INTERNATIONAL SOLAR ALLIANCE

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

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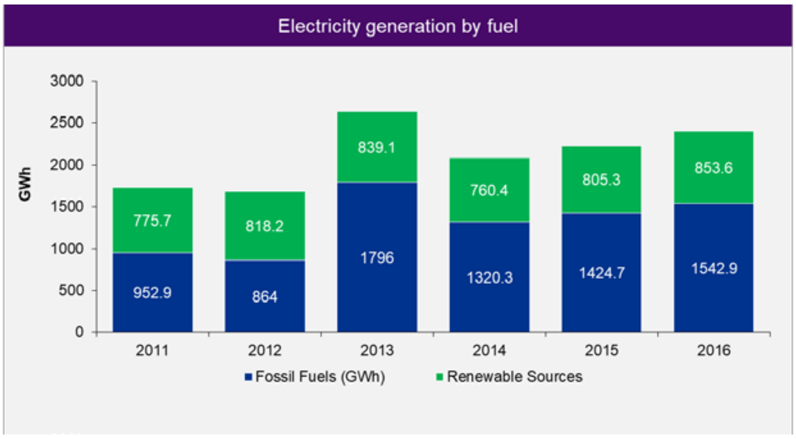
1. Executive Summary

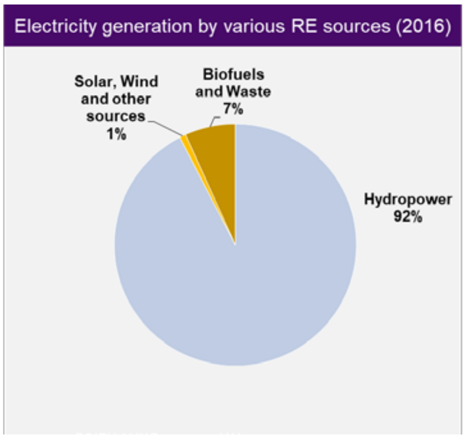
- Mali is undergoing a significant energy transition as government plans to increase access to electricity especially in rural areas. **The access to electricity in the rural areas of the country is one of the lowest at 18% which is significantly less than 83% access in urban areas**.
- The country primarily relies on **thermal and hydro resources** for energy generation. Hydropower forms more than **92% of the total electricity generated** by renewable energy sources.
- There is a huge solar potential in the country with **average sun duration of 7-9 hours** available everyday throughout the year.
- The grid unavailability in rural areas has led to increasing reliance on biomass for meeting the energy needs. **More than 78% of the country's primary energy needs is met by biomass**. This has led to rapid deforestation and growing concerns on climate change.
- **Subsistence farming is practiced by majority of the rural population**. Millet, Sorghum, Maize and Rice are the main crops grown for subsistence farming while seed cotton is used as a cash crop.
- Mali is dominated by small and medium farmers. **More than 60% of the total cultivated landholdings is less than 5 hectares** in size.
- **Irrigation occupies only a miniscule proportion in Mali (less than 1%)** and the farmers depend on rain fed irrigation for meeting their crop water requirements. Some of the common irrigation techniques used in Mali are Gravity Irrigation, Californian irrigation, Sprinkler irrigation and Drip Irrigation. Drip and Sprinklers are only used by large farmers.
- **The Ministry of Energy and Water (MEE)** acts as the main nodal ministry for implementation of energy and water related projects. MEE has in the past tied up with UNDP, USAID and KfW for implementation of irrigation projects in the country including solar pumps.
- **Increased access to electricity along with sustainable irrigation methods** remains the two critical needs of Mali which primarily depends on oil imports for meeting the supply requirements.
- Preliminary analysis indicates that implementation of solar pumps is feasible with a **payback period of around 3 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.
- At an average price of USD 4,064 per 3 HP pumpset, Mali requires financing of USD 60.96 million to roll out deployment of 15,000 Nos solar water pumping systems across the country.

2. Introduction

Mali is currently undergoing a major energy transition phase with efforts being made to increase the access to electricity especially in rural areas. **The average rate of access to electricity is on the rise- 35.1% in 2016 compared to 25% in 2012[1]. While access to electricity in urban areas is relatively high at 83.6%, only a small portion of rural population (18%) is connected to the grid indicating a wide disparity in availability of resources[2].** With **7-9 hours of sunlight** available all year around[3], the country has tremendous potential for scaling up of solar energy to meet the ever-increasing energy demand. The energy demand in the country is growing at the enormous pace of 10% every year[4], mainly due to the increasing population, which is growing at the rate of 3-5% per annum[5].

The primary energy supply in Mali is largely based on biomass which meets 78% of country's needs, fossil fuel contributes 18% of energy supply while remaining 4% is met by renewables mainly through hydropower. On the energy consumption side, households consume 86% of Mali's energy, road transport 10%, industry (mainly mining) 3% and agriculture consuming 1% of the energy supply[6].





Source: Africa Energy Portal

An estimated 20% of the fuel import is used for grid-based electricity production through approximately 170 MW installed capacity, corresponding to roughly half the total generation capacity, where the other half consists of hydropower. **Total annual electricity production is 2000-3000 GWh**. This electricity is mainly used for electrification of urban and peri-urban areas; the national utility EDM serves some 60 urban municipalities through the national grid. Grid extension into rural areas is limited and the country is too poor, too big and too sparsely populated to expect such extension to happen at any meaningful scale in the coming years. **Rural electrification, in so far it has been achieved, thus is by mini-grids or by individual systems**.

Currently, the country is **highly dependent on thermal and hydropower**. Further, Mali relies on oil imports to fuel some of its power plants which exposes it to global fluctuations in fuel prices leading to high uncertainty in the sector. The changing weather patterns poses significant risks to dependence on hydropower. The demand for electricity is growing at the rate of 6.6% with mining sector contributing to major chunk of the demand. **The per capita electricity consumption has been rising consistently at a CAGR of 13% since 2011**.

[1] SEforALL
[2] Africa Energy Portal
[3] ClimaTemps
[4] African Development Bank (AfDB)
[5] World Bank
[6] Energypedia

Country Statistics

Series	2010	2012	2014	2016
Access to electricity (% of population)	22.3%	25.6%	31.8%	35.1%
Urban (% of urban population)	46.5%	76%	77.2%	83.6%
Rural (% of rural population)	8.7%	11.9%	2.6%	1.8%
Access to clean fuels and technologies for cooking (% of population)	2%	1%	1%	1%
Population, total	15.2 Million	16.1 Million	17.1 Million	18 Million
RE consumption (% of total final energy consumption)	84.9%	85.1%	83.6%	
RE electricity output (% of total electricity output)	53.8%	57.5%	42.9%	
Electricity final consumption, per capita (kWh)		93.6	131.4	168.7

Figure 1: Country Statistics- Mali

The biggest issue henceforth facing the nation is **consistent and reliable supply of power**. The World Bank estimates note that manufacturing companies in Africa particularly Mali has to undergo power outages of approximately 50-60 days on an average per year. In terms of the agriculture sector, the major water improvement and access projects are funded by international development organizations especially Islamic Development Bank and European Union. Despite these efforts, **it is estimated that there will be still be unmet demand for drinking water and agriculture for many years to come**. The Government of Mali is actively looking for partnerships to develop the estimated 800 MW of hydroelectric power yet to be exploited, large amounts of solar energy, and over 300 MW of biomass. The government also seeks to increase the production capacity of EDM, improve the reach of rural electricity grids, and manage the entire production chain. In 2016, Mali passed a law governing public-private partnerships (PPP) and in early 2017 an office was established to implement the law, expedite PPPs, and ensure PPPs are successfully enacted.

Mali has a large renewable energy potential, which is only partially harnessed. Solar energy technology is particularly advantageous due to high radiation levels, especially in the north. Biomass is abundant in the southern regions and the GoM plans to dramatically scale up biofuel production. Hydroelectricity is partially exploited, especially by large dams, with new facilities being planned. However, the potential for mini- or micro-hydro is also present. Wind power is at the very early stage and wind mapping is being produced[7].

[7] African Development Bank (AfDB)

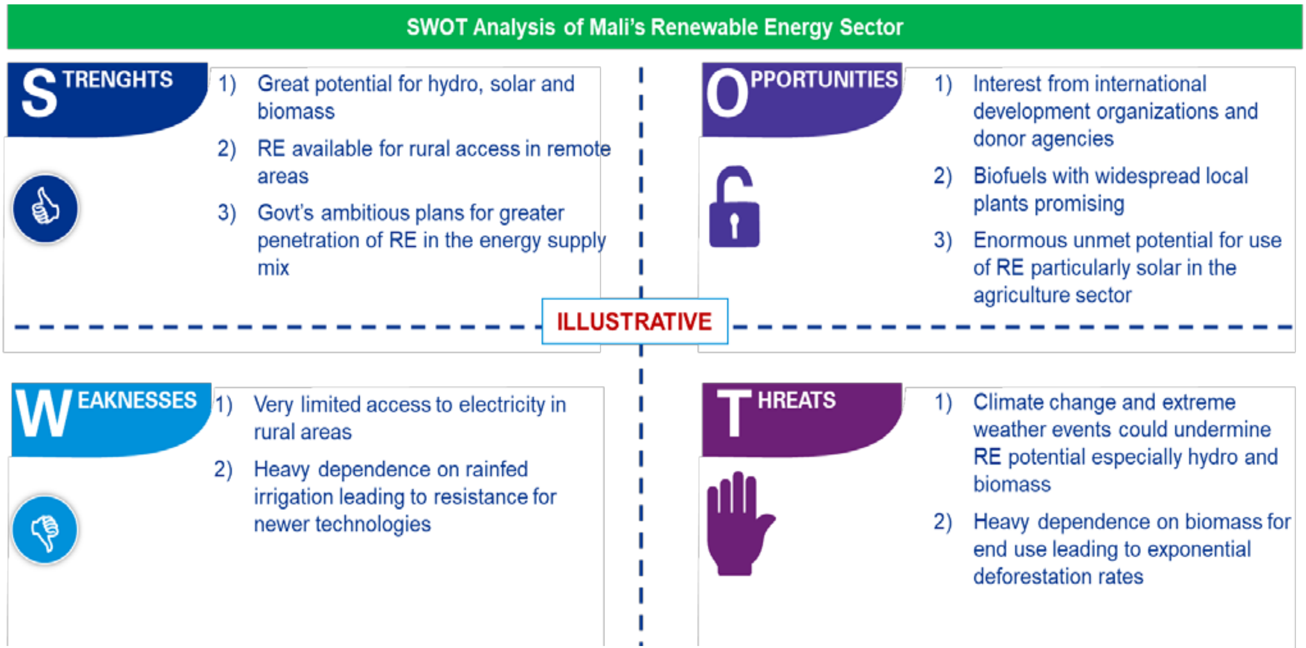


Figure 2: SWOT Analysis of Mali's Renewable Energy Sector

3. Geography

Mali is bounded on the north by Algeria, on the east by Niger and Burkina Faso, on the south by Côte d'Ivoire and Guinea, and on the west by Senegal and Mauritania. Mali's landscape is largely flat and monotonous. Two basic relief features can be distinguished: plateaus and plains, which are crossed by two of Africa's major river systems, the Niger and the Senegal. The highland regions are localized and discontinuous. Although Mali is one of the largest countries in Africa, it has a relatively small population, which is largely centered along the Niger River. The Bambara (Bamana) ethnic group and language predominate, with several other groups—including the Fulani (Fulbe), Dogon, and Tuareg—also present in the population. Agriculture is the dominant economic sector in the country, with cotton production, cattle and camel herding, and fishing among the major activities.

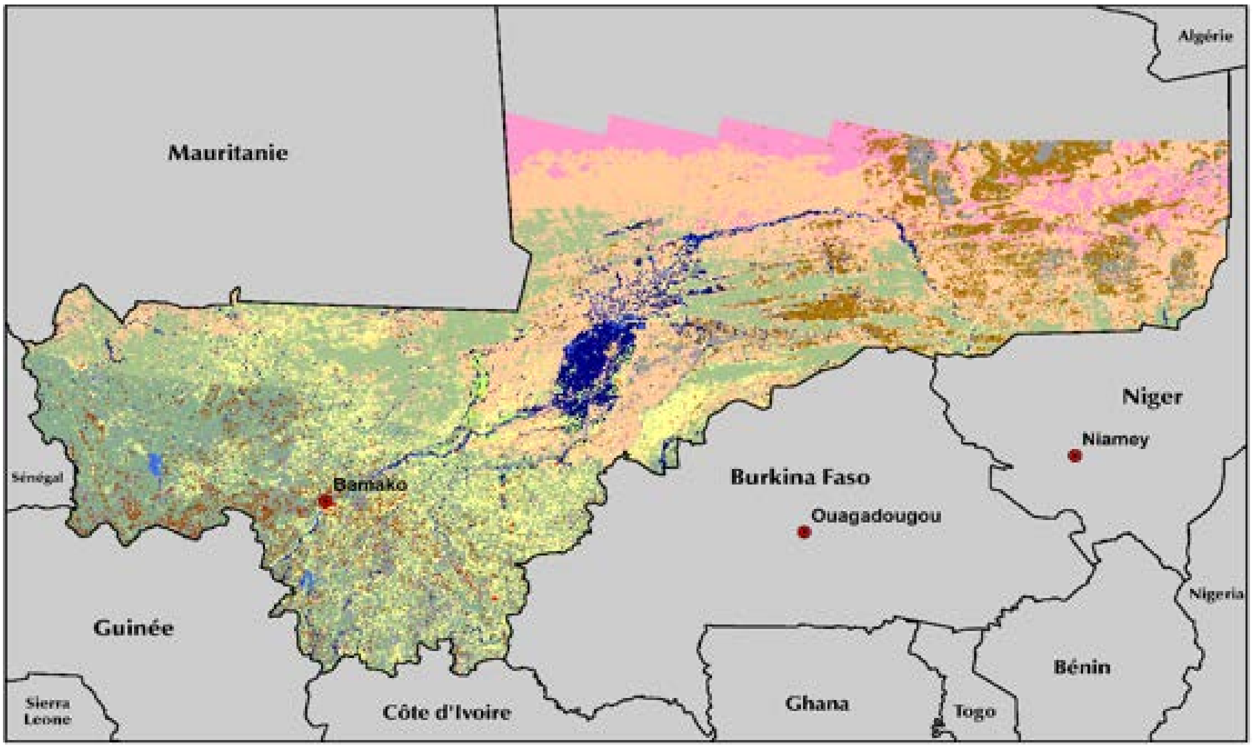
Source: Britannica

The plateaus of the south and southwest lie between about 1,000 and 1,600 feet above sea level but attain heights approaching 2,000 feet in the Mandingue Plateau near Bamako and more than 2,100 feet near Satadougou. Elevations in the southeast range between almost 1,000 feet around Sikasso and 1,740 feet at Mount Mina. East of the Niger River the Dogon Plateau descends gently westward to the river valley but ends in abrupt cliffs on the southeast. These cliffs reach an elevation approaching 3,300 feet at Bandiagara. Northwest of the region is the country's highest point, Mount Hombori Tondo, which rises to a height of 3,789 feet. Northern and central Mali are made up of the plains of the Niger River basin and of the Sahara. The only marked relief feature in the north is the Iforas Massif. An extension of the mountainous Hoggar region of the Sahara, this heavily eroded sandstone plateau rises to elevations of more than 2,000 feet.

Mali's landscape is mostly a savanna grassland that rolls into higher plateaus as you move north. Rugged hills with elevations that reach upwards of 3,280 ft. dot the northeast. Approximately 65% of the country is covered by desert or semi-desert. The lowest point of the country is the Senegal River at 75 ft.; the highest point of Mali is Hombori Tondo at 3,789 ft. The largest rivers in Mali are the Niger and Senegal. The Niger River is the main source of food, drinking water, irrigation and transportation and hence is considered to be the lifeline of Mali's economy[8].

[8] WorldAtlas

An interesting aspect of Mali geography is that the country is entirely situated on a plateau. Its position gives it a flat surface and the banks of the Niger River has a narrow coastal plain. The Southern part of Mali is flanked by these following landscapes: the Bandiagara Plateau, Fouta Djallon, and the Mountains of Hombori[9]. Northern Mali is arid and "deserted" of vegetation. It is a true desert, a part of the Sahara. Few people live there. Southern Mali is wetter, and natural vegetation is increasingly abundant. The short grasses and shrubs that mark the Sahel give way to the tall grasses of the savannah further south. It is in the southern part of the country, and along the course of the Niger, that most of Mali's people live.

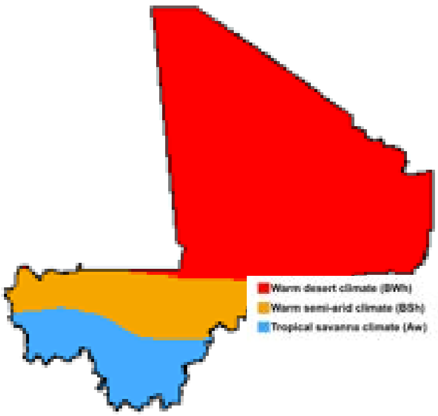


Mali is traditionally divided into the nomadic region of the Sahel and the Sahara and the agricultural region of the Sudanic zone. Roughly three-fifths of the population is rural, typically living in thatched dwellings grouped together in villages of between 150 and 600 inhabitants and surrounded by cultivated fields and grazing lands. The population of Mali has been growing at a rate that is higher than the world average but is comparable to the regional average. Life expectancy at birth, still comparatively low, has risen gradually for both males and females, and there has been a slight decline in both birth and death rates, though they remain high by both world and African standards. The population is heavily weighted toward the young, as are most African populations. Population densities throughout Mali are low especially in the more remote eastern and northeastern areas[10].

[9] Ancient Africa- Mali
[10] Britannica

4. Climate

[11]**Mali lies within inter tropical zone and has a hot, dry climate, with the sun near its zenith throughout most of the year**. In general, there are two distinct seasons, dry and wet. The dry season, which lasts from November to June, is marked by low humidity and high temperatures and is influenced by the alize and harmattan winds. The alize blows from the northeast from November to January and causes a relatively cool spell, **with temperatures averaging 25 °C while from March to June the maximum temperature ranges about 40 to 45 °C**. The country can be divided into three climatic zones—the Sudanic, the Sahelian, and the desert zones. Sudanic climate occurs in about one-third of the country, from the southern border to latitude 15° N. It is characterized by an annual rainfall of 510 to 1400 mm and average temperatures of 24 to 30 °C. The Sahel, or the area bordering the Sahara, receives between 200 and 510 mm of rain per year and has average temperatures between 23 and 36 °C. In the desert, temperatures during the day range from 47 to 60 °C, while at night the temperature drops to 4 to 5 °C.



The figure below[12] shows the span of the average temperatures in Mali for each month. As can be clearly seen from the temperature pattern, the average temperature range mostly remains flat between 26-27 ^{0}C for the country as a whole despite significant regional variations as detailed above.

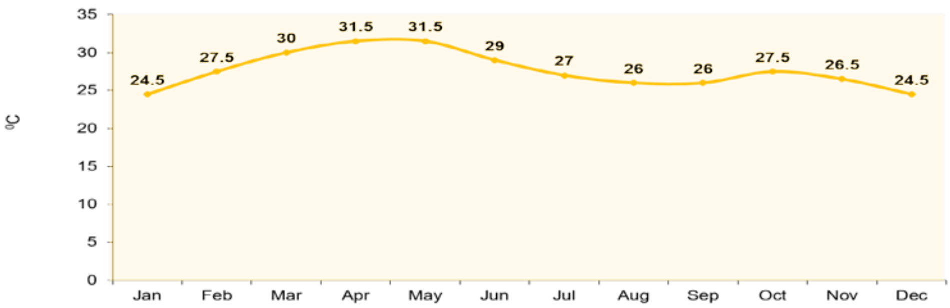


Figure 3: Average temperature pattern in Mali

Soils in arable regions are tropical ferruginous with textural differences, ranging from sandy, sandy loam, clay to clay loamy with more or less yellow coloration. Soil depths and topo-sequences vary from one place to another. In general, soils are very low in nitrogen and phosphorus, pH ranges from 4.2 to 5.6 in rain fed areas and to 7.0 in irrigated areas with strong water logging and surface evaporation. Crops cultivated include sorghum, cotton millet, maize, groundnuts, cowpeas, rice[13]. Periodic floods and the rich alluvial soils in the central delta make the Niger valley an important agricultural region. The soils outside the Niger valley in Mali are poor. In the south, ferruginous (iron-bearing) soils are shallow and form a hard, red crust because of intense evaporation. The desert region is composed of sand, rock, and gravel[14].

[11] EARTHWISE
[12] ClimaTemps
[13] Global Yield Gap Atlas
[14] Britannica

5. Rainfall

In Mali the annual rainfall is highly variable, ranging from less than 200 mm–1300 mm and its distribution is unevenly spread between north and south. Mali receives most of its rain between June and September, and rainfall during this season typically provide enough water for crops and livestock.

Southern and Western Mali have a Sudanese climate with a short rainy season from June to September. Rainfall averages 1400 mm at Sikasso in the far south. To the north is the Sahelian zone, a semiarid region along the southern border of the Sahara. At Gao, in Mali's northeast Sahel, rainfall is about 230 mm a year. Actual year-to-year rainfall, however, is extremely erratic. In the Sahelian zone there are considerable variations of temperature, especially in April, May, and June, the period of maximum heat, and in December, when the hot, dry harmattan blows. Continuing north, one gradually enters into a Saharan climate, marked by the virtual absence of rain and an extremely dry atmosphere. **Over 40% of the country is, in fact, desert, and unsuitable for agriculture**. The year is divided into three main seasons varying in length according to latitude: October–January, a cool and dry season; February–May, a hot and dry season; and June–September, a season of rains characterized by lower temperatures and an increase in humidity[15].

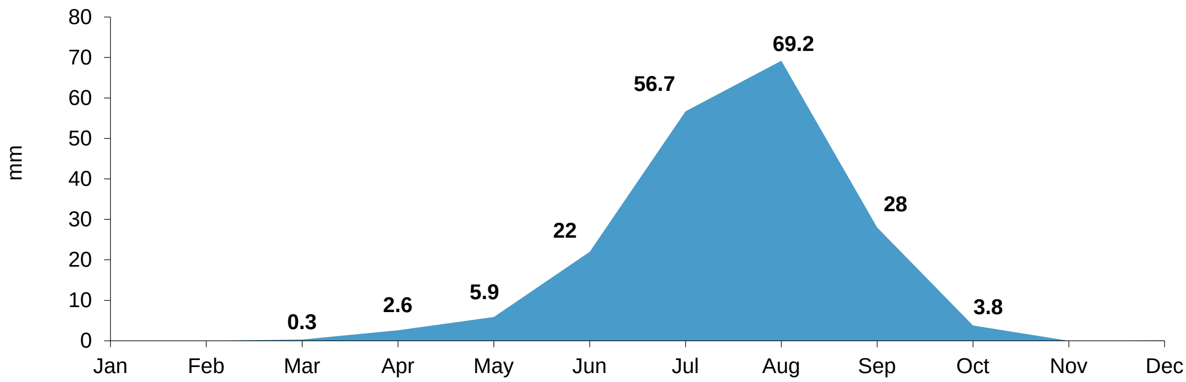


Figure 4: Rainfall pattern in Gao, Mali

Source: ClimaTemps

[15] Nations Encyclopedia

6. Agriculture in Mali

Agricultural activities represent around 33% of GDP and employ nearly 80% of Malians. Mali has important and underexploited agricultural potentialities, especially in the south and center of the country. A state owned enterprise, l'Office du Niger, manages around 127,000 ha of organized agricultural lands primarily through governing land transactions and water management. The state encourages foreign and national private investors to undertake agricultural activities in the Office du Niger's lands. **The Malian government dedicates 15% of its budget to the agricultural sector and subsidizes the cotton sector**. Despite investment opportunities, Malian agriculture depends strongly on erratic rainfall and is vulnerable to fluctuating commodity prices. Climate change is adding greater stress on natural resource management and has caused decreased production yields. **As per FAO 2016 estimates, the total agriculture area in Mali is 41,201,000 hectares which represents approximately 33% of total land area**.

Mali's agricultural production is largely dominated by cotton and cereals (rice, millet, sorghum, and wheat). Many agricultural sub-sectors, such as shea butter, mangos, peanuts, cashews, and biofuels remain largely underexploited and provide a unique opportunity for investors. Significant opportunities also exist in modernizing Mali's poultry and livestock production and transformation sectors. The Malian government decided to increase state support to the agricultural sector by allocating at least 15% of the state's budget each year[16].

Subsistence and commercial agriculture are the bases of the Malian economy. Some four-fifths of the working population is engaged in subsistence agriculture. The government supports the development of commercial products. An agricultural area of major importance is the inland Niger delta. Millet, rice, wheat, and corn (maize), as well as yams and cassava (manioc), are the main subsistence crops, while cotton is an important commercial crop; peanuts (groundnuts), sugarcane, tobacco, and tea are also grown for market. Market gardens produce a variety of vegetables and fruits, including cabbages, turnips, carrots, beans, tomatoes, bananas, mangoes, and oranges. Irrigation projects have been developed on the Niger near the towns of Ségou and Mopti. Fishing is also of economic significance, although this sector has declined since the 1980s. Still, Mali is one of the largest producers of fish in western Africa. The inland delta is a particularly important fishing ground, though periods of drought have hindered development of these fisheries. Large-scale dam construction and environmental pollution have also hindered this sector[17].

Mali has four major agro ecological zones: the Saharan, the Sahelian, the Sudanese and Sudano-Guinean as shown in the figure below[18]:

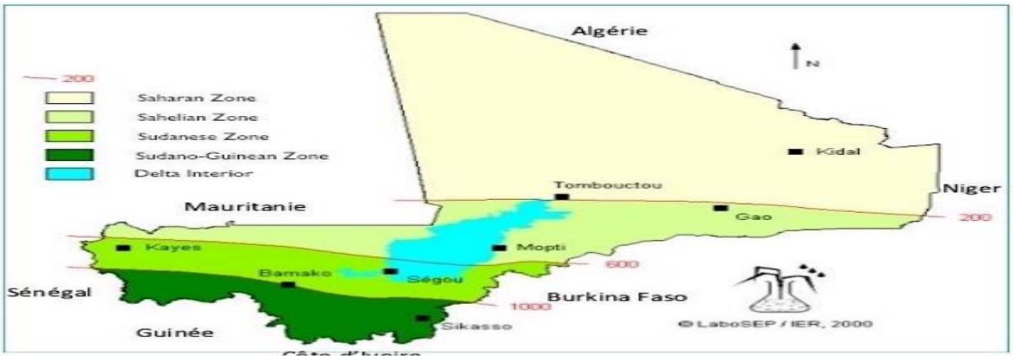


Figure 5: Agro ecological Zones in Mali

[16] export.gov
[17] Britannica
[18] USAID

Across these four agro ecological zones, there is great variety in climate, rainfall and temperature which impacts the crops and livestock choices of the population. The southern regions are the most fertile with greater rainfall levels and offer more options for smallholder farmers, both for subsistence needs as well as for economic and market opportunities.

Agro ecological Zone	Geographic Location	Area (% of country)	Rainfall (mm/year)	Primary Crops
Saharan Zone	North	51%	<150 to 200 mm	Rice, Wheat
Sahelian Zone	Center	26%	250-550 mm	Rice, Wheat and Vegetables
Sudanese Zone	South	12%	600-1200 mm	Sorghum, Millet, Rice, Wheat, Peas, Onions, Peanuts, Sweet Potatoes, Tomatoes, Corn, Beans, Potatoes, Mango, Citrus, Peanut, Cashew, Sugarcane
Sudano-Guinean Zone	Far South	11%	>1200 mm	Mango, Peach, Millet, Sorghum, Corn, Rice, Beans, Potatoes, Peanut, Cashew, Onions, Cotton

Table 1: Agro ecological Zones in Mali- Area, Rainfall and Primary Crops

Source: USAID

65% of Mali's land area is desert or semi-desert. Only 3.9% of Mali's land area (FAO 2005) can be classified as arable land of which 1.4 million hectares is currently cultivated. The countries most productive agricultural land lies south in the area between Bamako and Mopti extending to the borders of Guinea, Cote d'Ivoire, and Burkina Faso. The southernmost Sikasso region is the country's key agricultural area for the production of cotton, rice, millet, corn, vegetables, tobacco, and tree crops. The Malian agricultural sector is dominated by traditional small-scale subsistence farming. 86% of farmers work on less than 10 hectares. 72% of the cultivated area is devoted to cereals, mainly produced for home-consumption. Farmers sell only 15 to 20 percent of their produce. Most farms are under-equipped to adopt modern practices; farmers in Mali as in many Sub-Saharan countries rely mainly on human power. Post-harvest losses remain high and processing technologies of agricultural produce are largely underdeveloped.

Like many places in Africa, climate change has a detrimental impact on agriculture and livelihoods in Mali. **Some estimates indicate that up to 80 percent of the population involved in agriculture and dependent on natural resources is seriously impacted by increased drought and expanding risk of desertification**. **Extreme weather, such as droughts and strong winds, has impacted Mali's rain fed farming systems, particularly cotton and maize in the regions of Sikasso and Kayes**. Heavy rains after long dry periods caused erosion and flooding, damaging rural infrastructure. Drought in the north has led to migration toward the south, increasing the burden on natural resources in the southern regions. These disruptions to farmer production have led to lower yields, distorted markets and natural resource-based conflict[19]. Overall food production has increased over the last two decades at a rate consistent with population growth. However these increases have been primarily driven by increases in the area under cultivation rather than improved yield. Compounding the challenges that already face farmers in Mali is future climate change. Impacts include a shorter growing season potentially making it infeasible to produce a reasonable crop using traditional methods. Also, over the last 30 years rainfall has declined by around 30 percent meaning that yields from rain-fed agriculture could drop by as much as 50% by 2020[20].

[19] USAID
[20] ICIS

Subsistence farming is the dominant production model in Mali. As of the last agricultural census in 2004, there were approximately 800,000 farms in Mali from which 8.9 million people derived their subsistence. The majority of farms are small, with 60 percent of farmers owning less than 5 hectares of land and 85 percent with less than 10 hectares. With the exception of rice, most of the cultivated area (around 72%) is dedicated to cereal production, primarily for self-consumption. The agricultural sector is dominated by the production of cotton as a cash crop and rice, which is the dominant food crop. Outside of rice and cotton, production systems are mostly low intensive, based on traditional low input / low output cultivation techniques.

The typology of the farms based on the size of owned land is presented below[21]:

Typology of farms	Farm Size (in hectares)	% of farm type
Large farms	>10	15.15%
Average farms	5-10	24.5%
Small farms	<5	60.35%

Table 2: Typology of farms in Mali

Source: FARA Research Report

The main suppliers of agricultural credit are commercial banks and microfinance institutions. Banks typically finance larger agro-industries, input suppliers and agro-processing companies, like the CMDT. With the exception of BNDA, they rarely finance producer cooperatives and/or farmers directly. On the other hand, MFIs finance cooperatives and individual farmers. Bank and MFI credit flowing to producers is highly contingent on the institutional and managerial capacity of producer organizations in the country, which seems to be very weak by most measures. Banks are cautious in lending directly to producer organizations, as many have difficulty reimbursing loans on time. For example, in 2013 BNDA's default rate on loans made directly to producer cooperatives was 20 percent as compared zero percent on the loan made to CMDT to finance its contracted producer cooperatives. The cotton sector is well organized and well-financed by the banking sector. Cotton is an important sector to the Malian economy, accounting for 20 percent of export earnings and providing a livelihood for 25 percent of the population. CMDT, the only cotton company, has negotiated a pooled financing mechanism with the banks to fund cotton production and trade. It is a straight forward process – banks lend directly to CMDT who on-lends to their contracted farmers with in-kind loans of inputs and supplies to the producer organizations. After harvest and sale of the cotton, CMDT reimburses their loan to the banks. CMDT uses the trade loan to buy cotton from the contracted farmers. The volumes of pooled financing is highly dependent on the performance of the previous year and the market and pricing conditions for the current season. BNDA is the lead bank for the pooled financing of cotton production whereas BDM is the lead local bank and largest contributor for cotton trade finance[22].

The agriculture ecosystem in Mali comprise of four key actors namely public sector, non-state actors, research institutions and training institutes as elaborated below[23]:

- **Public Sector: The Ministry of Agriculture and the Ministry of Livestock and Fisheries are the principal public actors**. National directorates under these two ministries coordinate with regional directorates to oversee the implementation of national policies. These are the National Directorate of Agriculture (DNA) (under the Ministry of Agriculture), the National Directorate of Production and Animal Industries and the National Directorate of Fisheries (under the Ministry of Livestock and Fisheries). The DNA is the primary entity responsible for coordination of EAS activities. It aims to provide services and

[21] Based on the averages of Koulikoro and Mopti regions
[22] World Bank
[23] USAID

coordinate with other national directorates that offer advisory services, as well as with representatives in regional and cercle offices. Regional Directorates of Agriculture also manage coordination with regional Outreach and Agricultural Councils.

- **Non-state Actors:** Various non-state actors are important players in Mali's agricultural innovation system either as funding entities or as implementers, or both. These include bilateral entities, multilateral organizations, United Nations agencies, the private sector, national and international NGOs, civil society organizations, associations, producer's organizations and village leaders.
- **Research Institutions:** Agricultural research in Mali is donor-dependent and most research institutions work closely with international research centers. Human capital and funding limitations often present challenges. While the **Institute for Rural Economy (IER)** is the Malian government's principal agricultural research institute, a number of research institutions are active in research on issues critical to agriculture. Mali is also a beneficiary of the World Bank-funded West Africa Agricultural Productivity Program. This eight-year (2011-2019) USD $83.8 million program aims to generate and disseminate improved technologies in priority areas for 13 partner countries, as identified by the West and Central Africa Council for Agricultural Research. In Mali, it is managed by the French National Center for Scientific Research and the IER, with the involvement of various U.S., European and Canadian research universities.
- **Training Institutes:** There are a variety of public and private training institutes in Mali, including the **University of Segou's Department of Agriculture and Animal Medicine** that offers formalized training. Many extension staff obtain training from the public **Rural Polytechnic Institute of Training and Applied Research (IPR/IFRA)** in Katibougou, which is dedicated to agronomy, forestry and wildlife, livestock breeding and agricultural engineering. Outside of urban areas, there are 53 Rural Training Centers around the country, which under the supervision of the Ministry of Agriculture offer training to farmers. Twelve are co-educational and dedicated to training for young couples, offering the wives of male farmers' capacity building in agricultural product conservation and processing, nutrition, hygiene and family planning.

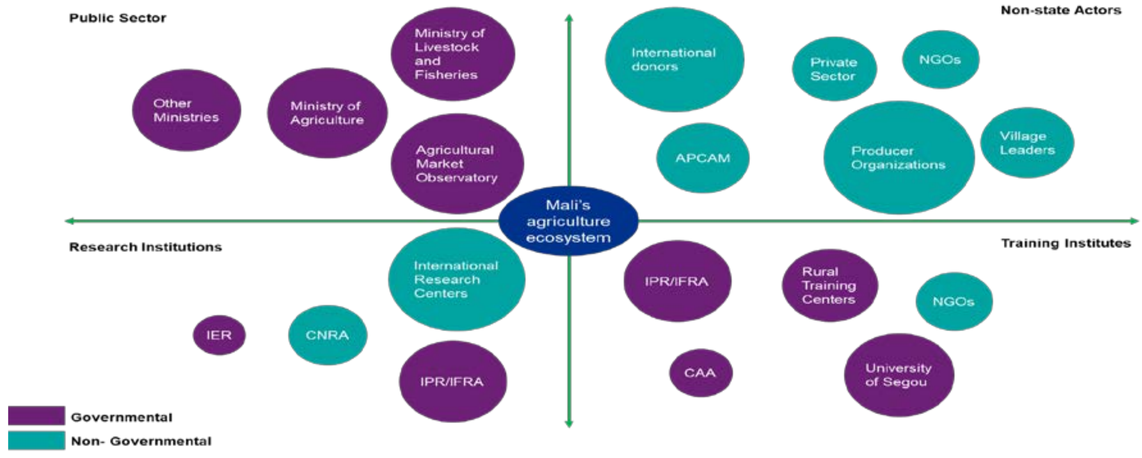


Figure 6: Mali's agriculture ecosystem

7. Irrigation

Mali is one of the least developed countries with an economy that relies heavily on rain fed cereal production. **Smallholder agricultural production is dominated by rain fed production of millet, sorghum and maize for meeting food demands and on cotton for the market. A major constraint for crop production is the amount of rainfall and its intra and inter-annual variability**. The rainy season is short and varies in length, with the number of rainy days varying from year. High evaporation losses (in excess of 50% of annual rainfall) and a dominance of sandy soils with low water holding capacity, result in soil water shortage during the growing season, when rains are erratic. Thus farmers have little control over the environment, with little access to irrigation, limited financial means with which to invest in water harvesting structures or inputs[24]. **As per USAID estimates, only 7% of total arable area in Mali is currently cultivated. Irrigation is equipped in less than 1% of the total agriculture area[25].** Considering the above, there is huge potential for agriculture expansion in Mali in general and irrigation in particular.

Many international organizations are working closely with the government in the areas of agriculture, irrigation, productivity and food security. **One of the most notable ones being the USAID's 'Feed the Future' programme.** The programme aims to improve the agriculture and nutrition by delivering technology and knowledge and building local institutional capacity to spur a private sector led approach to achieve economic and food security. The programme currently invests in three value chains of millet and sorghum, rice and livestock. The programme has also invested in providing small scale irrigation infrastructure in the country. The Small-Scale Irrigation Project is a donor-to-donor agreement between USAID and the German Development Bank (KfW) to support the Malian government's National Program for Small-Scale Irrigation, 2012-2021 (PNIP). The PNIP has the objective of developing 126,000 hectares benefiting potentially 3 million people with an estimated cost of 396 billion FCFA ($792 million USD). This project is managed in cooperation with KfW, the Ministry of Rural Development (MDR), and the National Directorate for Rural Infrastructure (DNGR). From 2016-2021, the PNIP plans to develop 48,000 hectares of land under improved irrigation for an estimated cost of 118 billion FCFA ($236.2 million USD). The USAID contribution as part of the agreement is $4.5 million over four years, 2016-2019. Germany, Canada, and the European Union are also contributing to this effort to develop small-scale irrigation in Mali in partnership with the Government of Mali.

Bilateral Entities	Multilateral Organizations	United Nations Agencies
• Belgium • France • Germany • Italy • Japan • Luxembourg • Spain • United Kingdom • United States	• ADB • European Union • IMF • International Fund for Agricultural Development (IFAD) • Islamic Development Bank (IDB) • West African Development Bank • World Bank	• FAO • International Organization for Migration • United Nations Children's Fund (UNICEF) • United Nations Industrial Development Organization • United Nations Multidimensional Integrated Stability Mission in Mali • United Nations Population Fund • UNESCO • WFP • World Health Organization

Table 3: Primary International Donors in Mali's Agriculture Sector

Many small scale irrigation technologies are used in Mali. **These technologies comprise manual watering and mechanical watering including pedal pump, Aeolian pump, electric pump and motor pump. For**

[24] Advances in Plants & Agriculture Research
[25] FAO

manual watering, water is lifted from wells, rivers or other surface water sources by human force using rope and a container. This technology is mainly used by poor resource farmers. For mechanical watering, water is lifted by pumping systems. This method is used for small and large irrigation systems by moderately well off and wealthy farmers. Water is distributed to plots through the gravity irrigation, Californian system, sprinkling system, drip irrigation and manual watering. Some of these irrigation technologies are explained in the detail below[26]:

1. Gravity Irrigation Technology

Figure 7: Gravity irrigation on a small scale system

Irrigation by gravity is used on small scale irrigated areas for cereals (rice, wheat, maize) and vegetables production. It is mainly practiced in the northern zones of Mali (Gao, Tombouctou and Mopti). In this system, water is lifted from the river, pond and lake using motor-pumps and distributed to plots through primary and secondary irrigation canals.

2. Californian Irrigation System

Figure 8: Californian irrigation system for onion

This irrigation method is used for vegetable crops production. Water is lifted from the surface or the underground and distributed to plants into furrows. With this system, crops are arranged on ridges. This system is mainly used for vegetables in urban areas.

[26] All the information including images subsequently have been taken from FARA Research Report

3. Sprinkling Irrigation System

It is practiced on commercial farms for high value crops such as fruit trees and currently on sugar cane in the Office du Niger. Irrigation operations are also simplified with an irrigation management optimized specifically tailored to the areas and speculation.

Figure 9: Sprinkler Irrigation System on Shallot Cropping

4. Drip Irrigation System

The drip irrigation practice is taking off in Mali. Development programs and services such as the PCDA (Compactivity and Diversification of Agricultural Program), NGOs and IER have contributed greatly to the awareness of this technology. The drip low pressure system is the most popular. The technology is mainly used for fruits and vegetables cropping in the urban areas by wealthy farmers.

Figure 10: Drip Irrigation Systems for banana

5. Manual Watering Practice

This system is commonly used in rural areas of Mali by the low-resource farmers. Buckets, calabashes, watering cans are used to distribute irrigation water to crops. Water sources for this practice are wells, rivers, lakes, etc. Crops irrigated by this system are mainly vegetables.

Figure 11: Manual watering practice in onion cropping in Mopti region

8. Cropping Pattern

Mali's population sustains itself on small-scale, rain fed subsistence agriculture and pastoralism. The agricultural sector is characterized by a predominance of cotton as a cash crop, while rice and coarse grains (maize, millet and sorghum) constitute the main food crops. **Cereals represent more than two-thirds of the country's dietary energy supply**. Mali is a net exporter of cotton and livestock and a net importer of rice. The main constraints in the agriculture sector are the lack of innovative technologies, irrigation, and private storage and infrastructure, combined with food price volatility.

Seed cotton is processed and exported in the form of fibre and cotton acreage and fibre exports have been increasing steadily. The cotton sector accounted for 46 percent of export earnings of the country between 1989 and 1994. However, cotton has been facing a major crisis since 2002, with lower yields since the mid-1990s due to declining soil quality, the use of the same varieties everywhere, entailing increased disease risk, and inadequate crop management practices. Thus, revenues of rural households and net margins have been stagnating since the early 2000s.

Grains are the other predominant agricultural products in Mali, particularly coarse grains. In 2007, they covered 72 percent of the cultivated areas in Mali. Rural households consume a large part of the production, and most of the surplus is sold on the domestic market. A small amount is exported to the sub regions. Rice and maize production in particular have been increasing. This is partly due to the expansion of cultivated areas and partly to the notably increased yields.

Millet and sorghum are essential crops for food security, providing around 35 percent of the daily calorie intake (FAOSTAT). However, millet and sorghum production has been increasing at a lower rate than maize and rice since the 1990s, while yields have stagnated. The most important secondary crops consist of legumes and oilseeds, especially groundnuts, but also the Bambara groundnut (Voandzou), cowpea and soybean. Cowpea is often intercropped with cereals. In 2004, according to the agricultural census (CPS, 2008), the area under pulses accounted for between 8 and 18 percent of the average area cultivated per farm in central and southern Mali (Mopti, Segou, Koulikoro, Sikasso, Kayes). These crops are important as both food and cash crops, particularly in terms of nutrition.

Planting of the 2019 maize, millet and sorghum crops started on time in May in the southern part of the country. Adequate rainfall amounts since early May resulted in favourable moisture conditions for crop development in recently planted areas. In northern cropping areas, the season is yet to start and the activities are limited to land preparation and early planting of rice. The continuing support by Government and partners in terms of agricultural inputs and generally adequate rainfall in 2018 benefitted crop development in most parts of the country. The country's aggregate cereal output in 2018 is estimated at 10.1 million tonnes, about 9 percent higher than the 2017 output and 26 percent above the five-year average. Major year-on-year production increases have been registered for millet 23 percent and rice 17 percent higher than the 2017 harvest. Despite the above-average 2018 production, import requirements for the 2018/19 (November/October) marketing year are set at average 2 million tonnes due to higher demand from traders to replenish stocks[27].

The total harvested area of the major crops along with their production levels is shown in the figure below. While millet is the most widely harvested crop in the nation with harvested area of around 2.15 million hectares, maize is the most widely produced at the production level of 2.81 million tonnes in 2017. Rice/ paddy has the highest yield of 3.62 tonne/ha followed by maize (2.28 tonne/ha) and seed cotton (0.94 tonne/ha). The yield of seed cotton is significantly lower compared to other West African nations and there is a huge potential to increase productivity using modern and sustainable irrigation techniques.

[27] FAO

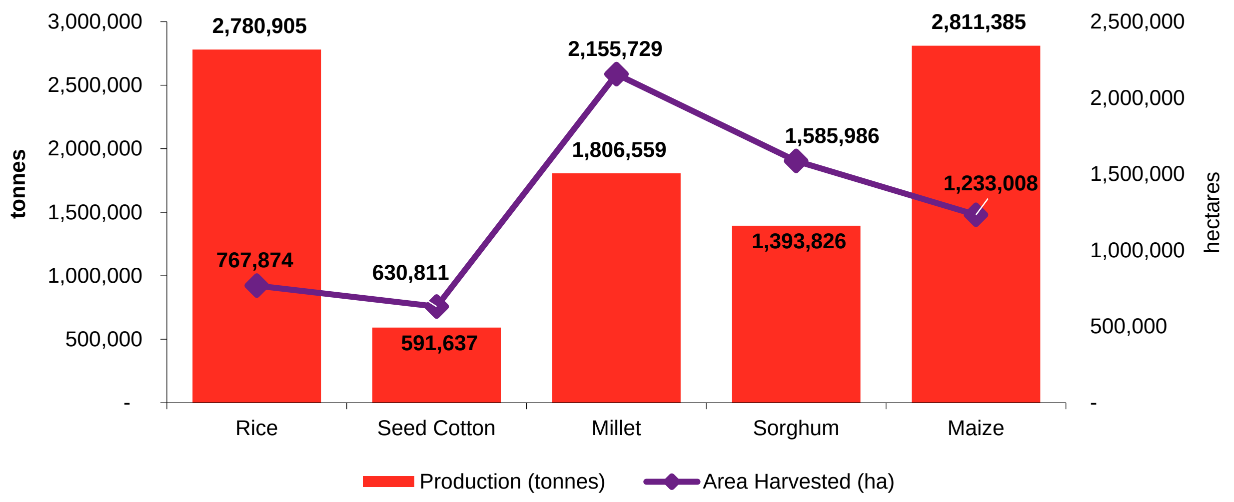


Figure 12: Area harvested and production quantities of major crops in Mali

Source: FAO

The typical cropping calendar for major crops grown in Mali is shown below:

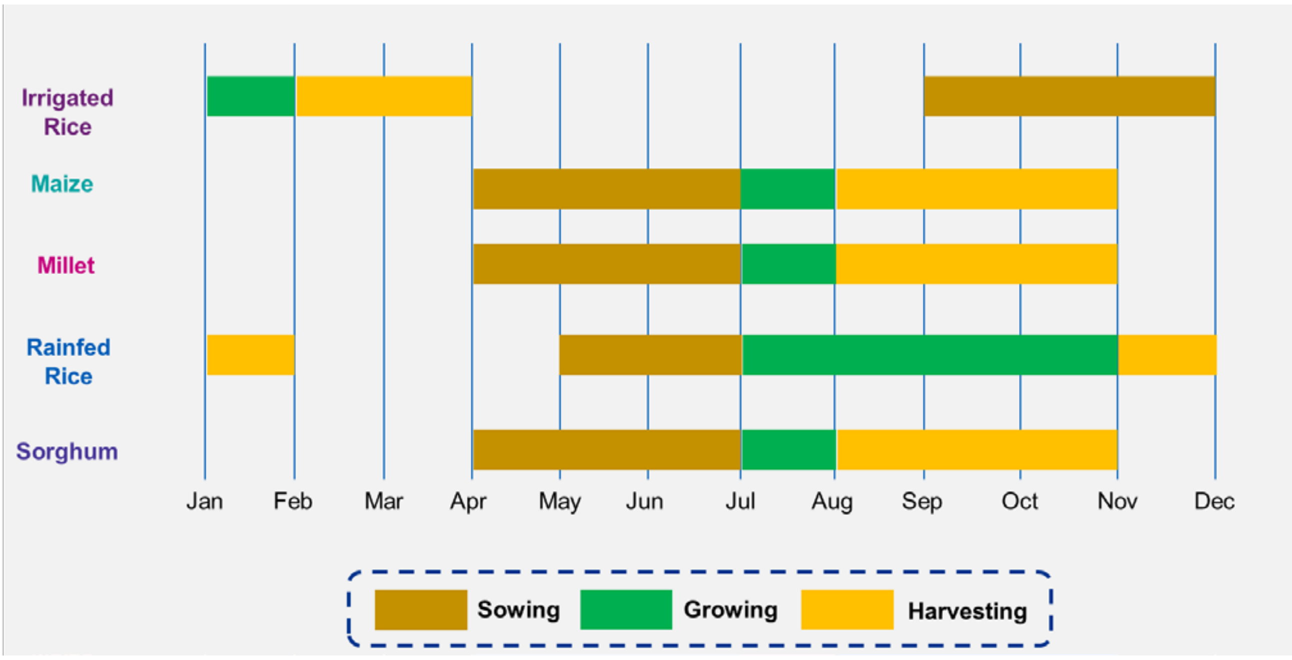


Figure 13: Cropping calendar for major crops in Mali

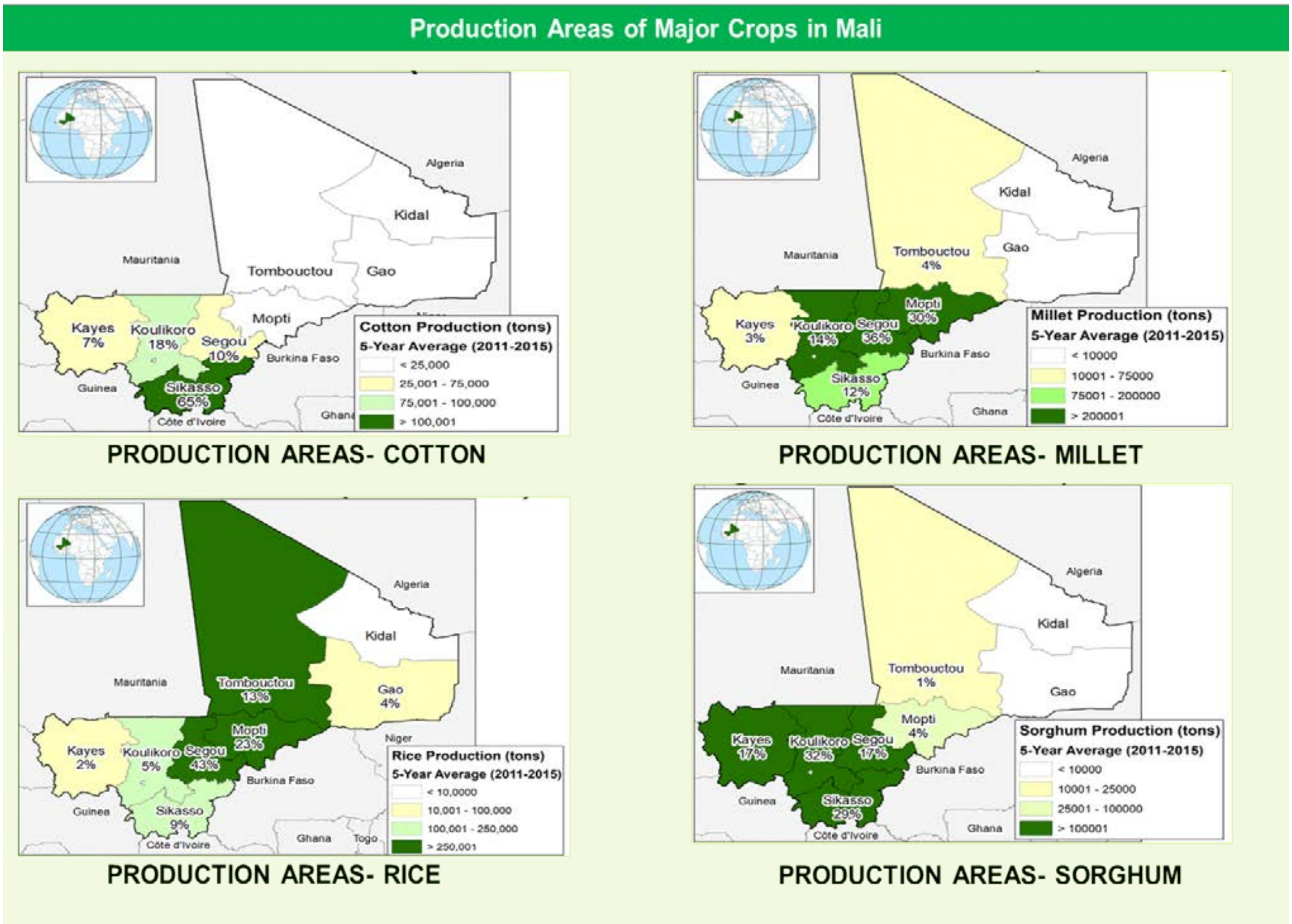


Figure 14: Production Areas of Major Crops in Mali

Source: United States Department of Agriculture

9. Background to solar water pumping in Mali

Agriculture in Mali is based on rainfall; however, Mali has a lot of water resources. Senegal and Niger rivers produce by themselves 70 billion m^3 of water on average by year. The estimated non-perennial water resource is about 15 billion m^3. This water fraction is particularly interesting for people far from rivers. Underground water resource in Mali is estimated to 2700 billion m^3 of static reserve with annual renewable rate of 66 billion m^3 representing the main source of consumption water for the population. The level of mobilization of this water resource is very low. Generally, the water table of Mali's underground water is not/or less affected by pollution mainly due to human activities. The total renewable water resource is found to be 137 billion m^3 corresponding to 11417 m^3 per inhabitant and per year. Nowadays, annual water needs are evaluated to about 6 billion m^3 distributed as 1% for pure water supply for the population, 1% for livestock and 98% agricultural and others uses.

There are many technologies used for small scale irrigation in Mali. These technologies include manual and mechanical lifting of water. Pedal pump (Nafasoro), Aeolian pump, electric pump and motor pump are used. For the manual, water is lifted from wells, rivers or other water source at the surface by human force using rope and a container. This is mainly used by poor resource farmers. In the mechanical systems, water is lifted by a pumping system. This method is used for small and medium irrigation by average and wealthy farmers. In both methods water is distributed to plots through gravity to cultivate vegetables and cereal crops (maize, rice and wheat). Californian system mainly used for vegetable crops in urban areas; Sprinkling system practiced on commercial farms for high value crops such as fruit trees; drip irrigation mainly used in vegetables cropping in the urban areas by wealthy farmers. For vegetable production farmers prefer Californian system in Koulikoro and Mopti; while for cereal production, they prefer motor pumps. But region wise, farmers in Koulikoro like the sprinkler system more than the others[28].

Much more successful has been the development of smaller scale pumps irrigating 30-50 hectares. This system is based around the initial supply of an appropriate capacity pump with the help of a loan. The villagers, usually grouped in an association are then entirely responsible for maintaining the pump. This involves both the regular collection of funds for diesel and the maintenance of the pump itself. Innovatively, the maintenance of the pump is carried out by garages in Mopti and Kona under contract to individual villages. One of the roles of local NGOs has been to create an association of recommended garages with the skills and access to parts to service the pumps effectively.

These smaller pump systems have been extraordinarily successful, both in the persistence of established schemes and in their spread to new areas. No estimates are available as to numbers, but they are now found all the way up to Timbuktu and along the river towards Gao. Moreover, new schemes through private investment by villages without any external help from Government or NGOs are promoting pump systems. Pump systems have also acted to provide additional income for women. Apart from the rice, which is largely controlled financially by men, women have also created small horticultural gardens fed from the same system as the main rice fields. The product of these is probably only useful as a cash-crop where a village has access to the road-system but there is a considerable benefit in terms of improved nutrition[29].

While the penetration of using pumps as a means of irrigation is slowly gaining pace through the use of innovative business models, there are still concerns regarding the sustainability of such practices. **The country primarily depends on oil imports to meet its needs and extensive and increased use of diesel in agriculture will only worsen the economic situation. There is a twin need of bringing more area under irrigation and at the same time increase the energy access in rural areas, both of which are abysmally low for a rapidly growing population of Mali.** Irregular rainfall and political instability have left as many as four million people lacking water, both for drinking and agriculture purposes. In this context, both government and international development organizations are investing in projects involving installation

[28] FARA Research Report
[29] ODI

of solar powered irrigation systems. The solar powered irrigation systems offer the dual benefit of improving access to irrigation as well as electricity, without relying on grid expansion. Furthermore, innovative business models such as using portable solar pumps are also being implemented on a pilot basis drawing inspiration from successful projects executed in Benin, Kenya, Ethiopia and Malawi.

Funding Agency	Implementing Partner	Project Title	Project Description
Not Applicable	Ministry of Energy and Water	The Programme for Mobilisation of Water Resources	The Programme for the Mobilisation of Water Resources has been spread out over a number of years and several phases, resulting in approximately 100 installations. One of the specificities of this project is the technical choice of a hybrid solar/thermal pumping technology and a water chlorination unit before the distribution tank.
Kreditanstalt Für Wiederaufbau (KfW)	Ministry of Energy and Water		The project which is funded by KfW involves installation of 269 water points in 20 localities fed by solar powered irrigation systems. The Ministry of Energy and Water is the local implementation water for the project.
United Nations Development Programme (UNDP)	Ministry of Energy and Water	Malian National Programme for Renewable Energy for the Advancement of Women (PENRAF)	More than 30,000 people living in the 55 villages benefit directly from the Malian National Programme for Renewable Energy for the Advancement of Women (PENRAF), a project started by the Malian government in 2003. UNDP provides financial support and manages all contributions to the project through an annual programme that emphasizes the use of a local work force. In the regions of Tombouctou, Kidal, Mopti, Kayes, Sikasso, Koulikoro, Gao and Ségou, solar panels are now generating electricity for water heaters, dryers, cookers, fridges and freezers, water pumps and communal lighting systems. They are also powering essential services, such as community health centres.

Funding Agency	Implementing Partner	Project Title	Project Description
Not Applicable	CADG	Community Solar Water Pump Rehabilitation	This project was carried out under CADG's Corporate Social Responsibility (CSR) program. Located in Kabara Village, it involved the rehabilitation of two solar water pump in critical need of repairs. The workforce for this project was drawn from the local community, which created a temporary employment opportunity. The inclusion of skilled and unskilled workers encouraged the sharing of valuable experience and sustainable skills.
Renewable Energy & Resource Efficiency Promotion in International Cooperation (REPIC)	Wirz Solar GmbH	Pilot Project for the Introduction of Solar Water Pumps for Food Production by Farmers in Mali	Within a pilot project, 50 solar water pumps for farmers' market gardening were installed in collaboration with local partners and shall prove if the deployment of a self-sustaining market for solar pumps is possible. REPIC co-financed the first phase with 10 solar pumps which shall be used for demonstration and promotion purposes with farmer associations and producer organizations.
United States Agency for International Development (USAID), Kreditanstalt Für Wiederaufbau (KfW)	Ministry of Rural Development	Mali Small-Scale Irrigation Project, Feed the Future	The objective of this program is to improve food security by providing irrigation infrastructure that will increase agricultural production by providing a supplemental water supply during periods of insufficient rainfall. This will be done by partnering with the KfW to install small-scale irrigation infrastructure in rural communities through the construction of micro-dams. These small irrigation dams work to trap available rainfall in retention ponds that can be used to irrigate farm lands and extend the season. Reliable access to water and better water management will increase and stabilize rice yields in these areas.

Table 4: Projects in Mali

10. Solar pump Technology Overview

A PVP 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).

Term	Description
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.
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.[30]

Table 5: Key technology terms in a solar powered irrigation system

[30] Ministry of Mines and Energy (Namibia), UNDP, GEF

11. 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[31].

[31] Ministry of Mines and Energy (Namibia), UNDP, GEF

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.

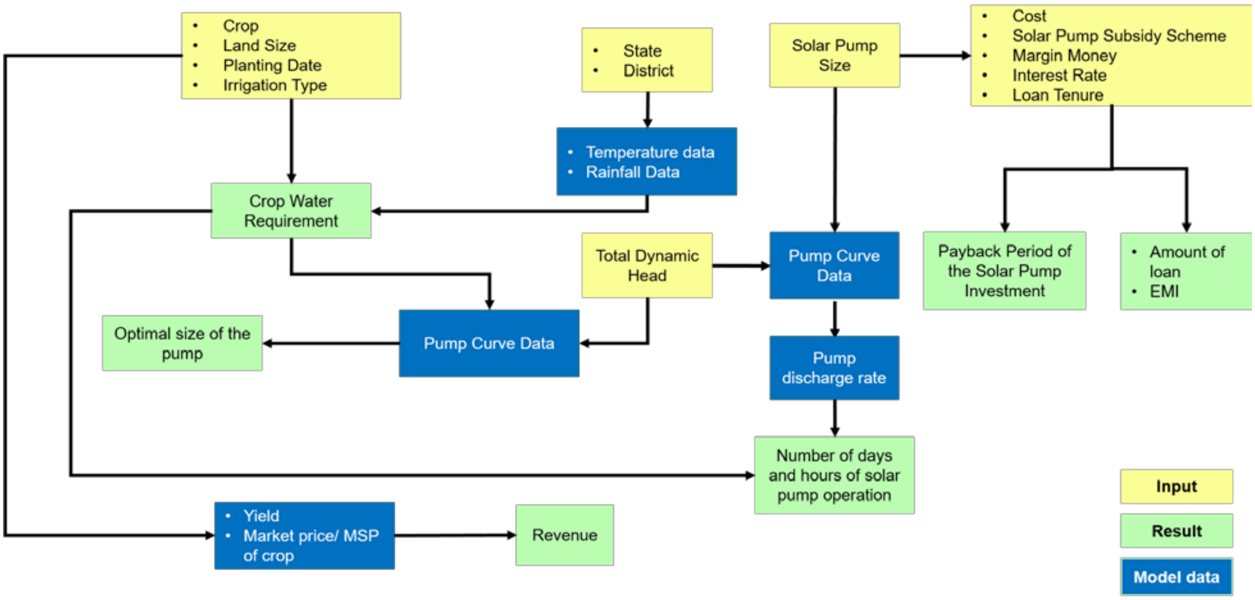


Figure 15: Factors involved in feasibility analysis of a solar powered irrigation system

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 Mali.

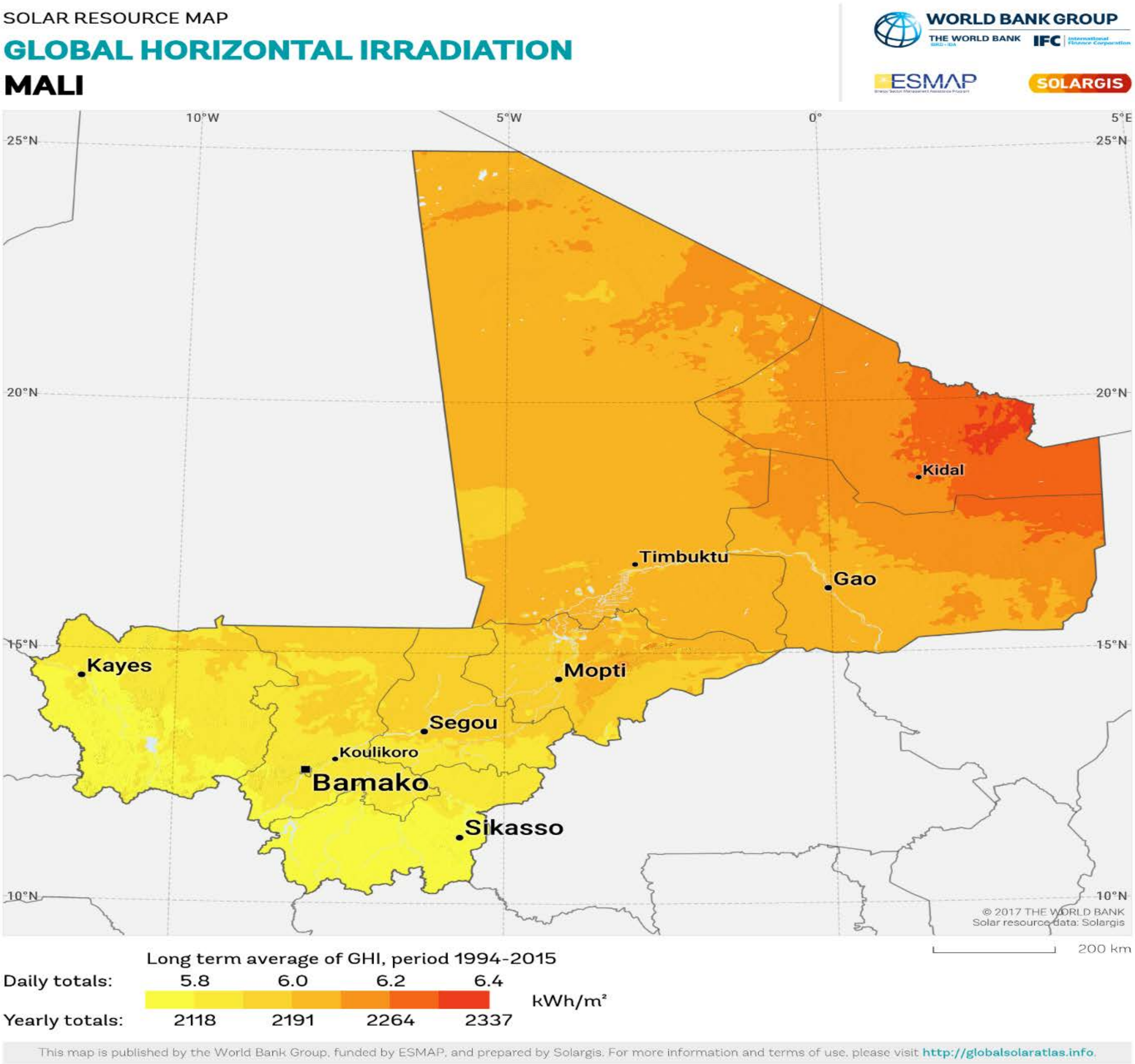


Figure 16: Solar Resource Map of Mali

As clearly indicated from the above, the North part of the country particularly in the warm desert areas particularly around Kidal, the GHI values vary between 6.3-6.4 kWh/m^2 while in the Southern part it is less than 5.8 kWh/m^2. The country receives around 7-9 hours every day throughout the year which signify great potential for development of solar technologies in the country owing to the abundance of solar insolation. 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 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[32].

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

[33]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.

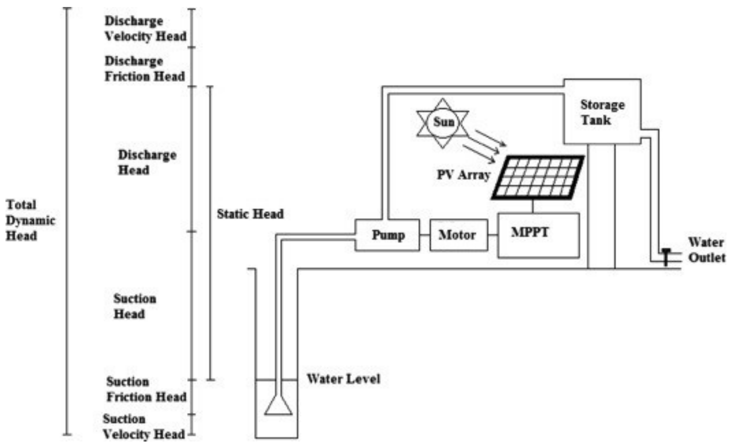


Figure 17: Total Dynamic Head of a solar pump

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, Maize	
2	Land Size	hectares	0.5 (for each crop)	
3	Planting date		As per cropping calendar of Mali	
4	Irrigation type		Flood: Lined canal supplied	
5	Selected Size of Solar Pump	HP	3	

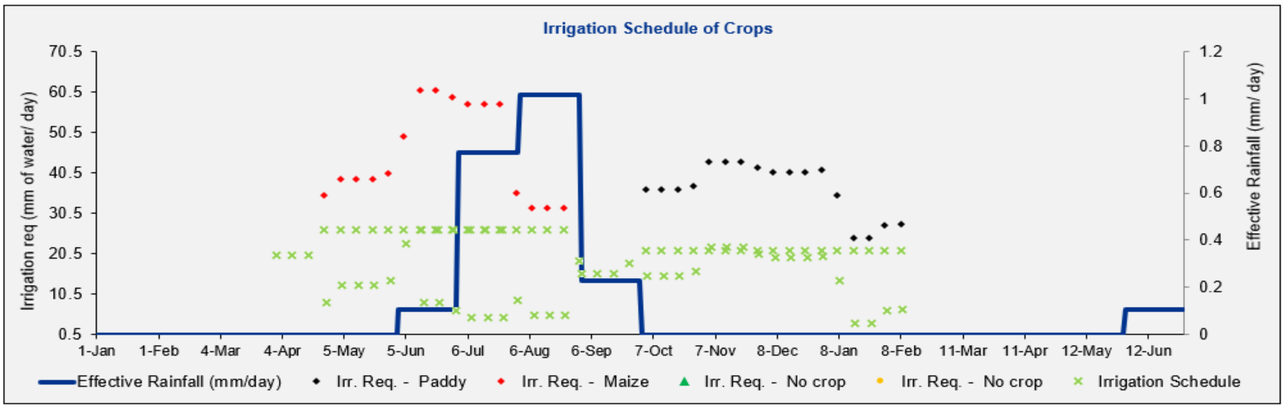
[32] Sun-Connect News
[33] ScienceDirect.com

6	Total dynamic head inclusive of friction losses	meters	40	
7	Cost of Solar Pump	USD	4,064	Average of L1 prices discovered in ISA tender for 3 HP AC/DC, Surface mounted/submersible pumpsets
8	Subsidy	%	0%	
9	Margin Money	%	10%	
10	Loan Amount	%	90%	
11	Interest Rate	%	1.5%	EXIM Bank LoC Interest rate
12	Loan Tenure	years	7	
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 Mali	%	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[34]

Indicative Crop Water Requirement

Total Crop Water Requirement (m^3)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
766	363	-	557	982	1350	1294	620	395	899	1046	1026
Annual crop water requirement (m^3)						9297					

[35]**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

[34] The toolkit developed by KPMG for Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH was used to undertake the analysis.
[35] Note: This is just an indicative analysis to be used only for reference purposes. We have taken reasonable assumptions wherever reliable data was not available. A more accurate analysis can be arrived at once data has been obtained from the respective nations.

Indicative Outputs

S. No.	Particulars	Unit	Value
1	Amount of subsidy	USD	0
2	Amount of loan to be availed	USD	3658
3	Yearly installment towards loan repayment	USD	554
4	Monthly installment towards loan repayment	USD	46
5	Savings in monthly diesel expenses on an average basis for 20 years	USD	128
6	Number of hours of solar pump operation required	Hours	870
7	Number of days of solar pump operation required	Days	109
8	**Incremental payback of solar pump w.r.t. diesel pump**	**years**	**3**

Mali has submitted demand for 15,000 Nos. solar water pumping systems. At an average price of USD 4,064 per 3 HP pumpset, Mali requires financing of USD 60.96 million to roll out deployment of 15,000 Nos solar water pumping systems across the country.

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 6: Advantages of solar powered irrigation

14. Key Stakeholders

Organization/ Agency	Role
Ministry of Energy and Water (MEE)	Nodal ministry for implementing all energy related projects in the country. MEE is also the implementation partner for majority of international development organizations including USAID, KfW and UNDP. MEE have implemented a number of solar pump projects through self-financing and international funding. The MEE is responsible for policy formulation, promotion, coordination, monitoring and evaluation.
Minister of Agriculture	Nodal ministry for implementing all energy related projects in the country. Ministry of Agriculture is responsible for aggregation of solar pumpset demand across Mali. It is structured into National Directorate of Agriculture (DNA), Rural Development Authority for the Protection of Plants (OPV), Agency for Land Management and Irrigation (ATI) and Sélingué Rural Development Authority (ODRS)
Malian Agency for the Development of Domestic Energy and Rural Electrification (AMADER)	AMADER is the Malian Agency for rural electrification and household energy. It's main tasks are: • Acceleration of the use of modern energy in rural and periurban areas. • Promotion of community-based forest management • Support the reform of the energy sector and related institutions Since 2005 AMADER with World Bank funding ran the PCASER programme, subsidizing the initial investment for rural and local electrification initiatives. This resulted in some 200 rural minigrids, nearly all diesel driven and operated by in total some 60 different operators. Recently AMADER received an additional funding by the World Bank under the Scaling up Renewable Energy Programme (SREP). A large share of this funding will serve to convert diesel-powered mini-grids to solar-diesel hybrid operation.
Mali Renewable Energy Agency (AER)	Mali Renewable Energy Agency (AER) is Mali Renewable Energy Agency (AER) is agency under MEE responsible for uptake of activities in Renewables sector. It is public establishment with legal and financial autonomy and may raise funding to carry on its activities
Commission for the Regulation of Electricity and Water (CREE)	The CREE is the regulatory authority of the water and electricity sector. It's main responsibilities are: • Assistance in the development of sector strategies • Control of tenders and grant of concessions • Approbation and control of tariffs
United States Agency for International Development (USAID)	USAID works extensively in Mali in the areas of energy access, agriculture modernization and food security. Its ongoing project, 'Feed the Future' aims to increase agriculture and nutrition by delivering technology and knowledge, and building local institutional capacity to spur private sector led approach to achieve economic and food security. One component of

	the project also focuses on development of small scale irrigation projects in Mali.
Food and Agriculture Organization of the United Nations (FAO)	FAO has been carrying out Integrated Production and Pest Management Programme (IPMM) activities in Mali since 2001, supporting government programmes and policies on agricultural development, food security and natural resource management. The IPPM programme in Mali is working to help farmers improve efficiencies, production levels and profits in the production of cotton, rice, vegetables, and a variety of other cash and food crops. The programme includes a project on climate change adaptation, which works with communities to explore how to adapt cropping methods to get more from their land amid increasing climate challenges such as drought and flooding.
United Nations Development Programme (UNDP)	UNDP is currently funding the Malian National Programme for Renewable Energy for the Advancement of Women (PENRAF), a project started by the Malian government in 2003. The project has seen significant success with solar panels generating electricity for water heaters, dryers, cookers, fridges and freezers, water pumps and communal lighting systems in over 300 villages.

15. Way Forward

Mali has submitted a demand of 15,000 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 Mali and to validate the demand. This report 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.

Further the country specific rates for various categories of pumps discovered through the International Competitive Bid carried out by ISA for Solar Agricultural Pumps were informed to Mali. The same may be examined and if acceptable, Mali may enter into a contract with the selected bidder(s). The prices discovered shall help Mali in ascertaining a benchmarking price for various capacities of solar water pumping systems for future projects.