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

Table of Contents

List of Tables

List of Figures

1. Executive Summary

- The population growth rate is estimated at 2.8 % per annum and is expected to reach 23 million by 2025. Malawi remains an overwhelmingly rural economy, however, the country is urbanizing at an annual rate of about 3.5 %, higher than the average for Sub-Saharan Africa.[1]
- Malawi's Intended Nationally Determined Contribution (INDC) is mentioned below and the timeframe for implementation is 2015 to 2040.
    - Energy supply
        - Produce 2000 solar water heaters
        - Install 20,000 solar PV systems
        - Produce 2 million litres of bio-diesel/year
        - Increase generation of HEP by 800 MW by 2025
    - Wastes
        - Construct controlled landfill for biogas recovery to generate up to 240 GWh of primary energy (95 GWh of electricity) per year
        - Promote solid and water waste reduction practices at household, institutional and industry level to reduce waste generation
        - Install waste to energy incinerators to generate up to 250 GWh of electricity per year[2]
- On an average Per capita electricity, consumption is about 72 kWh/person/year[3]. This is much lower than the Sub-Saharan Africa average of 488 kWh/person/year (World bank, 2017)
- All major power stations are located in the southern region along the Shire river. One small hydro station, the 4.5MW Wovwe plant, operates in the north of the country. According to World Bank project report, hydro potential at Shire river alone is estimated at 600 MW.[4]
- Malawi has an estimated gross theoretical potential of 1670 MW and the average power generation of 15,000 GWh/year. The technical and economically feasible hydro capacity has been estimated at 6, 000 and 7,000 GWh/year, respectively (Taulo, 2007). In addition, Malawi also has huge untapped small hydropower potential (with capacities of less than 10 MW each) which are spread out across the country. The exploitability of these is limited by their projected costs, but they could be useful for off-grid or stand-alone-mini grid electrification.[5]
- According to Malawi's Integrated Resource Plan (IRP), ESCOM aims to supply electricity to close to 30% of the population by 2030, quadrupling current generation levels to 1875 MW. To meet the growing demand, new generation capacity needs to be integrated into the grid on an average

[1] http://documents.worldbank.org/curated/en/313871549533419539/text/Concept-Project-Information-Document-Integrated-Safeguards-Data-Sheet-Malawi-Electricity-Access-Project-P164331.txt
[2] https://www4.unfccc.int/sites/NDCStaging/pages/Party.aspx?party=MWI
[3] https://www.theglobaleconomy.com/Malawi/electricity_consumption/
[4] http://documents.worldbank.org/curated/en/313871549533419539/pdf/Concept-Project-Information-Document-Integrated-Safeguards-Data-Sheet-Malawi-Electricity-Access-Project-P164331.pdf
[5] http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-447X2015000200003

annual basis of 157MW over the planning horizon (2017-2036). The IRP specifically mentions plans to add 650 MW of new installed capacity by 2032 – including 165MW of solar, 60MW of wind, 23MW of hydro, 50MW of fuel oil, 250MW of coal, and 100MW of biomass. Generation projects in Malawi are expected to benefit from possible trading and export opportunities when cross-border transmission projects are in place with Mozambique, Tanzania, and Zambia.[6]

- Malawi is ranked 111 among 190 economies in the ease of doing business, according to the latest World Bank annual ratings. The rank of Malawi deteriorated to 111 in 2018 from 110 in 2017. Ease of Doing Business in Malawi averaged 138.18 from 2008 until 2018, reaching an all-time high of 171 in 2013 and a record low of 110 in 2017[7].
- Malawi is ranked 32nd among 47 countries in the Sub-Saharan Africa region, and its overall score is below the regional and world averages.[8]
- Company Tax: The Corporate Tax Rate in Malawi stands at 30%
  The Sales Tax Rate in Malawi stands at 16.50.[9]

2. Introduction

Malawi, landlocked nation in southeastern Africa. A nation invested with fantastic good countries and broad lakes, it possesses a restricted, bending segment of land along the East African Rift Valley. Lake Nyasa, referred to in Malawi as Lake Malawi, represents more than one-fifth of the nation's complete zone.

The population growth rate is estimated at 2.8 % per annum and is required to reach 23 million by 2025. Malawi is predominantly a rural economy, nonetheless, the nation is urbanizing at a yearly pace of about 3.5 %, higher than the normal for Sub-Saharan Africa. Malawi has had a stable fair political framework since 2014 and has started monetary and political changes in open money related administration, business guidelines and the outside trade system.[10] With no reserve margin and a stressed system, the reliability and quality of electricity supply is poor. Malawi depends on domestic generation, as there are currently no significant interconnections to neighboring countries.

Following are the key stakeholders in the electricity subsector in Malawi[11]:

S.No.	Key Stakeholders	Institution
1	Ministry	Ministry of Natural Resources Energy and Mining (MNREM)
		Ministry of Agriculture, Irrigation and Water Development (MAIWD)

[6] https://www.export.gov/article?id=Malawi-Energy
[7] https://tradingeconomics.com/malawi/ease-of-doing-business
[8] https://www.heritage.org/index/country/malawi
[9] https://tradingeconomics.com/malawi/sales-tax-rate
[10] http://documents.worldbank.org/curated/en/313871549533419539/text/Concept-Project-Information-Document-Integrated-Safeguards-Data-Sheet-Malawi-Electricity-Access-Project-P164331.txt
[11] http://documents.worldbank.org/curated/en/313871549533419539/text/Concept-Project-Information-Document-Integrated-Safeguards-Data-Sheet-Malawi-Electricity-Access-Project-P164331.txt

		Ministry of Foreign Affairs and International Cooperation (MoFA)
2	National institutions and policy makers	National Energy Commission
		Société nationale d'électricité (SNEL)
		National Renewable Energies Service (SENEN)
		National Society for Rural Hydraulics (SNHR)
3	Regulator	Malawi Energy Regulatory Authority (MERA)
4	DISCOM	Electricity Supply Corporation of Malawi Limited (ESCOM)

Table 1 Role of various institutions involved in the electricity sector in Malawi

The total installed capacity is ~439 MW where hydroelectric is 384 MW and solar is 55 MW. Access to electricity in the rural areas at 4% which is significantly less than 57% access in urban areas.[12] Biomass and oil are the largest contributor to energy supply followed by hydro as illustrated in Figure 2.

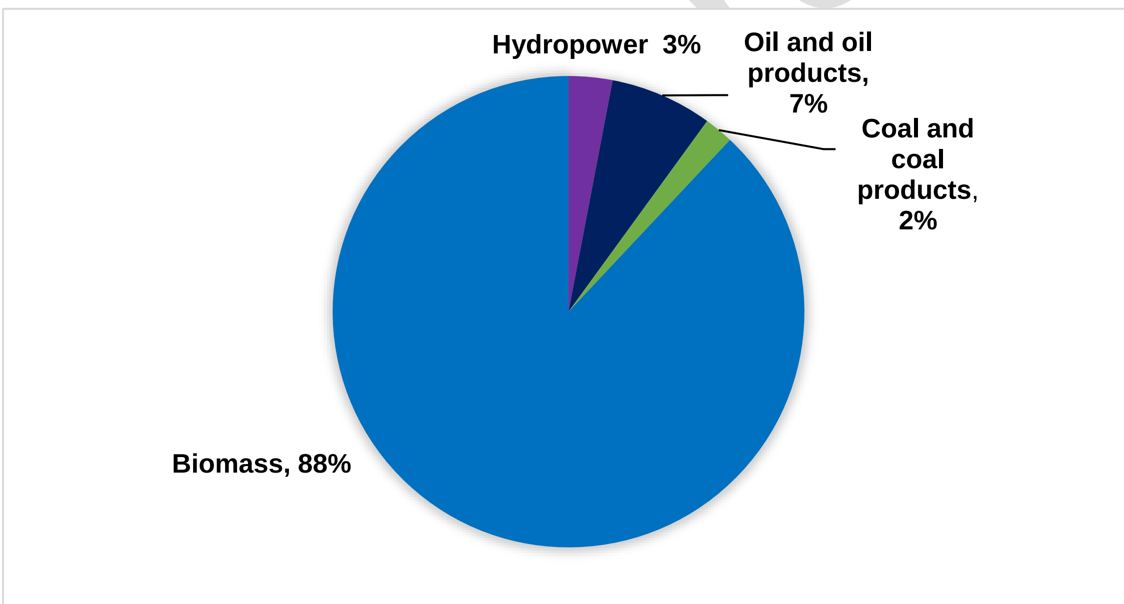

Figure 1: Energy Supply Mix

Source: Energy Charter

Grid unavailability in rural areas has led to increasing reliance on biomass for meeting the energy needs leading to rapid deforestation

[12] https://www.usaid.gov/powerafrica/malawi

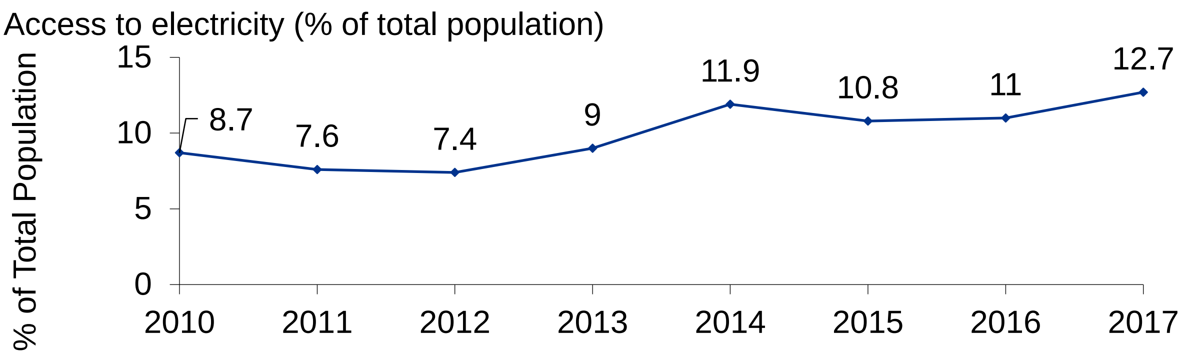

Figure 2 Access to electricity

Farmers primarily depend on rain fed irrigation for meeting their crop water requirements. The country has faced frequent droughts in the recent past and the huge solar potential in the country, with average daily solar insolation of 10-11 hours, can help the farmers develop solar powered irrigation facilities.

3. Geography

Malawi is a landlocked country in southeastern Africa. It has highlands and extensive lakes, occupies a narrow, curving strip of land along the East African Rift Valley. Lake Nyasa, known in Malawi as Lake Malawi, accounts for more than one-fifth of the country's total area.

Figure 3: Malawi Map

Source: Britannica

Majority of Malawi's population takes part in cash crop harvest and subsistence agriculture. Malawi has received a lot of foreign capital as development aid, which has contributed significantly toward the misuse of its normal assets and has enabled Malawi to occasionally produce food surplus. The nation's exports comprise of the produce of both little landholdings and huge tea and tobacco domains. All things considered, its populace has experienced incessant hunger, high rates of infant mortality, and grinding poverty—a paradox regularly credited to agricultural system that has favored large estate owners.[13]

4. Climate

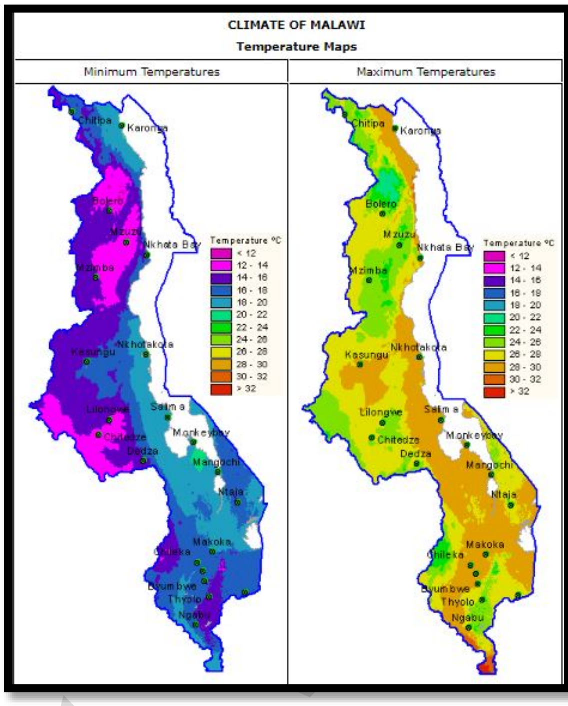

Figure 4: Climate Classification Map

Source: metmalawi.com

Malawi has a sub-tropical atmosphere, which is generally dry and strongly seasonal. The warm-wet season extends from November to April, during which 95% of the yearly precipitation happens. Annual average rainfall varies from 725mm to 2,500mm with Lilongwe having a normal of 900mm, Blantyre 1,127mm, Mzuzu 1,289mm and Zomba 1,433mm. Extraordinary conditions incorporate the dry season that happened in 1991/92 season and surges of 1988/89 season. The low-lying territories, for example, Lower Shire Valley and a few areas in Salima and Karonga are more powerless against floods than higher grounds.

A cool, dry winter season is clear from May to August with mean temperatures fluctuating somewhere in the range of 17 and 27 degrees Celsius, with temperatures falling somewhere in the range of 4 and 10 degrees Celsius. Likewise, frost may happen in isolated regions in June and July. A hot, dry season keeps going from September to October with normal temperatures changing somewhere in the range of 25 and

[13] https://www.britannica.com/place/Malawi

37 degrees Celsius. Humidity ranges from 50% to 87% for the drier long stretches of September/October and wetter long periods of January/February individually.[14]

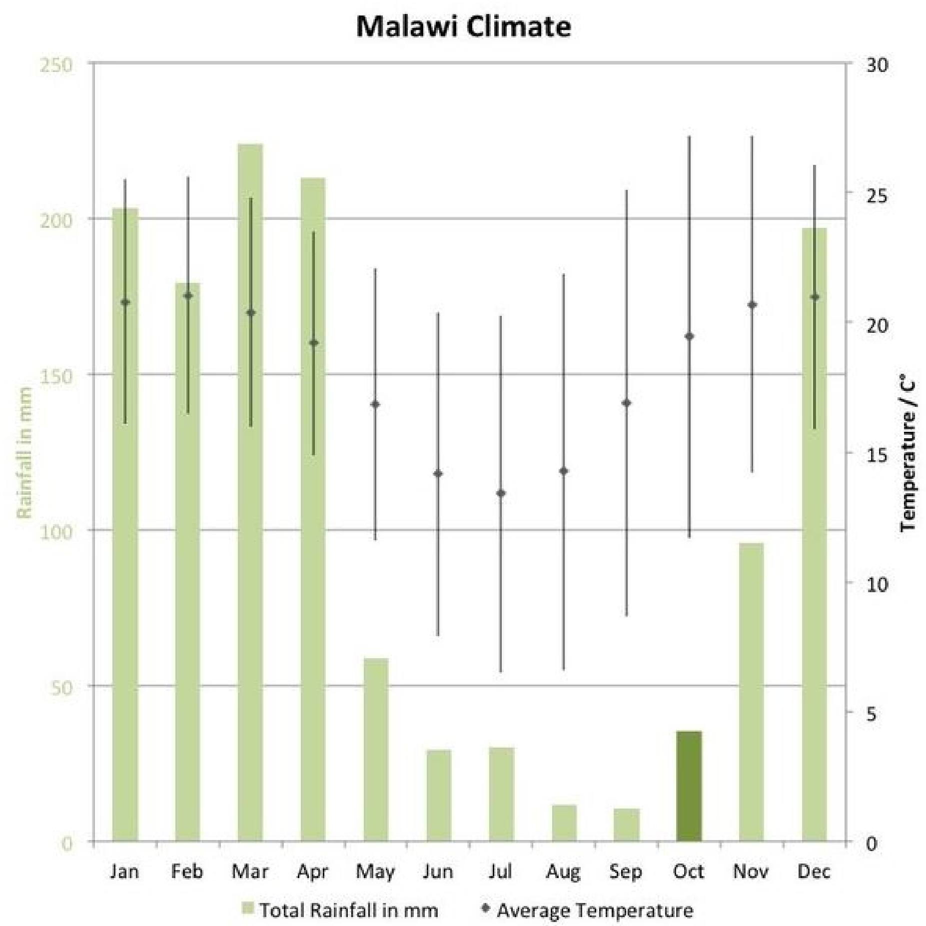

Figure 5: Average Temperature Trend

Source: expertafrica.com

5. Rainfall

The period October to April is the primary precipitation season over Malawi. For the most part the fundamental downpours start from November in the south and dynamically spread northwards. During this period, the primary downpour bearing frameworks that impact precipitation over Malawi incorporate the Inter-Tropical Convergence Zone (ITCZ), Congo air mass, Easterly Waves and Tropical Cyclones.

[14] https://www.metmalawi.com/climate/climate.php

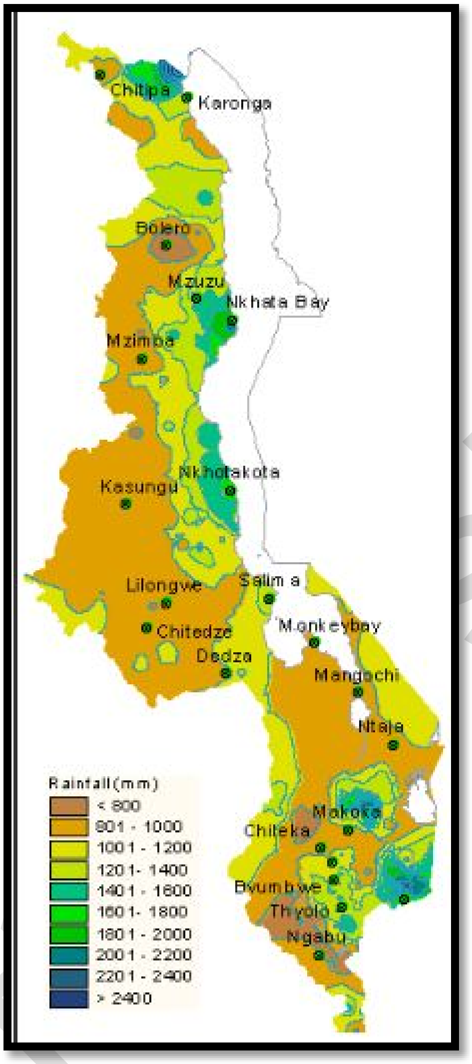

Figure 6 Rainfall map

Source: Department of Climate Change and Meteorological Services, Malawi

The key driving variable on precipitation frameworks over Malawi are Sea Surface Temperatures (SSTs) over the tropical Pacific, Indian and Atlantic Oceans. At present, nonpartisan ElNino Southern Oscillation (ENSO) conditions have created over the Eastern Central Equatorial Pacific Ocean and are required to persevere up to the finish of the 2017/2018 precipitation season. This infers the season will be portrayed by neither El Nino nor La Nina conditions.

As of late, the precipitation seasons that have been practically equivalent to the momentum impartial conditions are 1990/1991, 1993/1994, 2001/2002 and 2012/2013 seasons. Examinations on these past impartial years show that the nation experienced late beginning of the downpours and typical to underneath ordinary all out precipitation sums over generally zones. Anyway, better than average sums were experienced over good countries and lakeshore zones.[15]

[15] https://www.metmalawi.com/forecasts/seasonal.php

6. Soil

The significant soil types in Malawi are commanded by Luvisols, Lixisols, and Cambisols, involving seventy five percent of the region. Lixisols are overwhelmingly in the northern locale, Luvisols in the focal, and Cambisols along the Rift Valley and to a great extent in the southern districts. Cambisols also, Luvisols are soils with moderately great common supplement attributes; henceforth, they are very susceptible to abuse through agricultural exercises. They are additionally inclined to soil disintegration because of their synthetic and physical attributes. Lixisols don't have natural fertility. Their low total steadiness and slaking inclinations are unwanted agricultural characteristics. Altogether, the three soil types which possess 76% of Malawi are susceptible to soil erosion.

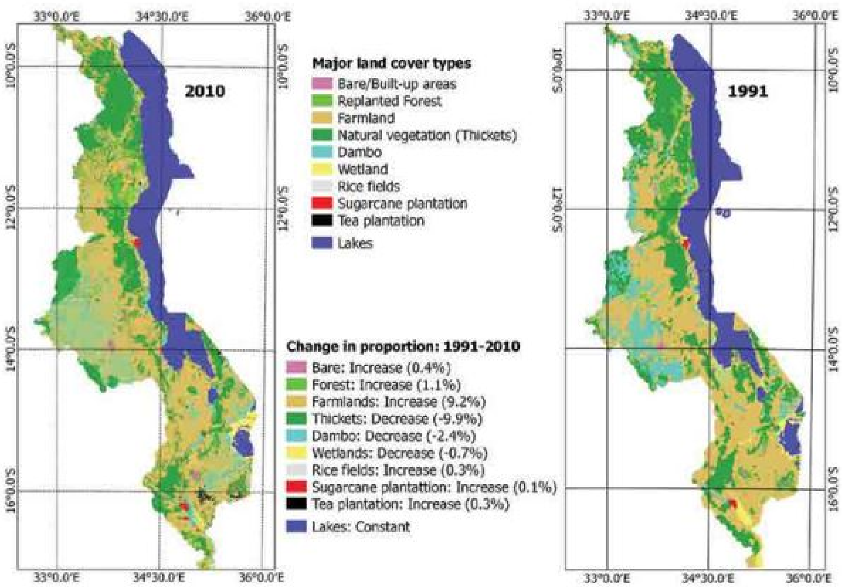

Figure 7: Soil Map

Source: UNPEI

As far as vegetation spread, the principle spread/land use types are farmlands, common woodlands, timberland estate, wetlands, and lakes. These spread sorts have changed in extent due to land use elements. A portion of the progressions could be connected to the dirt misfortune issues in the nation. For instance, during 1991-2010 period, there was a recognizable 9% decrease in regular timberland spread and practically relating corresponding increment in zones under agriculture. This recommends agricultural land could have recovered a few pieces of the characteristic backwoods. This perception was especially clear in the southern and northern areas. Specific consideration was attracted to the territories where these progressions happened in the structurally unstable Lixisols in Nkhata Bay and in vulnerable Luvisols and Cambisols in Mulanje, Phalombe, and Nsanje Districts.[16]

7. Agriculture and Irrigation in Malawi

Agriculture adds to work, financial development, export earnings, poverty reduction and food security. Transforming the nation's agriculture segment into an engine of growth is a significant improvement objective for Malawi.

Agriculture is the segment wherein Malawi contends most effectively in worldwide markets. While maize has been the significant nourishment crop as far as the arrangement motivation and hectarage planted, tobacco has been, and keeps on being, the predominant money crop in the economy representing roughly 58% of the nation's absolute fare profit. Other significant yields incorporate dried vegetables, sugar, tea, cotton, and nuts. Agricultural expansion is significant for Malawi. U.S. merchandise or specialized learning

[16] https://unpei.org/sites/default/files/Soil_Loss_Assessment_in%20Malawi.pdf

that could be adjusted in a savvy way to Malawi's rural conditions and lift the quality, amount, or decent variety of yields may locate a beneficial market.[17]

The emphasis of National Agriculture Policy (NAP) is commercialization as one method for advancing continued development in the agribusiness segment. The approach will encourage progress of cultivating networks from subsistence generation to non-conventional high-esteem rural worth chains that would eventually bring about value addition. The NAP recognizes a lot of need activities fundamental for understanding this imagined agrarian change. These territories are supportable agrarian creation and efficiency; reasonable water system advancement; motorization of horticulture; rural market improvement, agro-preparing and esteem expansion. With NAP, the administration seeks after improved administration of agrarian assets, expanded farming fares and salaries, and improved nourishment and sustenance security. Other NAP need regions are strengthening of youth, ladies and helpless gatherings in farming; and institutional advancement, coordination and limit reinforcing.

Maize is the significant grain that comprises nourishment security in Malawi. To pad the nation against maize creation deficiencies, government set up the key grain save supervised by the National Food Reserve Agency. Additional time, various developing issues have required the audit of rules to address holes in the present framework and improve the board of the SGR. The overhauled rules require improving the nation's initial admonition framework for better readiness, early arrival of assets to secure grain during the gathering time frame; a 14-member committee to regulate drawing down of maize and has indicated conditions to trigger drawing down both in crisis and non-crisis conditions. Issues of grain stockpiling, quality control, and reusing of stock are additionally nitty gritty in the rules. These rules will be looked into at regular intervals. By and large, government built up the strategies and rules through consultative procedures and furthermore took insight of different worldwide instruments Malawi is signatory to, to guarantee congruity with universal practice.[18]

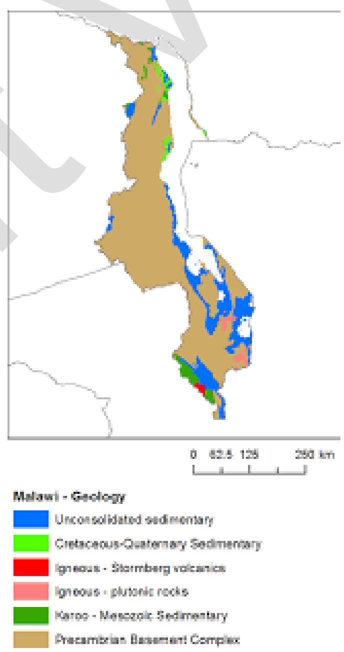

Figure 8: Irrigation Map

[17] https://www.export.gov/article?id=Malawi-agricultural-products
[18] https://www.worldbank.org/en/news/feature/2017/01/31/new-policies-to-transform-malawi-agriculture-sector

8. Cropping Pattern

The agriculture sector is thus expected to contribute to sustainable economic growth, central to Malawi's aim to reduce poverty. It is recognized that, without achieving this agricultural growth, it will be impossible to deliver on the Government's vision of creating wealth and employment for all the people of Malawi. The agriculture sector is divided into two main sub-sectors, i.e. the smallholder and the estate sub-sectors. The smallholder sub-sector concentrates mostly on producing food for their own consumption, with only surpluses sold for cash. The average land holding size per household for smallholders in Malawi is 1.2 hectares (World Bank, 1994). Over 90% of the total agricultural value-added comes from about 1.8 million smallholders who on average own only 1 hectare of land. Malawi is also highly dependent on rain-fed agriculture which partly explains the low productivity levels in the country, with considerable gaps between current and potential yields. According to the Ministry of Agriculture, Irrigation and Water Development (MoAIWD), the potential irrigable land area lies between 480,000 and 620,000 hectares. However, the land that has been developed for irrigation is about 97,000 hectares accounting for between 16% and 20% of the irrigation potential. Agricultural intensification through irrigation has the potential to quadruple yields and provide at least two harvests per hectare to the small farmer in a given year (MoAIWD, 2009).

Malawi is endowed with abundant natural resources for energy. However, the country suffers from intermittent energy supplies. The need to meet the current and projected demand calls for adequate investment in the energy sector. Currently, due to undiversified sources of power, Malawi's energy supply faces significant hydrological risks. The fact that 98% of the Electricity Supply Commission of Malawi's (ESCOM) generating capacity power production is dependent on the flow of the Shire River and the level in Lake Malawi renders Malawi very vulnerable to fluctuations in rainfall patterns (World Bank, 2011).[19]

The typical cropping calendar for Malawi is provided below:

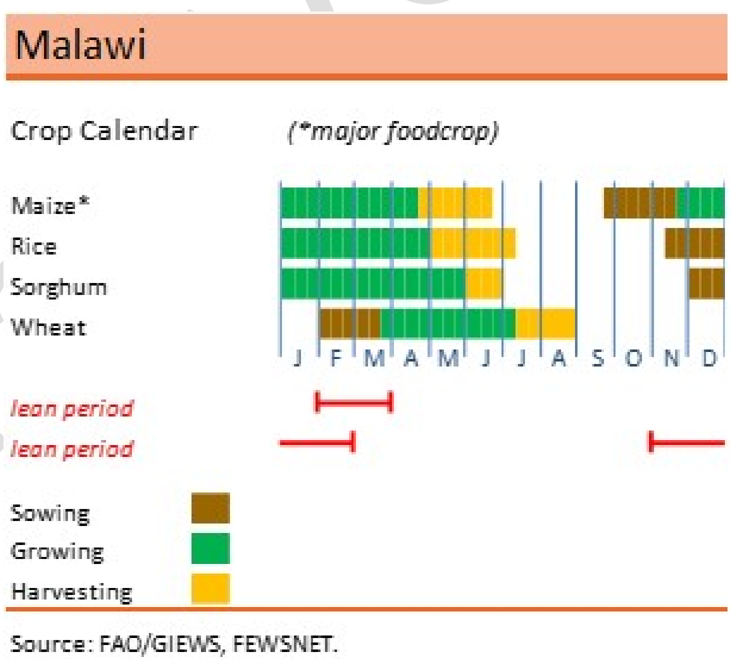

Figure 9: Cropping Calendar

Source: FAO

[19] http://www.fao.org/giews/countrybrief/country.jsp?code=MWI

9. Background to solar water pumping in Malawi

Malawi is predominantly an agro-based economy and is heavily dependent on rains for irrigation. The ISA mission team discussed the potential of solar water pumping system for irrigation and the likely transformational change it will bring to agricultural sector by ways of increased productivity and higher income for farmers. The Country templates have been shared with the National Focal Point to consider submitting their demand for Solar Pumping Systems. Additionally, ISA team shared with NFP and Ministry of Agriculture, Irrigation and Water Development about its initiatives in conducting a price discovery bid through Energy Efficiency Services Ltd for 272,579 Solar Pumping Systems based on aggregated demand from 22 Member Countries. It is expected that there shall be a significant reduction of price through demand aggregation. Republic of Malawi has expressed interest in the program and the Department of Energy Affairs will be coordinating with the concerned Ministries and Departments for aggregating requirement of solar pumps which can be used for irrigation, drinking water and sanitation purposes to cover agriculture, health and education sector.

10. 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.
AC Motors	The motor operates on alternating current; the direct current produced by solar panels gets converted to AC using the inverter. The conversion from DC to AC leads to loss of power from generation to consumption. AC motors gain importance in applications where higher output/head combinations are required.
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.
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.
Surface pump	Surface pumps are installed at ground level to lift water from shallow water sources such as shallow wells, ponds, streams or storage tanks. Surface pumps can also be used to provide pressurized water for irrigation or home water systems. These pumps are suitable for lifting and pumping water from a maximum depth of 20 meters.
Submersible pump	Submersible pumps installed where there is a requirement for the submerged in the fluid to be pumped These pumps can be used in areas where water is available at a greater depth and where open wells are not available. Typically the maximum recommended depth these systems can pumps is 50 meters.

Table 2 Key technology terms in a solar powered irrigation system

11. Experience and Perceptions

1. **Theft**: This is a problem for both PVP (Photo Voltaic Pump) 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[20].

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.

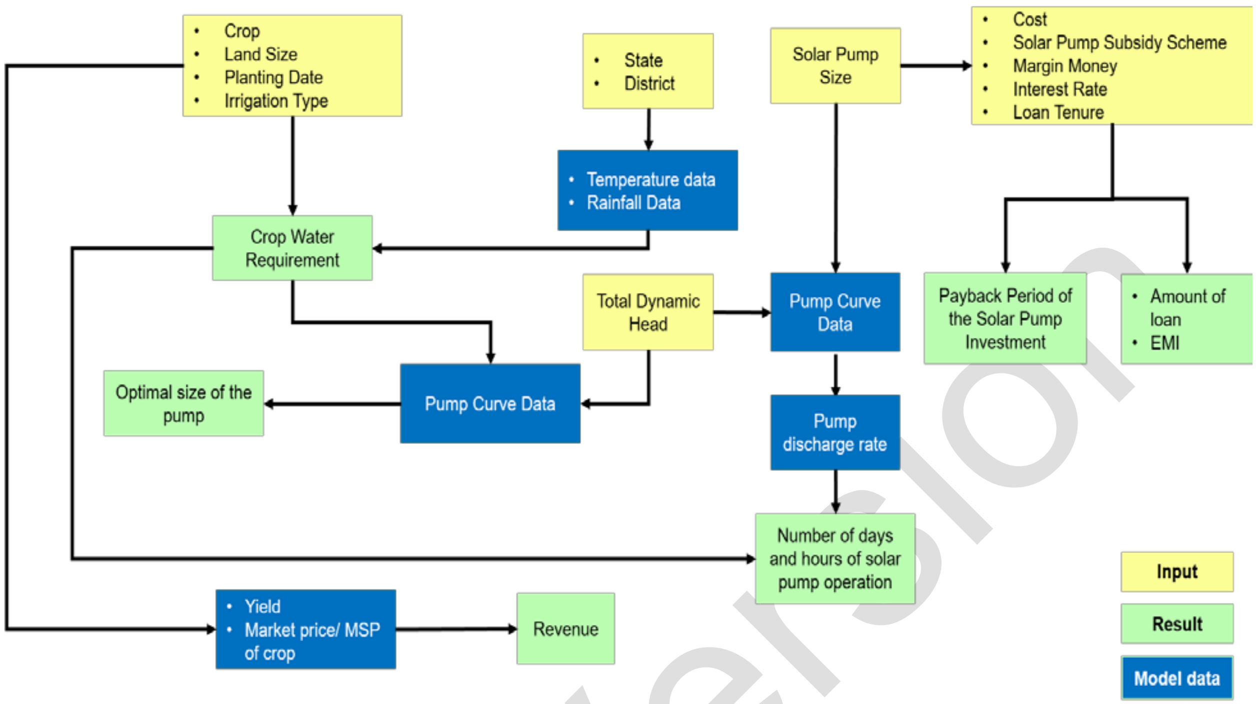

Figure 10: Technical and Feasibility Analysis

12.1 Technical Feasibility Analysis

12.1.1 Solar Irradiance

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. The below figure shows the long term global horizontal irradiance over Malawi.

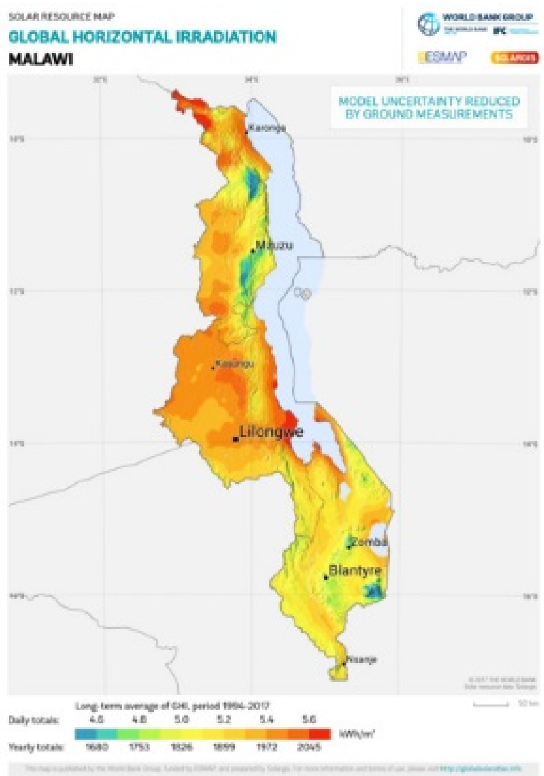

Figure 11: Solar Irradiation Map

The average solar radiation in Malawi is 4.3 – 4.5 kWh/kWp. Existing solar data clearly indicate that the solar energy resource in Malawi is high throughout the year. Grid connected Utility Scale Solar could play a big role in future addition of electricity installed capacity. Hydro resources could help in balancing the intermittence of solar generation.

12.1.2 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.

12.1.3 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.

12.1.4 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

12.1.5 Total Dynamic Head

[21]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.

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 3 Advantages of solar powered irrigation

14. Key Stakeholders

Organization/ Agency	Role
Ministry of Natural Resources Energy and Mining (MNREM)	Ministry for coordination and implementation of solar related projects. Assess the requirements for solar mini grids and solar rooftop projects and monitor their implementation.
Ministry of Finance	The Ministry's mandate cuts across all sectors of Government. Not only is it entrusted with the formulation of sound economic and fiscal policies, but it also mobilizes resources for the implementation of government programs and ensure that all public resources are disbursed as appropriated by Parliament and accounted for in accordance with national laws and international best practice. Their role is to mobilize and approve the financing for solar related projects in Malawi
Ministry of Foreign Affairs and International Cooperation (MoFA)	The Ministry of Foreign Affairs (MOFA) is a cabinet-level government ministry responsible for the implementation and management of Malawi's foreign policy and international activity
Ministry of Agriculture, Irrigation and Water Development (MAIWD)	Government Ministry charged with creating an enabling environment in the Agricultural Sector. It carries out its role by enhancing crop production, improving food and nutrition security, widening export base and improved incomes of the farmers. The Ministry oversees agricultural sector where it formulates, reviews and implement national policies, plans, strategies, regulations and standards and enforce laws, regulations and standards.
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.
USAID	USAID supports Malawi's efforts to address weather-related impacts on agriculture through access to reliable climate data, development of effective climate policies, and research and education. USAID is doing feasibility study for developing a 20 MW solar IPP in Malawi. 150,000 solar home systems will be distributed using results-based financing model. These solar home systems can support four light bulbs, mobile phone charging and ceiling fan. This can be upgraded to support television as well. Facility to supply electricity for cooking and refrigerators have not been included.
World Bank	World Bank is supporting a number of projects in Malawi in the area of energy, agriculture, education, transportation, water and sanitation. World Bank assisted the Republic of Malawi in developing a Solar Resource Map and a report on Energy Sector Support Project. USD 10 million have been earmarked for solar mini grid projects.
UNDP	UNDP is executing solar minigrid projects in Malawi in coordination with nodal ministries and NGOs. Malawi Innovation Challenge Fund for Solar Water Pumps has been operating for last 4 years where UNDP is putting a 50% minimum cost and is able to leverage from the private sector to invest the balance.

Table 4 Key stakeholders in Malawi

15. Recommendations for implementation

Following are the recommendations for the implementation of solar pumps in Malawi based on the above analysis and discussions undertaken during the visit of delegation from ISA secretariat to Malawi:

1. **Number and type of pumps**: NFP to coordinate with different concerned departments to collate the demand for solar water pumping systems.
2. **Financing:** There are limited sources available for the government of Malawi to fund the solar pumps and therefore subsidy shall not necessarily be available for solar pumps. Hence, the financing models envisaged should majorly consider either subsidy from external donor agencies or financing by MFIs/DFIs for the cost of the pump. The subsidy may be required for initial implementation of the solar pumps considering the technology is still new in the country. With the progress of deployment and improvement in costs, the subsidy may be reduced in a phased manner. Further, some amount may be paid by the farmers upfront while the remaining may be done on periodic basis in the form of loan repayments.
3. **Financing structures:** Considering external financing would be required as mentioned in point 2. above, mobilization of financing should be done by the authorities and suitable financing structures should be developed to enable the deployment of pumps.
4. **Knowledge development:** Awareness creation and knowledge development of the farmer with regard to deployment of solar pumps is necessary to enable effective adoption and utilization of the pumps. Initially these activities may be undertaken by i-STARCs to be developed in Malawi under the ISA's programme.
5. **Ecosystem availability:** Solar ecosystem is at a very nascent stage in the country. There is a need for local manpower for facilitating solar initiatives. However initial training may be required on the operations and maintenance aspects of the solar pumps.

16. Proposed next steps

1. **Pre-feasibility report:** The pre-feasibility report may be shared with NFP, Malawi for any further suggestions or inputs.
2. **National Irrigation Master Plan:** National Irrigation Master Plan needs to be shared with ISA through NFP.
3. **Submit Demand:** NFP to coordinate with different concerned departments to collate the demand for solar water pumping systems.
4. **Bid for solar pumps and price discovery:** The bidding shall be completed for 2, 72,000 solar pumps basis the demand aggregation undertaken by ISA and price be discovered for solar pumps in the participating countries including Malawi.
5. **Financing arrangement:** Government of Malawi with ISA may explore suitable sources of financing for solar pumps.
6. **Capacity building:** Post bid process and financing arrangement, capacity building of farmers and knowledge development of local technicians may be initiated by pump suppliers and through i-STARCs
7. **Field preparation:** Boring activities may also be suitably initiated by farmers in the area where the solar pumps are planned to be initially implemented.
8. **Supply and project monitoring:** Regular project monitoring for supply and installation of pumps may be undertaken by ISA and NFP Malawi basis field reports and feedback from farmers, suppliers and government agencies.