Source
1	Crop to be Irrigated		Rice	
2	Land Size	hectares	0.5	
3	Planting date		May	As per cropping calendar of Togo
4	Irrigation type		Flood: Earth canal supplied	
5	Selected Size of Solar Pump	HP	3	
6	Total dynamic head inclusive of friction losses	meters	40	
7	Cost of Solar Pump	USD	~8696	Based on FAO global estimates
8	Subsidy	%	70%	
9	Margin Money	%	10%	
10	Loan Amount	%	20%	
11	Interest Rate	%	5%	Trading Economics
12	Loan Tenure	years	10	
13	Cost of diesel pump per HP	USD	56	FAO
14	Cost of diesel	USD/litre	1.09	Published reports and articles
15	Hike in diesel prices (y-o-y)	%	3%	Based on global averages
16	Inflation rate in Togo	%	1.8%	World Data Info
17	Living expense of the farmer (as a % of crop revenue)	%	60%	Based on global estimates, KPMG Analysis
18	Maintenance costs for diesel pump (as a % of capital costs)	%	10%	Based on global estimates, KPMG Analysis

Indicative Crop Water Requirement

Total Crop Water Requirement (m^3)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2451	359	-	-	-	-	-	-	-	2993	3692	3890
Annual crop water requirement (m^3)						13385					

Indicative Irrigation Schedule



Irri. Req. indicates the net irrigation requirement (considering rainfall) for individual crops
Irrigation Schedule indicates the consolidated schedule over the time period for all the crops

Indicative Outputs

S.No.	Particulars	Unit	Value
1	Amount of subsidy	USD	6087
2	Amount of loan to be availed	USD	1739
3	Yearly installment towards loan repayment	USD	225
4	Monthly installment towards loan repayment	USD	19
5	Savings in monthly diesel expenses on an average basis for 20 years	USD	66
6	Number of hours of solar pump operation required	Hours	447
7	Number of days of solar pump operation required	Days	56
8	**Incremental payback of solar pump w.r.t. diesel pump**	**years**	**5**

13. Advantages of solar powered irrigation

Socio-economic advantages		Environmental advantages
Farm level	**National level**	
Financing and cost of solar panels continue to drop, making SPIS economically viable and competitive with other sources of energy.	Potential for job creation in the renewable energy sector.	No greenhouse gas emissions.
Rural electrification and access to renewable energy, especially in remote areas.	Contribution to rural electrification and renewable energy targets.	Potential for adaptation to climate change by mobilizing groundwater resources when rains fail or rainfall patterns are erratic.
Independence from volatile fuel prices and unreliable and costly fuel supplies.	Reduced dependence on energy exports. Energy subsidies for fossil fuels can be reduced while offering an alternative to farmers and rural communities whose livelihoods would otherwise be negatively affected.	Potential for improving water quality through filtration and fertigation systems. Less pollution resulting from inadequate fuel handling from diesel pumps.
Potential for increasing agricultural productivity and income due to improved access to water.	Food security may be improved if introduction of SPIS is accompanied by changes in irrigation technologies and agricultural practices.	
Potential for income diversification due to multiple uses of energy (e.g. feed-in to grid, lighting, cooling) and water (e.g. livestock watering, domestic uses).	Rural development through improved access to water and energy.	
Reduced cost for water pumping in the long run. If system is being modernized for pressurized irrigation, increases in energy costs are offset through the use of solar energy.		
Potential time saving due to replacement of labour intensive manual irrigation, which can lead to other income-generating activities. Women and/or children might profit from time not spent on watering anymore.		

Table 5: Advantages of solar powered irrigation

14. Key Stakeholders

Organization/ Agency	Role
Ministry of Mines and Energy	The Ministry of Energy and Mines is responsible for the development and implementation of government policy in the areas of energy, mining and geology as well as control of other sectors dependent of his authority. It ensures the supervision of companies and public institutions that fall under its jurisdiction.
Ministry of Economy and Finance	Ministry of Economy and Finance is in charge of the general orientation of the economic and financial policy of the government and the management of the state's patrimony
Ministry of Agriculture, Animal Husbandry and Fisheries	The ministry is the principal organization which provides regulatory and technical advice, training, and support for subsistence farmers, commercial farmers, agri-processors, and exporters to effectively manage and use the potential in agriculture and fisheries for food security, income generating opportunities, commercial development, and sustainable management of resource.
Ministry of Water, Sanitation and Village Hydraulics	The ministry is responsible for managing the water supply, sewage, drainage, hygiene and related aspects.
Green Climate Fund (GCF)	GCF is working on 3 projects with GCF funding being ~600 million.
World Bank	The World Bank portfolio comprises 12 active projects and programs worth a total commitment of US$220.6 million. These cover agriculture, education, health, and the environment, as well as community development, social protection, telecommunications, and infrastructure.
Global Environment Facility (GEF)	GEF has engaged in 47 projects in Togo involving GEF Grant Funding of USD 243 Million, in the areas of land degradation, climate change and biodiversity.
African Development Bank (AfDB)	AfDB is supporting a number of projects in the country in the area of energy, agriculture, transportation, water supply and sanitation through financial and knowledge support.
United States Agency for International Development (USAID)	USAID through its programme Power Africa is providing transaction advisory assistance to private sector companies seeking to operate in Togo.
Millennium Challenge Corporation (MCC)	MCC is undertaking the Togo Threshold Program which is designed to support policy and institutional reforms in two areas identified as critical constraints to economic growth and poverty reduction: information and communication technology (ICT) and land tenure.
Food and Agriculture Organization of the United Nations (FAO)	FAO assistance in Togo hinges on three priority areas: Strengthening agricultural production and food security, through capacity building, greater productivity and value addition, and access to safe and adequate food supplies; Improving the framework for sustainable environmental and natural resource management; Effective response and preparedness for food and agricultural threats and emergencies.

Organization/ Agency	Role
International Fund for Agricultural Development (IFAD)	IFAD and Togo are partnering on a number of programmes such as 'Share-risk Agricultural Financing Incentive Mechanism Support Project' and 'National Programme for the Promotion of Rural Entrepreneurship'.

Table 6: Key Stakeholders in Togo

15. Recommendations

Togo has submitted a demand of 5,000 solar water pumping systems as part of ISA's Demand Aggregation activity under the Scaling Solar Applications for Agriculture Use (SSAAU) programme. A five-day mission visit with delegates from ISA and KPMG was undertaken to understand the existing ground level scenario in Togo and to validate the demand. During the discussions, it was noted that while Togo has participated in the programme, the details of the location, sizing and other aspects of demand estimation has not been worked out by the respective Ministry. This report, hence assesses the feasibility of implementation of solar pumps with reasonable assumptions as detailed in the report. However, to arrive at a detailed feasibility assessment, site specific and other relevant details (such as costing of solar pumps, applicable taxes etc.) are required from the relevant Ministry so as to support the country in developing a bankable project.

Further, it is expected that the outcome of Price Discovery International Competitive Bid being carried out by ISA for Solar Agricultural Pumps will be finalized by November 2019 and the country specific rates for various categories of pumps will be informed to Togo. The same may be examined and if acceptable, Togo may enter into a contract with the selected bidder(s). The prices discovered will also help Togo in ascertaining a benchmarking price for various capacities of solar water pumping systems for future projects.