Draft Pre-Feasibility Report for Implementation of Solar Pumps in Yemen

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List of Abbreviations

AC	Alternating Current
ADB	Asian Development Bank
AFDB	African Development Bank
AIIB	Asian Infrastructure Investment Bank
DC	Direct Current
EBRD	European Bank for Reconstruction and Development
EESL	Energy Efficiency Services Limited
EIB	European Investment Bank
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Green House Gas
HP	Horsepower
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
km	Kilometre
kW	Kilowatt
kWh	Kilowatt Hours
LNG	Liquefied Natural Gas
LoC	Line of Credit
MW	Megawatt
NDB	New Development Bank
NFP	National Focal Points
PV	Photovoltaic
R&D	Research and Development
REPS	Rural Electrification Policy Statement
REREDP	Rural Electrification and Renewable Energy Development Project
RHH	Rural Households
SHS	Solar Home Systems
SSAAU	Scaling Solar Applications for Agricultural Use
SSLS	Solar Street Lighting System
SWPS	Solar Water Pumping Systems
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
UL	Underwriters Laboratories

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1. Executive Summary

Background

Yemen is a desert country in the Middle East on the southern tip of the Arabian Peninsula, bordered in West by the Red Sea and the Bab-el-Mandeb Strait, in north by Saudi Arabia and in north east by Oman. Yemen has maritime borders with Djibouti, Eritrea, and Somalia.

In 1918, North Yemen became independent from the Ottoman Empire. The British controlled the southern territory around the port of Aden, withdrew in 1967 and the area became known as South Yemen. Finally, in 1990, the North and South united as the Republic of Yemen. The capital of Yemen is Sana'a.

Yemen's Electricity Sector

Yemen produces and exports oil and gas from its indigenous fossil fuel resources. The country's primary energy consumption is entirely based on fossil fuels. Yemen is also significant in the international energy trade due to its proximity to shipping routes. Yemen's economy is dependent on the hydrocarbon sector, which accounts for nearly 60% of government revenues.

Yemen's electricity infrastructure is not sufficient to meet the country's needs. Data from the World Bank indicated that, as recently as 2017, only 79% of Yemen's population had access to electricity. Even for grid-connected consumers, blackouts are frequent as a result of persistent attacks on the country's energy infrastructure.

Yemen benefits from its strong potential for renewable energies which remains relatively untapped. Solar power represents a massive opportunity for development. Indeed, solar irradiation exceeds 2200 kWh/m^2/year (for Global Horizontal Irradiance) across most of the country. Thus, Yemen has real potential for development and scaling up of photovoltaic projects. The highest solar radiation is around 2556 kWh/m^2/year, whereas the coast line receives radiation around 2000 kWh/m^2/year. The highest global horizontal irradiance is in Sanna and Dhamar.

Connectivity and Accessibility

Relative to the area of the country, the road transportation system is very limited. Yemen has 71,300 kilometres of primary and secondary roads, and only 14,093 kilometres are paved (4,867 km of main roads, 3,647 km of international roads, 3,113 km of secondary roads, and 2,466 km of rural roads).

Yemen has 46 airports, 16 of which have paved runways. Of the 46 airports, five are international: Aden International, Sana'a International, Taiz, Rayyan, and Al Hudaydah.

There is no railway network in Yemen, though there have been several plans and proposals. The first of these appeared in the days of the Ottoman Empire, when it was suggested that the Hejaz railway might eventually be extended to as far as Yemen, but this never materialised.

Climate and Rainfall

The Climate of Yemen is referred to as subtropical dry, hot desert climate with low annual rainfall, very high temperatures in summer and a big difference between maximum and minimum temperatures, especially in the inland areas.

Summer (June to September) is very low rainfall. Daily maximum temperatures can reach easily 40°C or more. Winter is cooler with occasional rainfall. Spring and autumn are warm, mostly dry and pleasant, with maximum temperatures between 25°C and 35°C and cooler night Temperatures between 15°C and 22°C.

A hot, dust-laden wind, the Shamal, blows in the spring and summer-period, from March till August. Sometimes these winds can be very strong, and cause Sandstorms, that can occur throughout the year, although they are most common in the spring. Most rain falls during the winter months in sudden, short but heavy cloudbursts and thunderstorms.

Soil

Soils in Yemen are generally soiling of alluvial deposits produced by water and wind weathering. The country's soils are sandy to silty and loamy in coastal regions and silty to loamy and clay loamy in the highlands. The soils are generally low in nitrogen, phosphorus and organic material. In areas in the highlands soil are shallow with often calcareous layer which leads to poor moisture retention.

Groundwater Status

Yemen's groundwater is the main source of water in the country, but the water tables have dropped severely leaving the country without a viable source of water. For example, in Sana'a, the water table was 30 meters below surface in the 1970s but had dropped to 1200 meters below surface by 2012. The groundwater has not been regulated by Yemen's governments. Even before the revolution, Yemen's water situation had been described as increasingly dire by experts who worried that Yemen would be the "first country to run out of water". Agriculture in Yemen takes up about 90% of water in Yemen even though it only generates 20% of GDP.

Agriculture and Cropping Pattern

Crop production in Yemen is generally reflected by the availability of water supply as being the most important factor. Crops predominantly grown in flood irrigation are sorghum, millet, cotton, cucurbitas, legumes, sesame and groundnuts. The base of intensive agriculture mainly for cash crops such as qat, vegetables, fruits and forage crops are irrigated on wells and springs.

Due to a variety of natural conditions, the calendar of agricultural activities differs depending on location. In Central Highlands, with two distinct cropping seasons, harvesting of rainfed wheat, planted in July, will start in October. In Southern Uplands, with only one rainy season, the sorghum harvest just started in mid-September.

Financial Feasibility

Yemen has submitted demand for 1500 Nos. solar water pumping systems. At an average price of USD 4,967 for each 5 HP pumpset, Yemen requires financing of USD 7.5 million to roll out deployment of 1500 Nos. solar water pumping systems across the country.

Indicative Outputs

S.No.	Particulars	Unit	Value
1	Amount of subsidy	USD	0
2	Amount of loan to be availed	USD	4470
3	Yearly installment towards loan repayment	USD	1486
4	Monthly installment towards loan repayment	USD	124
5	Savings in monthly diesel expenses on an average basis for 20 years	USD	346
6	Number of hours of solar pump operation required	Hours	901
7	Number of days of solar pump operation required	Days	129
8	Incremental payback of solar pump w.r.t. diesel pump	years	3

2. Background

2.1 About ISA

International Solar Alliance was launched on November 30, 2015 by India and France to implement the Paris Agreement and the ISA Framework Agreement came into force on December 7, 2017. The headquarter agreement with India was signed on June 6, 2018 when the ISA Secretariat acquired a judicial personality under the Framework Agreement. ISA held its first Assembly on October 3, 2018 and the second one is being held on October 31, 2019. To date, 79 countries have signed the Framework Agreement. ISA aims to provide a dedicated platform for cooperation among solar resource-rich countries where the global community, including bilateral and multilateral organizations, corporates, industry and other stakeholders can collaborate and help achieve the aim of increasing the use of solar energy in a safe, convenient, affordable, equitable and sustainable manner.

The International Solar Alliance (ISA) has been conceived as an action-oriented, member-driven, collaborative platform for increased deployment of solar energy technologies to enhance energy security and sustainable development, and to improve access to energy in developing member countries. In this respect, ISA has been continuously working towards coordinating joint and collaborative efforts for mobilizing more than USD 1000 billion investments in the solar sector thereby facilitating scaling up of solar deployment in various member countries.

As guided by the Framework Agreement of the ISA, the interests and objectives of the ISA are as follows:

1. To collectively address key common challenges to scale up solar energy applications in line with their needs;
2. To mobilize investments of more than USD 1000 billion by 2030;
3. To take coordinated action through programmes and activities launched on a voluntary basis, aimed at better harmonization, aggregation of demand, risk and resources, for promoting solar finance, solar technologies, innovation, R&D, capacity building etc.;
4. Reduce the cost of finance to increase investments in solar energy in member countries by promoting innovative financial mechanisms and mobilizing finance from Institutions;
5. Scale up applications of solar technologies in member countries, and
6. Facilitate collaborative research and development (R&D) activities in solar energy technologies among member countries.

To expand its reach, the ISA has entered into strategic and financial partnerships with the UNDP, the World Bank, the European Investment Bank (EIB), the European Bank for Reconstruction and Development (EBRD), the African Development Bank (AFDB), the Asian Development Bank (ADB), the Asian Infrastructure Investment Bank (AIIB), New Development Bank (NDB), and the Green Climate Fund (GCF), IEA, IRENA, Climate Parliament and UNIDO on enhancing cooperation on solar energy deployment to further the mandate of the ISA. The United Nations including its organs are strategic partners of the ISA.

On the request of the ISA, the Government of India has earmarked around US $ 2 billion Line of Credit (LoC) to the African countries for implementation of solar and solar related projects out of its total US $ 10 billion LoC under the Indian Development and Economic Assistance Scheme (IDEAS) to various African and other developing countries. India has set up a project preparation facility which will provide consultancy support to partner countries to design bankable projects.

Following these commitments, India has provided $ 1.4 billion concessional financing to 27 solar projects in 15 developing countries so far. As a co-founding member of the ISA, Government of France through the Agence Française de Développement, has also offered €1000 million for solar projects across ISA member countries. 17 projects have been funded by AFD for approximately Euro 300 million. ISA will similarly persuade other countries to contribute to the cause of solar deployment globally.

ISA is currently working towards coordinating a joint and collaborative effort amongst member countries so that strategies suited to the requirements of individual countries can be formed, and feasible solar technologies can be deployed. ISA is acting as a facilitator to contribute to the solar deployment efforts of individual member country. For this, ISA has formed a framework of programs and initiatives to develop a dedicated approach towards scaling up of various solar technologies. All the Programmes of ISA are member driven. The current programmes of ISA are:

1. Affordable finance at scale
2. Scaling Solar Applications for Agricultural Use (SSAAU)
3. Scaling Solar Mini-Grids
4. Scaling Solar Rooftop
5. Scaling solar supported e-mobility and storage

2.2 About SSAAU Programme

ISA's first programme, Scaling Solar Applications for Agricultural Use (SSAAU), was launched in New York, USA on 22nd April 2016. The SSAAU Programme mainly focusses on decentralized solar applications in rural settings. Major focus areas of the programme include Solar Water Pumping Systems (SWPS), solar drying, solar chilling, solar milling, etc. Other activities under the programme include R&D, capacity building, and developing common standards, facilitate transfer of technology, etc.

More than twenty-one countries namely Bangladesh, Benin, Djibouti, Ethiopia, France, Guinea-Bissau, India, Kiribati, Mali, Mauritius, Niger, Nigeria, Rwanda, Senegal, Seychelles, Somalia, Sudan, Togo, Tonga, Uganda, Vanuatu have been frequently interacting regarding the programme strategy and implementation through the network of NFPs and country representatives via video conferencing. To understand specific requirements of these countries, needs assessment questionnaires have been developed for Solar Water Pumping System (SWPS) and Solar Street Lighting System (SSLS). These questionnaires have been circulated to all participating and signatory countries of the ISA as a first step towards demand aggregation.

The key activities under the SSAAU programme are as under:

S No.	Category	Key Activities
1	Demand Aggregation	▪ Obtaining data for demand aggregation models from various member countries ▪ Bid process management, fixation of price, identification of manufacturer(s)/ supplier(s) for each of the participating member countries
2	Country Strategy	▪ Developing baseline studies and roadmaps for member nations ▪ Constituting global task force for the programme ▪ Facilitating affordable financing for implementation of solar water pumping programme in participating member countries
3	Facilitating Deployment	▪ Facilitating in setting Standards, Performance Benchmarks, Testing and Certification Protocols through identified test centers ▪ Development of base document for global tendering and best practices for procurement, installation and maintenance ▪ Monitoring and Evaluation
4	Outreach Strategy	▪ Development of media outreach strategy for the programme ▪ Organization of workshops and seminars for promotion of SSAAU programme

Table 1: Key Activities under SSAAU Programme

As a part of the demand aggregation exercise, ISA has aggregated a demand of 272,579 Nos. of off-grid solar pumps to be implemented across 22 countries spanning 4 different continents. The key objective of the demand aggregation exercise was to bring down the costs of the system so as to enable implementation of viable and bankable solar pumps projects in various ISA countries.

The demand aggregation exercise comprised of the following sub-steps:

1. Needs Assessment: In collaboration with National Focal Points (NFPs) and Country Representatives, need assessment questionnaires for Solar Water Pumping Systems (SWPS) were circulated to participating member countries
2. Ascertaining Demand: The filled in needs assessment questionnaires were used to ascertain demand of solar water pumping systems including information on type, quantity and technical specifications in each of the participating member countries
3. Demand Validation: Coordinating with National Focal Points and Country Representatives for obtaining country specific data and information and for validation of demand
4. International Competitive Bidding for Price-Discovery: Energy Efficiency Services Limited was hired for management of International Competitive Bidding for price discovery of various types of solar water pumping systems in participating member countries

The results of the demand aggregation exercise are summarized in the figure below:

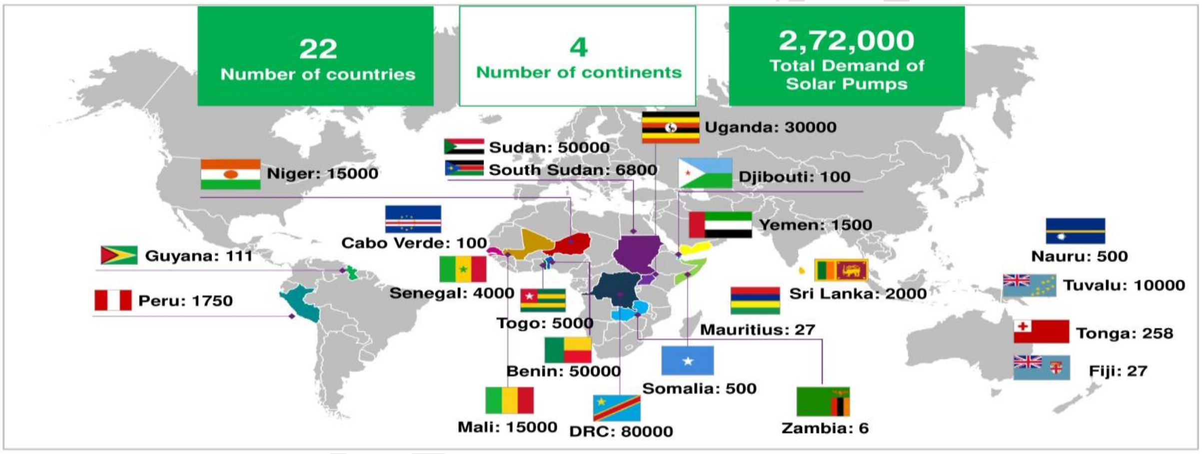


Figure 1: Demand received from various ISA member countries for solar pumps

Subsequent to the demand aggregation exercise, Internal Competitive Bidding was undertaken by EESL on behalf of ISA for price discovery of various types of solar pumps in the participating member countries. The price discovery tender is one of the largest tenders for solar pumping systems globally and is expected to open up huge market opportunity for implementation of solar pump programme in participating member countries. Through this tender, it is expected that local market ecosystem for solar pumps will be developed which will help in greater penetration of technology amongst the farmers. It is envisaged that in the long-run solar pumps would replace the existing diesel pumpsets in these member countries thereby leading to significant reduction in GHG emissions apart from providing a reliable irrigation solution for the farmers. The key features of the International Competitive Bidding for price discovery is summarized as below:

S. No	Category	Description
1	International Standards for Solar Pumps	▪ Internationally accepted IEC and UL standards for various solar pump components
2	Technical and Financial Qualifying Criteria	▪ Technical Qualifying Criteria: Based on experience of supply and installation of solar pump sets and solar power plants ▪ Financial Qualifying Criteria: Based on average annual turnover and net worth

S. No	Category	Description
3	Specifications for minimum bidding quantity	▪ Mandatory to bid for 5 countries with a total bid quantity of at least 27000
4	Two separate bid packages	▪ Only supply ▪ Supply and Five-Year Comprehensive Maintenance Contract
5	Two stage evaluation process	▪ Based on technical and commercial evaluation ▪ Award of contract to various bidders based on L1 prices

Table 2: Key features of Internal Competitive Bidding for Price Discovery of Solar Pumps

The price discovery was conducted for two broad services contract namely:

- Service 1: Supply, Custom clearance, Local transportation, installation, testing and commissioning of complete system & services at Employer's site of Solar PV based Agricultural Pump Set system
- Service 2: Supply Custom clearance, Local transportation, installation, testing and commissioning of complete system at site of Solar PV based Agricultural Pump Set system

The roles and responsibilities of the bidder and the respective member nation as a part of the price discovery tender is summarized in the figure below:

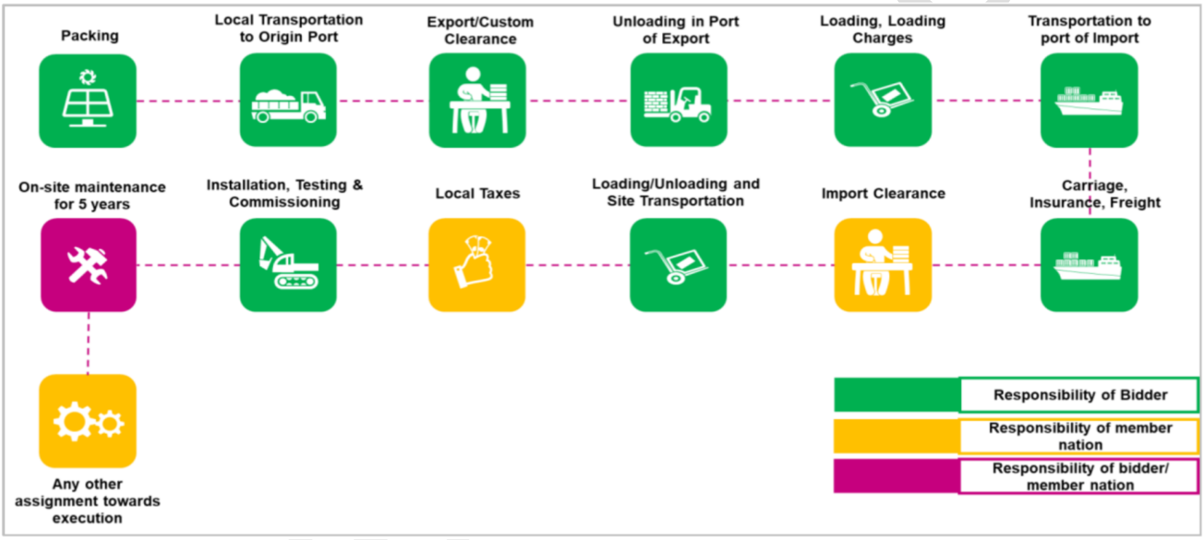


Figure 2: Work Packages and Responsibility Division

Five bidders have participated in the price discovery tender and have submitted the prices for various capacities of solar pumps in the participating member countries. ISA is currently analyzing and evaluating the prices and will subsequently share with the member countries for final decision at their end.

3. Introduction

3.1 About Yemen

Yemen is a desert country in the Middle East on the southern tip of the Arabian Peninsula, bordered in West by the Red Sea and the Bab-el-Mandeb Strait, in north by Saudi Arabia and in north east by Oman. Yemen has maritime borders with Djibouti, Eritrea, and Somalia.

In 1918, North Yemen became independent from the Ottoman Empire. The British controlled the southern territory around the port of Aden, withdrew in 1967 and the area became known as South Yemen. Finally, in 1990, the North and South united as the Republic of Yemen. The capital of Yemen is Sana'a.

With an area of 527,970 sq km (including the islands of Perim and Socotra), 28.5 million people live in the country. Sana'a is the largest city and the national capital and is situated in a mountain valley at an altitude of 2,200 m, the Old City of Sana'a is a UNESCO World Heritage Site. Yemen's primary seaport and economic center is Aden.[1]

Figure 3: Map of Yemen[2]

The Nation's principal agricultural commodities produced in the country include grain, vegetables, fruits, pulses, qat, coffee, cotton, dairy products, fish, livestock (sheep, goats, cattle, camels), and poultry.

Most Yemenis are employed in agriculture. Sorghum is the most common crop. Cotton and many fruit trees are also grown, with mangoes being the most valuable. A big problem in Yemen is the cultivation of Khat (or qat), a psychoactive plant that releases a stimulant when chewed, and accounts for up to 40 percent of the water drawn from the Sana'a Basin each year, and that figure is rising. Some

[1] The World Factbook, CIA
[2] International Institute for Democracy and Electoral Assistance

agricultural practices are drying the Sana'a Basin and displaced vital crops, which has resulted in increasing food prices.

Yemen has endured Civil War since early 2015. Already the poorest country in the Middle East and North Africa region before the conflict broke out, the UN says Yemen is now suffering the worst humanitarian crisis in the world. Fighting has devastated the country's economy, destroyed critical infrastructure, and led to food insecurity verging on famine.

In 2019, the UN estimated that 24.1 million people—80 percent of the Yemen's population—were "at risk" of hunger and disease, of which roughly 14.3 million were in acute need of assistance. An estimated 17.8 million people were without safe water and sanitation, and 19.7 million without adequate healthcare.[3]

As a result, Yemen has been grappling with mass outbreaks of preventable diseases, such as cholera, diphtheria, measles, and Dengue Fever. Waves of currency depreciations in 2018 and 2019 created inflationary pressure that have exacerbated the humanitarian crisis, and disruptions to public infrastructure and financial services have severely affected private sector activity.

More than 40 percent of Yemeni households are estimated to have lost their primary source of income and consequently find it difficult to buy even the minimum amount of food. Poverty is worsening: before the crisis, it affected almost half the population, and it now affects an estimated 71 to 78 percent of Yemenis[4]. Women are more severely affected than men.

3.2 Overview of Energy Scenario

Yemen produces and exports oil and gas from its indigenous fossil fuel resources. The country's primary energy consumption is entirely based on fossil fuels and also important on international energy trade due to its proximity to shipping routes. Yemen's economy is dependent on the hydrocarbon sector, which accounts for nearly 60% of government revenues.[5]

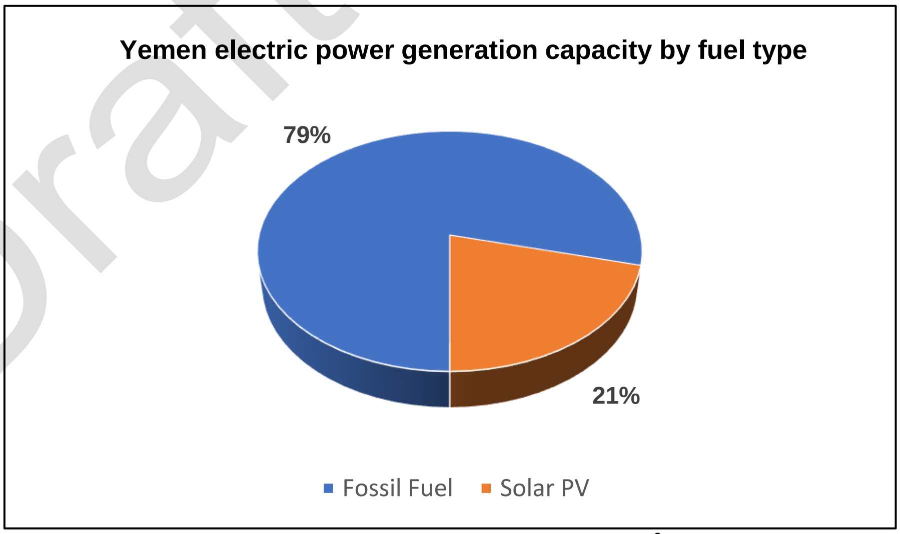


Figure 4: Installed Capacity by source (2018)[6]

Yemen's electricity infrastructure is outdated and insufficient to meet the country's needs. Data from the World Bank indicated that, as recently as 2017, only 88% of Yemen's population had access to

[3] World Bank
[4] World Bank
[5] RCREEE
[6] Theodora

electricity. Even for grid-connected consumers, blackouts are frequent as a result of persistent attacks on the country's energy infrastructure.

Petroleum, including distillate and residual fuel oil, fuels much of Yemen's electricity generation, although natural gas is capturing a growing market share as the country develops its natural gas resources.

In 2007, Yemen established a grid interconnection with neighbour Saudi Arabia, with an investment of $400 million allowing for transfers of between 500 megawatts and 1,000 megawatts between the two countries.[7]

Yemeni government's policy on renewable energy is to optimize the use of energy from domestic sources, increase renewable energy in electricity generation to 15-20% by 2025, and promote sustainable development within the electricity sector.[8]

In March 2009, a new Electricity Law, which sets out to improve the management of the power sector and to facilitate investment by private capital, was issued. One of the key objectives of the law is to encourage environmentally friendly power production through renewable energy sources. In addition, the 2009 Electricity Law creates a regulatory office to be known as the Electricity Sector Regulatory Board as well as a new authority called the Rural Electrification Authority.

3.3 Electricity Generation

Yemen's generating capacity as of 2016 was just 4.784 billion kWh according to Yemen's Ministry of Electricity, one of the lowest in the Middle East region despite the country having the fourth-largest population in the region. According to the CIA World Factbook, capacity in 2016 was only 1,819 MW. Many of Yemen's electric plants are now able to use natural gas as fuel, which has helped the country move away from burning petroleum to generate electricity.

Today one of the great challenges is scarcity of electricity in Yemen since it depends totally on fossil fuels including Diesel, Heavy Crude Oil (Mazot), and Liquefied Natural Gas (LNG). These resources are of great concern to environmentalists due to various hazard they pose on the environment.

Yemen is rich in renewable energy resources such as wind, solar, biomass, geothermal, and hydropower energies. These abundant resources in Yemen are potentially enough to produce electricity in order to fill this existing energy gap.

Resources	Theoretical potential (MW)	Practical potential (MW)
Wind	308,722	123,429
Geothermal	304,000	29,000
Solar PV	2,446,000	1,426,000
Biomass-landfills	10	8
Hydropower- Major Wadies	12 – 31	11 – 30
Solar Thermal-Solar Water Heater	3,014	278

Table 3: Renewable Energy Potential in Yemen[9]

Yemen has a long coastal strip of over than 2500 km long and an average width of 45 km along the Red Sea, and the Arabian Sea. These coastal areas have an annual wind speed average of more than 8 m/s. There is a good potential for making wind farms on the coastal strip as well as on the offshore areas. One of the most suitable coastal areas is Al-Mokha Zone, Taiz, which has favourable conditions of wind in Yemen.

[7] Energy Charter
[8] IEA
[9] Joint Socio-economic assessment; UNDP

Geographically, Yemen is located in the Sunbelt area of the world. Yemen is one of the regions in the world that has high levels of solar radiation ranging between 5.4–7.0 kWh/m^2 per day and annual average of daily sunshine ranges between 7.3 and 9.1 hours/day. Even in winter, the daily average of sunshine hours is estimated of about more than 8 hours/day.

Yemen has one of the lowest supplies of freshwater per capita in the world. The effects of a growing population and limited water resources have been exacerbated a great deal by climate change and the escalating conflict. An estimated 90 per cent of Yemen's population does not have access to sufficient water and only 40 per cent have access to safe drinking water.

In response to severe water scarcity, IOM, the UN Migration Agency, is utilizing solar energy to provide reliable and affordable access to clean water for communities using the roof space of three high schools in the Amanat Al Asimah and Sana'a Governorates. 940 strategically-installed solar panels are supporting two 120 KW and one 65 KW power systems, providing 834,000 litres of water every day by pumping water for 7 hours from three different wells into the water systems in 7 neighbourhoods. Some 55,000 people can now access adequate safe water on a daily basis. In addition to the immediate public health and livelihood benefits of having more reliable and affordable water, this initiative is helping save an estimated 162,000 litres of diesel worth 58.3 million Yemeni Rials or USD 121,0000 (at current prices) and 400 tonnes of carbon emissions every year.[10]

3.4 Electricity Transmission

Yemen has one main 132 kV grid as shown in Figure below. A new gas-fired power plant was commissioned at Ma'rib, to the east of Sana'a in 2010 and connected to the main grid via a 400 kV double circuit transmission line at Bani Hoshish. A second 400 kV transmission line is also planned from Ma'rib to connect to the 132 kV substation at Dhamar, south of Sana'a. There are smaller grids to the east centered on Wadi Hadramaut (Al Bayda), Al Mukhalla (on the coast), Balhaf (the site of the new LNG liquefaction plant) and Ataq. There is also an isolated network around Sada in the north.[11]

A number of studies undertaken in the past have recommended the interconnection of Yemen's isolated grids. The most recent of these, prepared by EdF in 2008 for the Ministry of Electricity and Energy and the Public Electricity Corporation, recommended the connection of three currently isolated grids in the Hadramaut, Al Mukhalla, Balhaf (LNG terminal) and Ataq areas to form an eastern grid and to connect these to the main grid. This scheme is summarized in The EdF study recommended connecting the eastern grid via a 400 kV transmission line from Ma'rib.

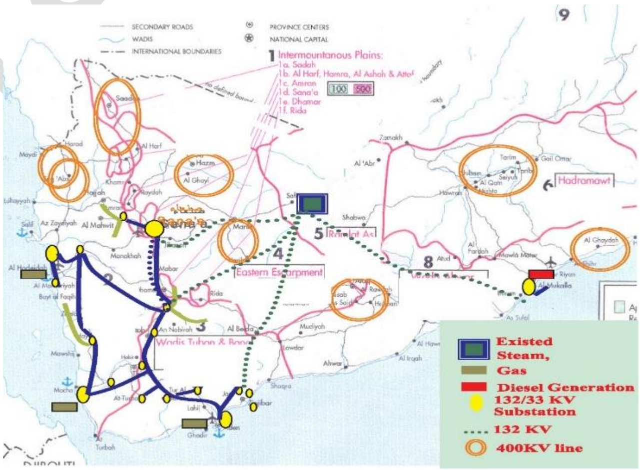


Figure 5: Power transmission network of Yemen[12]

[10] International Organization for Migration
[11] Energy Charter
[12] Global Energy Network Institute

3.5 Electricity Distribution

The Public Electricity Corporation of the Republic of Yemen serves more than 1.1 million consumers in 20 Governorates through centralized electricity supply or isolated generation systems accounting around 41 percent of the total number of dwellings. PEC is committed to increase access to grid electricity services of rural population in the country. In accordance to the Electricity Master Plan, PEC recently carried out a study to supply electricity in local areas either through isolated diesel power generation or distribution network expansion from 2006-2020. This distribution projects will cover 12 Governorates and target almost 637,000 consumers[13].

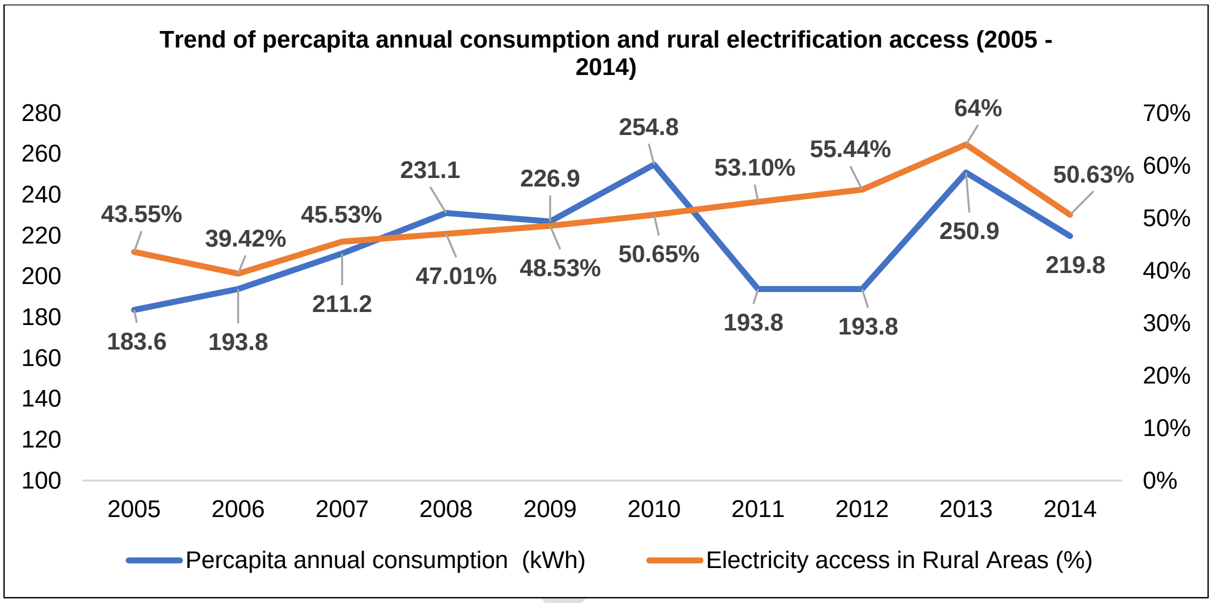


Figure 6: Trend of per capita electricity consumption and rural electrification access[14]

A nationwide rural electrification programme has been committed through the Power Sector Development Strategy Note of 1997, updated in 2006. Based on preparatory market assessment studies conducted through a GEF-funded Rural Electrification and Renewable Energy Development Project (REREDP), the Cabinet approved a Rural Electrification Policy Statement (REPS) in July 2008. The National Rural Electrification Strategy will result in increased access for over 520,000 new rural households that will increase access from the current level of about 20% to about 46% of rural households and benefit more than 3.5 million people.[15] The Rural Energy Access Project is funded by the World Bank from 2006 to 2015 in order to improve electricity access of rural populations in the selected project areas and to demonstrate the feasibility of increasing the access to electricity of Rural Households (RHH) in off-grid areas through implementation of Solar Home Systems (SHS). In June 2009, the government approved the National Strategy for Renewable Energy and Energy Efficiency which targets a 15% increase of energy efficiency in the power sector by 2025.

Tariff Categories (Low Voltage)	Cost of Electricity (YER / kWh)
Urban Households:	
0 -200 kWh	6
201 – 350 kWh	9
351 – 700 kWh	12
>700 kWh	19
Rural Households:	
0 – 100 kWh	9
>100 kWh	19
Small Commercial	25

[13] Energy Charter
[14] World Bank
[15] World Bank

Tariff Categories (Low Voltage)	Cost of Electricity (YER / kWh)
Large Commercial	35
Hotels	30
Agriculture	30
Large Industry	35
Public Water Pumping	30
Government Buildings	30

Table 4: PEC Yemen Electricity Tariff as of Year 2017[16]

[16] Public Electricity Corporation, Yemen

4. Technical Feasibility Assessment

4.1 Assessment Criteria

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.

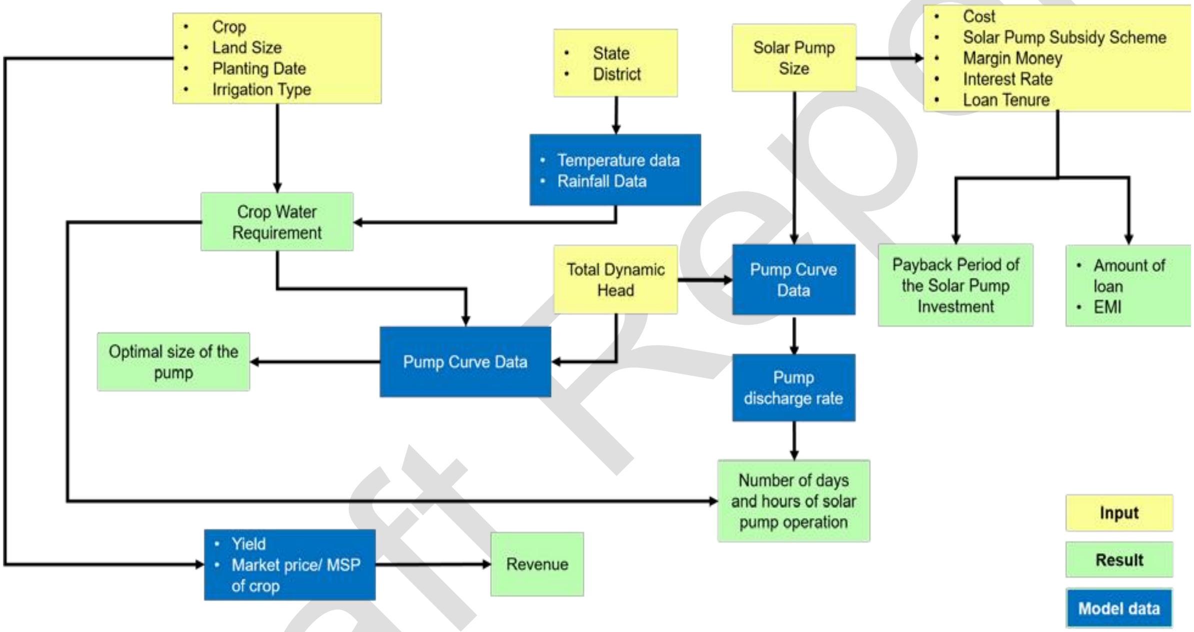


Figure 7: Factors involved in feasibility analysis of solar pump

4.1.1 Total Dynamic Head

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.

The static head, discharge head and the total dynamic head is explained through the image below[17]:

[17] Science Direct

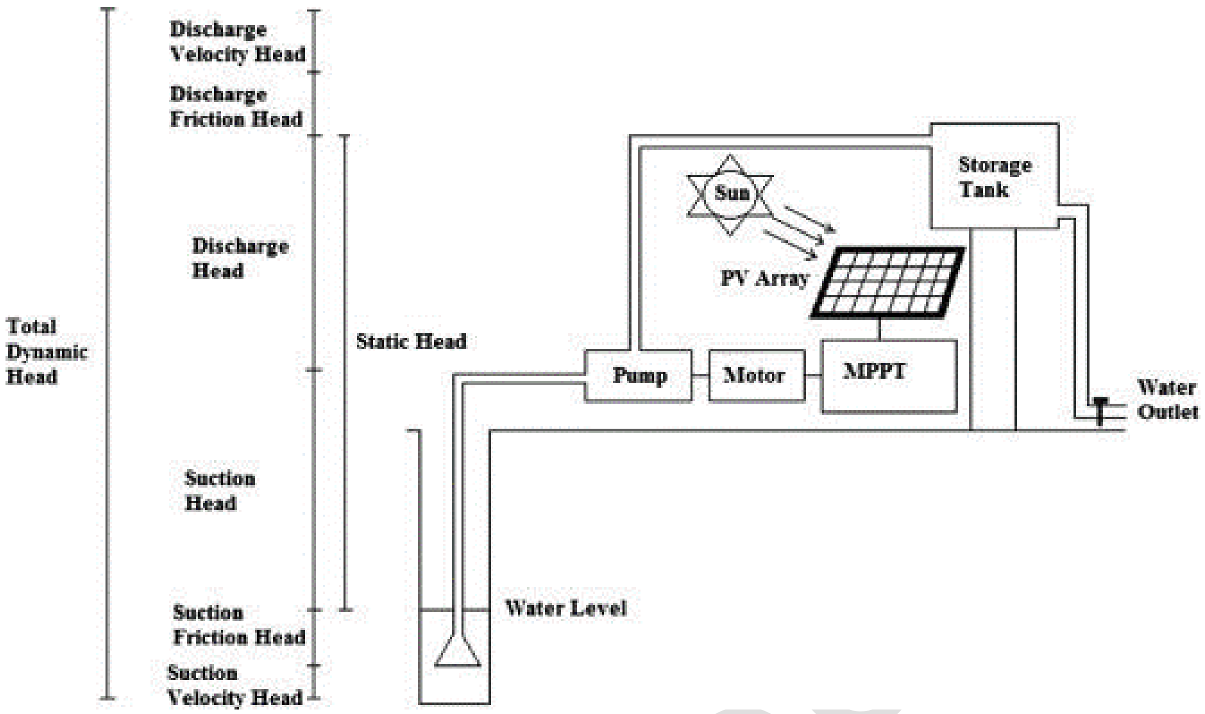


Figure 8: Total Dynamic Head of a solar pump

4.1.2 Pump Curves

The pump characteristic is normally described graphically by the manufacturer as the pump performance curve. Other important information for a proper pump selection is also included - like efficiency curves, NPSHr curve, pump curves for several impeller diameters and different speeds, and power consumption[18]. The performance curve indicates the variation in the discharge rate of a pump with a change in required head and input power. The pump curves are analyzed to determine the optimal size of a solar pump for a given manufacturer and also to assess whether the system will be able to the peak demand requirements of the farmer. The performance curves for a 5 HP AC and 5 HP DC pump is shown as below[19]:

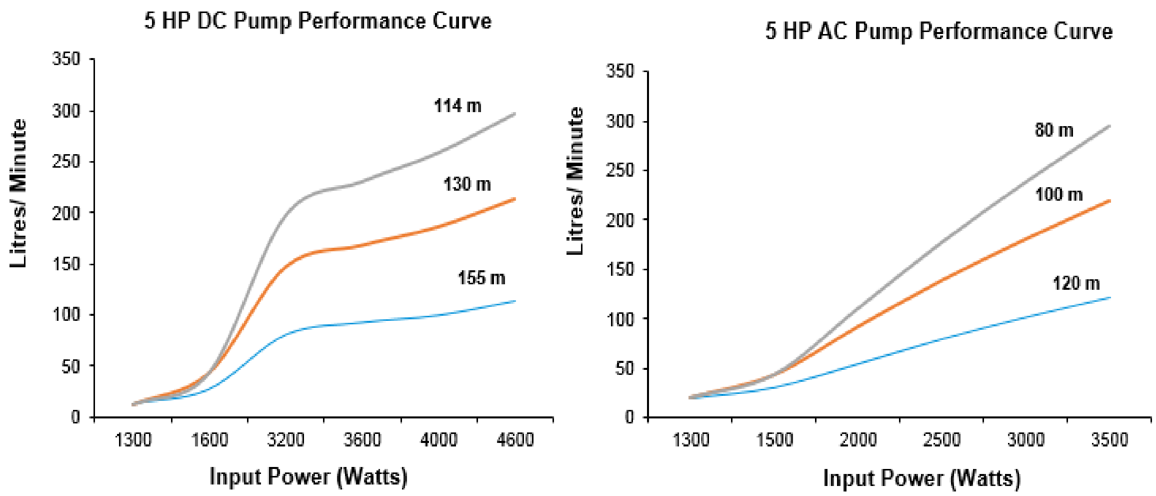


Figure 9: Pump Performance Curves

[18] The Engineering Toolbox
[19] Shakti Pumps (DC pump: 5 DCSSP 2700/3600/4600; AC pump: SSP 5000-100-11)

4.1.3 Crop Water Requirement

The crop water need is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally. The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- **the climate**: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- **the crop type**: crops like maize or sugarcane need more water than crops like millet or sorghum
- **the growth stage of the crop**: fully grown crops need more water than crops that have just been planted.

The below table showcases the effect of various climatic factors on the crop water requirement:

Climatic Factor	Crop Water Requirement	
	High	Low
Temperature	Hot	Cool
Humidity	Low (Dry)	High (Humid)
Windspeed	Windy	Little Wind
Sunshine	Sunny (no clouds)	Cloudy (no sun)[20]

Table 5: Effect of major climatic factors on crop water requirement

The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind. The influence of the climate on crop water needs is given by the reference crop evapotranspiration (ETo). The ETo is usually expressed in millimetres per unit of time, e.g. mm/day, mm/month, or mm/season. ETo is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water[21].

4.1.4 Pump Sizing

Oversizing would incur unnecessary costs, and under sizing would lead to insufficient performance. This is why each component needs to be properly designed and sized to meet the specific requirements of the project. It is the only way to guarantee reliability and system durability to 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[22].

[20] Food and Agriculture Organization of the United Nations (FAO)
[21] Food and Agriculture Organization of the United Nations (FAO)
[22] Sun-Connect News

4.2 Country Assessment

4.2.1 Connectivity and Accessibility

Relative to the area of the country, the road transportation system is very limited. Yemen has 71,300 kilometres of primary and secondary roads, and only 14,093 kilometres are paved (4,867 km of main roads, 3,647 km of international roads, 3,113 km of secondary roads, and 2,466 km of rural roads).[23]

Level of road security is unsafe. In the region of the Sada'a conflict insecurity is rife, transporters are taking lengthy diversions through mountainous areas following dirt tacks in order to avoid the conflict.

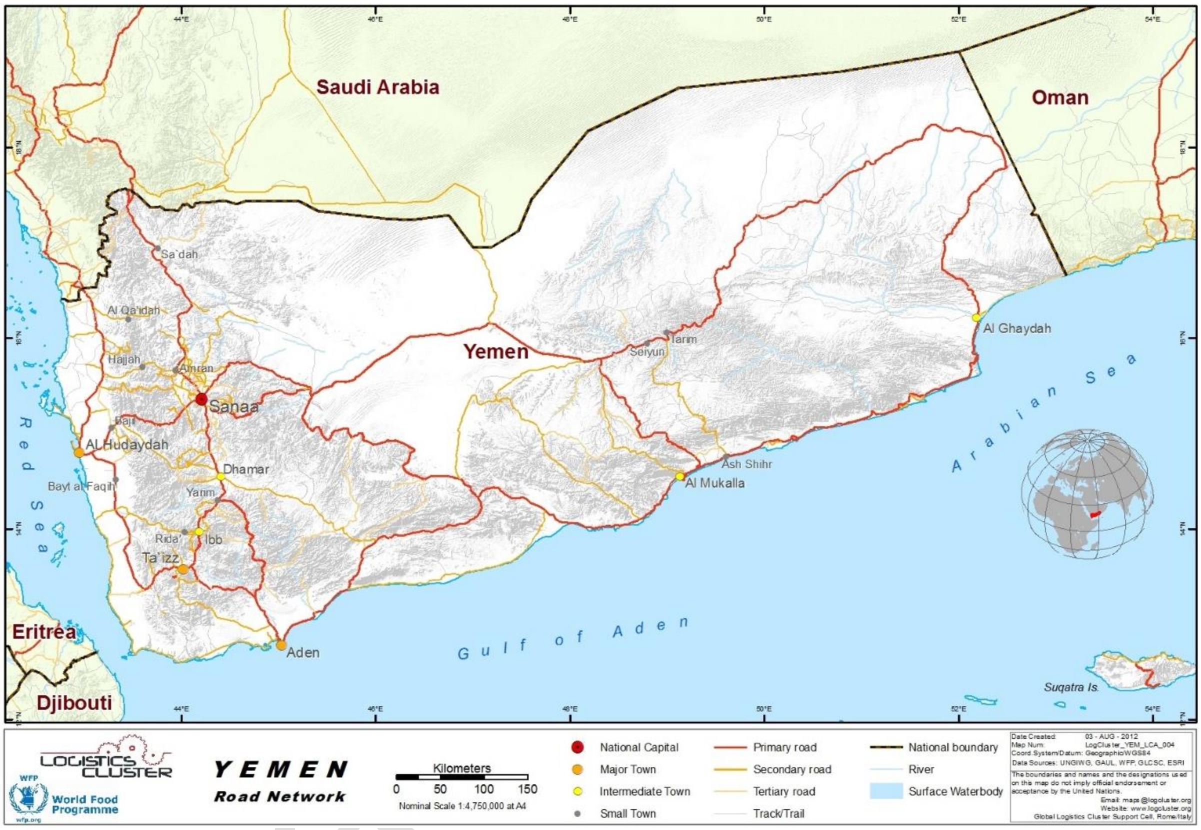


Figure 10: Road Network of Yemen[24]

The distance between key cities of Yemen are given as below:

	Sana'a	Aden	Taiz	Al Mukalla	Hodeidah	Sadaa	Al Ghayda	Sayon	Makha
Sana'a		365	256	800	226	242	990	609	364
Aden			169	621	441	607	1122	942	277
Taiz				790	272	498	1247	865	108
Al Mukalla					1062	1042	501	321	898
Hodeidah						429	1217	835	252
Sadaa							1233	851	606
Al Ghayda								381	1355
Sayon									973
Makha									

Table 6: Distances from Capital City to Major Towns (km)[25]

[23] The Ministry of Public Works and Highways, Yemen
[24] Logistics Cluster
[25] Logistics Cluster

Yemen has 46 airports, 17 of which have paved runways. Of the 46 airports, five are international: Aden International, Sana'a International, Taiz, Rayyan, and Al Hudaydah.[26]

There is no railway network in Yemen, though there have been a number of plans and proposals. The first of these appeared in the days of the Ottoman Empire, when it was suggested that the Hejaz railway might eventually be extended as far as Yemen, but this never materialised.

4.2.2 Climate and Rainfall

The Climate of Yemen is referred to as subtropical dry, hot desert climate with low annual rainfall, very high temperatures in summer and a big difference between maximum and minimum temperatures, especially in the inland areas.

Summer (June to September) is very low rainfall. Daily maximum temperatures can reach easily 40°C or more. Winter is cooler with occasional rainfall. Spring and autumn are warm, mostly dry and pleasant, with maximum temperatures between 25°C and 35°C and cooler night Temperatures between 15°C and 22°C.

A hot, dust-laden wind, the Shamal, blows in the spring and summer-period, from March till August. sometimes these winds can be very strong, and cause Sandstorms, that can occur throughout the year, although they are most common in the spring. Most rain falls during the winter months in sudden, short but heavy cloudbursts and thunderstorms.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature (°C)	12.6	14.1	16.3	16.6	18	19.3	20	19.6	17.8	15	12.9	12.4
Min. Temperature (°C)	3	3.6	7	8.5	10.4	10.5	13.4	13.3	10.6	7.9	5.5	4.4
Max. Temperature (°C)	22.3	24.7	25.6	24.8	25.7	28.2	26.6	25.9	25.1	22.2	20.3	20.5
Precipitation / Rainfall (mm)	3	4	6	5	1	1	4	4	7	1	2	5

Table 7: Temperature Variation in Sana'a [27]

The climate here is "desert." There is virtually no rainfall during the year in Sana'a. This climate is considered to be BWk according to the Köppen-Geiger climate classification[28]. The average temperature in Sana'a is 16.2°C. Precipitation here averages 265 mm.

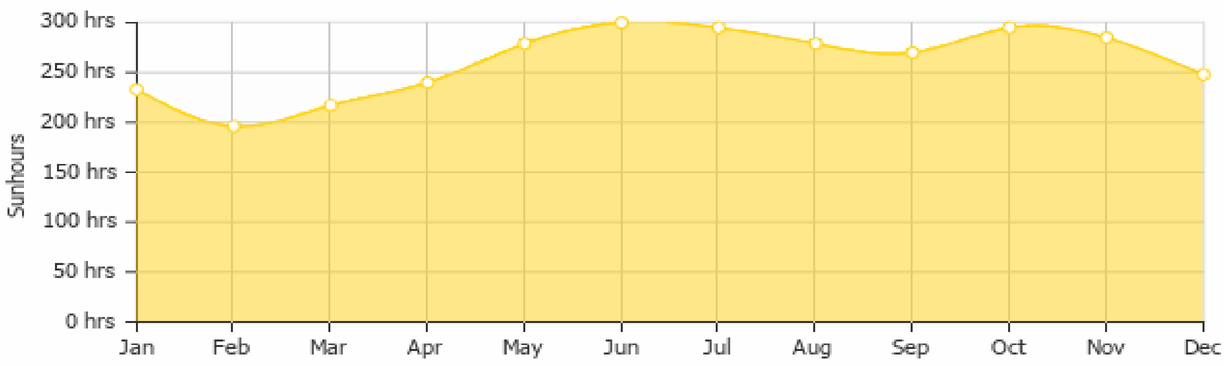


Figure 11: No. of sun hours in Aden region[29]

[26] CIA Factbook
[27] en.climate-data
[28] Cold desert climates (BWk) usually feature hot (or warm in a few instances), dry summers, though summers are not typically as hot as hot desert climates. Unlike hot desert climates, cold desert climates tend to feature cold, dry winters.
[29] Weather & Climate

The length of the day in Aden varies over the course of the year. The longest day of the year is 12:45 hours long and the shortest day is 11:14 hours long. The longest day is 1 hour 30 min longer than the shortest day. At midday the sun is on average 73° above the horizon at Aden.

Aden acquires an average of 39 mm (1.5 in) of rainfall per year, or 3.3 mm (0.1 in) per month. On average there are 8 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 0.7 days with a quantity of rain, sleet, snow etc. per month. The driest weather is in April & June when an average of 0 mm (0 in) of rainfall (precipitation) occurs. The wettest weather is in January & September when an average of 7 mm (0.3 in) of rainfall (precipitation) occurs[30].

4.2.3 Soil Pattern

Soils in Yemen are generally soiling of alluvial deposits produced by water and wind weathering. The country's soils are sandy to silty and loamy in coastal regions and silty to loamy and clay loamy in the highlands. The soils are generally low in nitrogen, phosphorus and organic material. In areas in the highlands soil are shallow with often calcareous layer which leads to poor moisture retention.

The highland regions are interspersed with wadis, or river valleys, that are dry in the winter months (Yemen has no permanent rivers) Most notable is the Wadi Hadhramaut in eastern Yemen, the upper portions of which contain alluvial soil and floodwaters and the lower portion of which is barren and largely uninhabited. Both the eastern plateau region and the desert in the north are hot and dry with little vegetation. The western highlands have peaks reaching around 3,000 metres (1.9 miles), with relatively fertile soil and sufficient and plentiful rainfall. The central highlands are more like a plateau of about 2,000–3,200 metres[31] (1.2–2.0 miles), with rolling hills, small knolls, and some very prominent peaks, but is still relatively more elevated. Less rainfall can be seen in this region, but the summer months give enough to sustain crops.

Types	In thousand hectares
Rainfed	
> 600 mm	190
450-600 mm	220
250-350 mm	62
< 450 mm	710
Irrigated	
Permanent	
Wells	146
Springs	25
semi-irrigated	
spate (floods)	116
Total	**1,469**

Table 8: Types of Rainfed and Irrigated Areas [32]

4.2.4 Groundwater Status

Yemen's groundwater is the main source of water in the country, but the water tables have dropped severely leaving the country without a viable source of water. For example, in Sana'a, the water table was 30 meters below surface in the 1970s but had dropped to 1200 meters below surface by 2012 [33]. The groundwater has not been regulated by Yemen's governments. Even before the revolution, Yemen's water situation had been described as increasingly dire by experts who worried that Yemen

[30] Clima Temps
[31] Nations Online
[32] FAO: Food and Agriculture Organization
[33] The Atlas of Water: Mapping the World's Most Critical Resource ; authored by Maggie Black

would be the "first country to run out of water". Agriculture in Yemen takes up about 90% of water in Yemen even though it only generates 6% of GDP.[34]

Figure 12: Irrigation map of Yemen [35]

4.2.5 Solar Irradiance

Yemen benefits from its strong potential for renewable energies which remains relatively untapped. Solar power represents a massive opportunity for development. Indeed, solar irradiation exceeds 2200 kWh/m^2/year (for Global Horizontal Irradiance) across most of the country. Thus, Yemen has real potential for development and scaling up of photovoltaic projects. The highest solar radiation is around 2556 kWh/m^2/year, whereas the coast line receives radiation around 2000 kWh/m^2/year. The highest global horizontal irradiance is in Sanna and Dhamar.

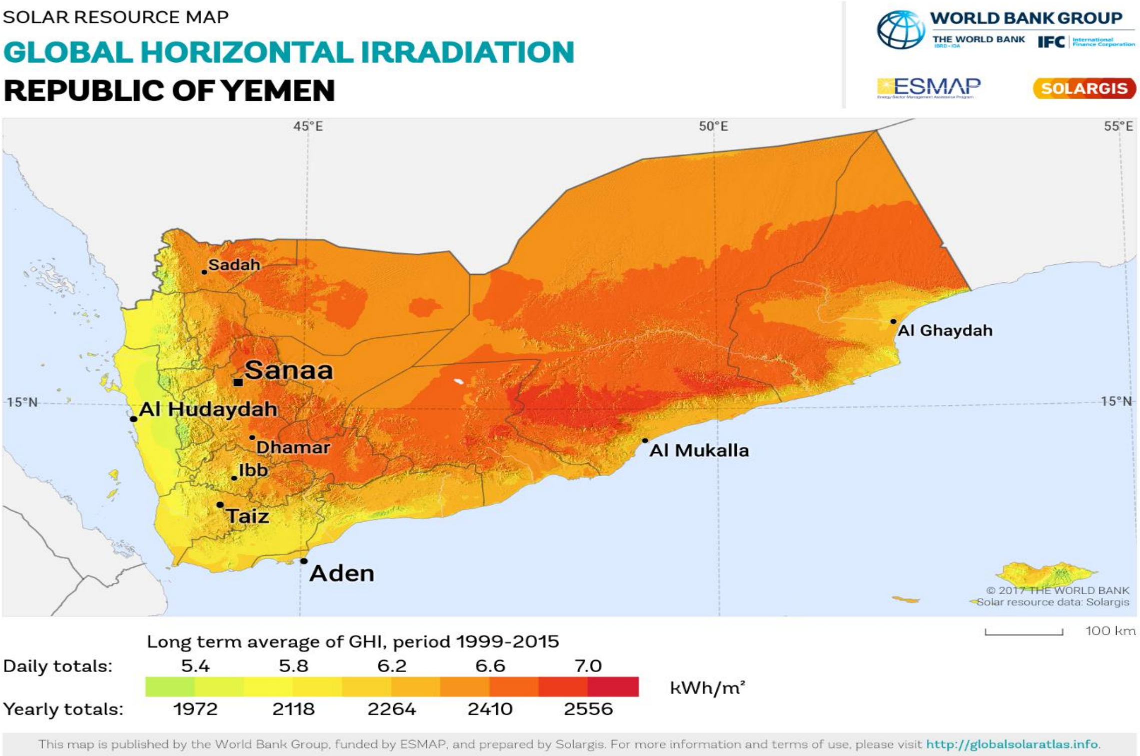


Figure 13: Global Horizontal Irradiation for Yemen[36]

[34] FAO
[35] FAO Aquastat
[36] Solar GIS

4.2.6 Agriculture and Cropping Pattern

Crop production system in Yemen is generally reflected by the availability of water supply as being the most important factor. The cultivated area may vary from year to year depending mainly on the amount and distribution of rainfall.

Crop production system can be divided into two as depending on water supply:

A. Rainfed farming system

This system can be classified into three categories:

1. The low rainfed system with rainfall average < 450 mm
2. The moderate rainfed with rainfall average between 450–620 mm; and
3. The high rainfed system with rainfall average > 600 mm

Major crops grown under rainfed farming are: sorghum, wheat, barley, millet and legumes. Barley is considered to be the base of dry land farming system in the highlands while millet is a marginal crop of low lands and sand dunes. Generally, rainfed farming system is considered as the base of agriculture where more than 77% of the total cultivated area is under this system.[37]

B. Irrigated farming system.

There are two types of irrigation under this system. These are flood irrigation which is basically used in coastal region and the deltas. Crops predominantly grown under this system are sorghum, millet, cotton, cucurbitas, legumes, sesame and groundnuts. The second system is wells and springs irrigation farming system. It forms the base of intensive agriculture mainly for cash crops such as qat, vegetables, fruits and forage crops. Under such system intercropping and crop rotations can be easily utilized

Due to a variety of natural conditions, the calendar of agricultural activities differs depending on location. In Central Highlands, with two distinct cropping seasons, harvesting of rainfed wheat, planted in July, will start in October. In Southern Uplands, with only one rainy season, the sorghum harvest just started in mid-September. In coastal areas, forage sorghum is also being harvested.

Persistent conflict continues to seriously compromise all economic activities, including agricultural livelihoods. The supply of urea, seeds and fuel is particularly scarce in Aden, Hodeidah and Al Baidha governorates, while high input prices are reported across the whole country. High fuel prices are constraining agricultural activities, particularly those related to irrigated crops, with consequent increases in the share of rainfed crops which, in turn, bear lower yields. Hired agricultural labour tends to be replaced by unskilled family labour to cope with the increased costs of production. By replacing hired labour by family labour, livelihoods of many landless rural households relying on casual labour opportunities as their main source of income are imperilled.

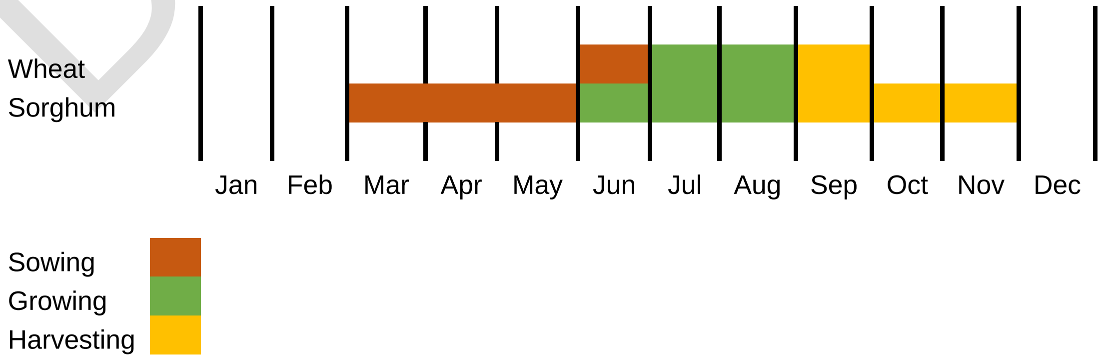


Figure 14: Cropping Calendar of Yemen [38]

[37] FAO: Food and Agriculture Organization
[38] FAO: Food and Agriculture Organization

Taking into account conflict-related constraints as well as outbreaks of pests, total cereal production in 2019 is forecast at 385,000 tonnes, about 12 percent below the previous year's harvest and over 30 percent below the five-year average.

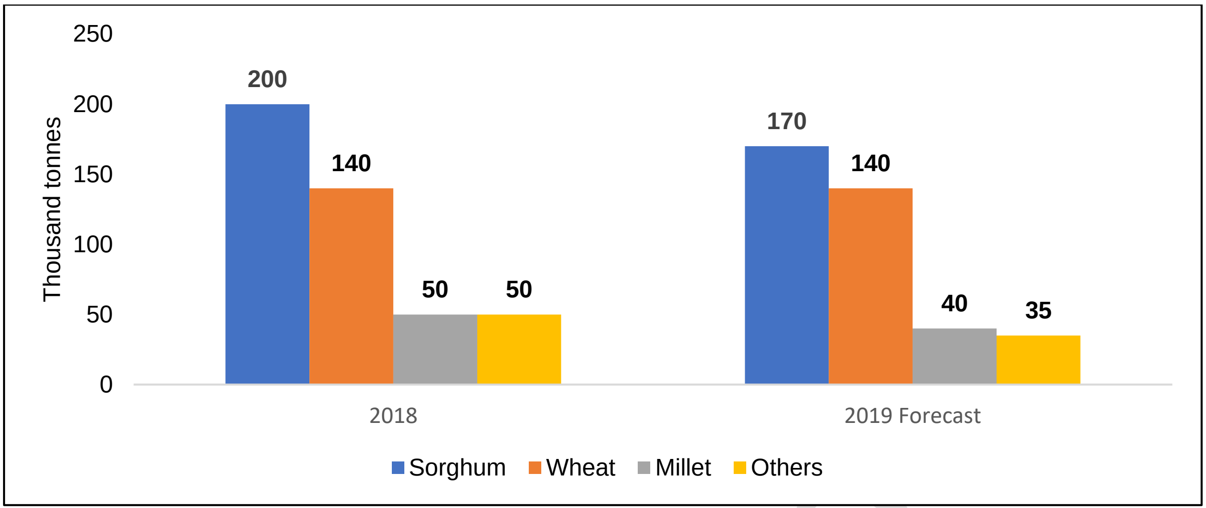


Figure 15: Cereal Production in Yemen [39]

On average, total domestic cereal production covers less than 20 percent of the total utilization (food, feed and other uses). The country is largely dependent on food assistance and commercial imports to satisfy its domestic consumption requirement for wheat, the main staple. The share of domestic wheat production in total food utilization in the last ten years is between 5 to 10 percent, depending on the domestic harvest.

The import requirement for cereals to guarantee an enough calorie intake in the 2019 marketing year (January/December) is estimated at an average level of 4.3 million tonnes, including 3.2 million tonnes of wheat, 700 000 tonnes of maize and 400 000 tonnes of rice.

It is estimated that, between January and July 2019, about 3.8 million tonnes of food (out of which 60 percent was wheat grain and flour) entered the country through maritime seaports (Aden, Al Hodeidah, Al Salif and Al Mukalla) and land ports (Shahin and Wadiea'ah). About 95 percent of goods were imported via Aden, Al Hodeidah and Al Salif seaports. The total amount is 7 percent higher than in the corresponding period in 2018.[40]

[39] FAO: Food and Agriculture Organization
[40] FAO: Food and Agriculture Organization

5. Financial Feasibility Analysis

5.1 Indicative Inputs

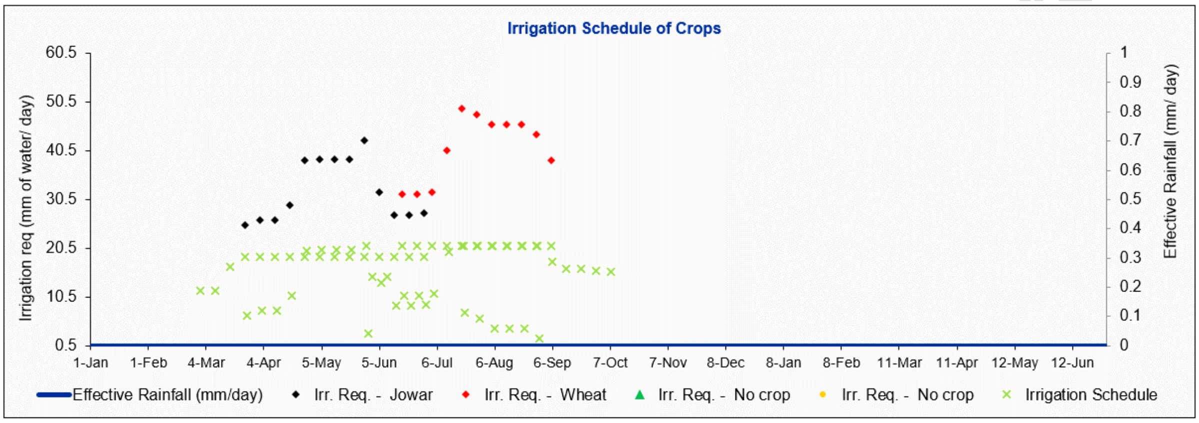
S.No.	Particulars	Unit	Value		Source
1	Crop to be Irrigated		Sorghum, Wheat		
2	Land Size	Hectares	0.5 (for each crop)		
3	Planting date		As per cropping calendar of Yemen		
4	Irrigation type		Flood: Lined canal supplied		
5	Annual average yield of crop	Kg/hectare	Sorghum	661	FAOSTAT
			Wheat	1125	
6	Market Price	USD/quintal	Sorghum	193	FAO: Food Price Monitoring and Analysis
			Wheat	97	
7	Selected Size of Solar Pump	HP	5		
8	Total dynamic head inclusive of friction losses	Meters	120		
9	Cost of Solar Pump	USD	4,967 [41]		Average of L1 prices discovered in ISA tender for Various categories of pumpsets
10	Subsidy	%	0 %		
11	Margin Money	%	10 %		
12	Loan Amount	%	90 %		
13	Interest Rate	%	27 %		Central Bank of Yemen
14	Loan Tenure	Years	7		
15	Cost of diesel pump per HP	USD	56		
16	Cost of diesel	USD/litre	1.75		Published reports and articles
17	Hike in diesel prices (y-o-y)	%	3%		Based on global averages
18	Inflation rate	%	14 %		World Data Info
19	Living expense of the farmer (as a % of crop revenue)	%	60 %		Based on global estimates, KPMG Analysis
20	Maintenance costs for diesel pump (as a % of capital costs)	%	10 %		Based on global estimates, KPMG Analysis[42]

[41] Cost of Solar pumpset includes on-site Comprehensive Maintenance Contract (CMC) for 5 years but exclusive of custom import clearance, duties and local taxes as per ISA International Competitive Bid
[42] The toolkit developed by KPMG for Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH was used to undertake the analysis.

5.2 Indicative Crop Water Requirement [43]

Total crop water requirement (m³)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-	-	404	710	977	1,310	1,201	1,155	625	217	-	-
Annual crop water requirement (m³)				6,599							

5.3 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

5.4 Indicative Outputs

S.No.	Particulars	Unit	Value
1	Amount of subsidy	USD	0
2	Amount of loan to be availed	USD	4470
3	Yearly installment towards loan repayment	USD	1486
4	Monthly installment towards loan repayment	USD	124
5	Savings in monthly diesel expenses on an average basis for 20 years	USD	346
6	Number of hours of solar pump operation required	Hours	901
7	Number of days of solar pump operation required	Days	129
8	Incremental payback of solar pump w.r.t. diesel pump	years	3

Yemen has submitted demand for 1500 Nos. solar water pumping systems. At an average price of USD 4,967 per 5 HP pumpset, Yemen requires financing of USD 7.5 million to roll out deployment of 1500 Nos. solar water pumping systems across the country.

[43] 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 conducted after more data has been obtained from the respective nations.

6. Recommendations

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

1. **Number and type of pumps**: Yemen has submitted demand for procurement of 1500 solar water pumps. Considering the low levels of electricity access and frequent brownouts/ blackouts especially in rural areas, off-grid pumps are required to be installed.
2. **Capacity of Pumps**: There is almost nil rainfall in Aden and ground water table depth is also below 100 meters. Hence the pumps should be adequately sized so as to meet the crop water requirements of the area, since a smaller sized pump may not be able to give sufficient discharge for the crops.
3. **Location of pumps:** In the initial phase, it is advisable to select few concentrated areas and install the solar water pumps in order to have a good demonstration effect. For example, solar pumps may be installed at wells where farmer user groups have been formed and are already paying for water irrigation facilities provided by Government of Yemen. If the solar water pumps are scattered across different areas, it will lead to high transportation and maintenance costs. Also, the installation of solar water pumps in a concentrated area will help in better visibility and strong impact of the programme**.**
4. **Financing:** There are limited sources available for the government of Yemen 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 maybe paid by the farmers upfront while the remaining may be done on periodic basis in the form of loan repayments.
5. **Financing structures:** Considering external financing would be required as mentioned in point 3. above, mobilization of financing should be done by the authorities and suitable financing structures should be developed to enable the deployment of pumps.
6. **Knowledge development:** Number of motorized agricultural pumps deployed in Yemen are very limited and farmers have relied on wells, surface water or hand pumps for irrigation. Therefore, 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 solar enabled pumps. Initially these activities may be undertaken by i-STARCs to be developed in Yemen under the ISA's programme.
7. **Ecosystem availability:** Though Ministry of Water and Environment has already implemented solar water pumping systems for drinking water, the solar ecosystem is not well developed in the country. Therefore, availability of local manpower for solar and pumps may be a challenge during the initial phase of implementation. However initial training on the operations and maintenance aspects of the solar pumps will mitigate the challenge to an extent.
8. **Community Based Service Delivery Models:** Since the country is facing water crisis, a community-based model is advisable for sharing of solar pump between group of farmers. One of the preconditions for formation of the group is that the farmers sharing the solar pump either need to have their land adjacent to the water pump or within the catchment area which the pump can cater to. Apart from an operator, a group leader elected by the group members for collection of service charges is usually appointed. The service charge to be collected is also decided by the irrigation group and the collected money can be partly used for bearing the operation and maintenance expenses including the salary of the operator.

7. Proposed next steps

1. **Pre-feasibility report**: The pre-feasibility report may be shared with Multilateral Development Banks (MDBs) such as World Bank, EXIM Bank for financing solar water pumping systems in Yemen. 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, applicable taxes, duties, government incentives etc.) are required from the relevant Ministry.

2. **Capacity building**: Post bid process and financing arrangement, Identification of foundations/ institutions in Yemen to assist in the capacity building of farmers and knowledge development of local technicians may be initiated by pump suppliers and through i-STARCs.

3. **Implementation scale**: Considering solar pumps have not been deployed at a major scale in Yemen, implementation may be planned in phased manner for better visibility and strong impact of the programme which may further be scaled to the country level. The roadmap for the same may be prepared by Government of Yemen in consultation with ISA.

4. **Field preparation**: Boring activities may also be suitably initiated by farmers in the area where the solar pumps are planned to be initially implemented.

5. **Supply and project monitoring**: Regular project monitoring for supply and installation of pumps may be undertaken by ISA and NFP Yemen basis field reports and feedback from farmers, suppliers / installers and government agencies.