Draft Pre-Feasibility Report for Implementation of Solar pumps in Tonga

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List of Abbreviations

AC	Alternating Current
ADB	Asian Development Bank
AfDB	African Development Bank
AIIB	Asian Infrastructure Investment Bank
CIE	Department of Commerce, Industry and Environment
CSCRE	Cabinet Sub Committee on Renewable Energy
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
GoT	Government of Tonga
GHG	Green House Gas
HP	Horsepower
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
kW	Kilowatt
kWh	Kilowatt Hours
LNG	Liquefied Natural Gas
LoC	Line of Credit
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications
MW	Megawatt
NDB	New Development Bank
NFP	National Focal Points
TPL	Tonga Power Limited
PV	Photovoltaic
R&D	Research and Development
REA	Electricity Regulatory Authority
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
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
UL	Underwriters Laboratories

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1. Executive Summary

The Kingdom of Tonga is a Polynesian country that lies to the south of Samoa, southeast of Fiji and north east of New Zealand. The Tongan archipelago is comprised of 176 islands with a total area of 748 km^2 and an Exclusive Economic Zone (EEZ) of about 700,000 km^2. The total land area is dispersed between latitudes 15° and 23°S and longitudes 173° and 177°W. The capital, Nuku'alofa, is located on the largest Island, Tongatapu. There are four groups of islands (Tongatapu, Ha'apai, Vava'u and Niuas) comprising 36 inhabited islands.

Tonga Electricity Sector

There are four grid systems owned and operated by Tonga Power Limited (TPL), the major electric utility of Tonga, which generates, distributes, and does retail supply of electricity to three of the four major island groups of Tongatapu, Vava'u, and Ha'apai. The fourth grid is on 'Eua, an island close to Tongatapu. The ownership of electricity assets has changed twice in recent years, first in 1998 when the national utility was bought by Shoreline Power and more recently in mid-2008 when the Government of Tonga bought the assets from Shoreline to create TPL as a state-owned enterprise.

The 2018 cumulative installed capacity of the four island grid systems is 24 MW. Tongatapu's system represents most of the installed capacity, predominantly supplied by diesel fuel. The 2018 cumulative installed capacity of the four island grid systems is 24 MW. Installed solar capacity in Tonga is 6.23 MW in 2018.

Connectivity and Accessibility

Tonga has an extensive network of 680 km of highways and one of the highest levels of road network density in the region. There are six airports in Tonga, one airport on each of the main islands. Of these, one has paved runways, the Fua'amotu International Airport on Tongatapu. There are three main ports in Tonga: Neiafu, Nuku'alofa and Pangai. Nuku'alofa is the central hub for transport in Tonga and international import and export cargo shipping.

Climate and Rainfall

The climate of Tonga is humid maritime subtropical with distinct seasonal temperature variations. The temperatures are highest in February and reach their minima in July and August. The relative humidity varies between 65% and 95% in a day but remains rather constant on a monthly basis at 70-80%.

Soil

The soils of Tonga are derived from a mixture of volcanic ash and coral. Tongatapu island soil is a coral base covered with around 3 m of volcanic ash. Outer islands area of Tongatapu is also coral base but covered with volcanic ash and coral sand. The main islands of the Vava'u group originated from raised coral. The soils of the group are volcanic ash, up to 9 m thick, overlaying the coral limestone. And shore area and Outer Islands area beach areas are covered with coral based soils.

Agriculture

The national gross domestic product (GDP) was $450.35 million in 2018. The per capita GDP in 2018 was 9,574. The agricultural sector contributed nearly 14% of the GDP in 2016 employed 34% of the labor force represented over 65% of total exports.

Agriculture is the main economic activity after services. Most are smallholder farmers practicing a mix of subsistence and cash crop production, they typically grow root crops, which provide food security, employment and income. The main products exported are kava, squash, pumpkins, root crops, coconuts, and fish.

Traditional cash crops include root crops as taro, yams, cassava and sweet potatoes, but also kava, breadfruit, papaya, banana, watermelon and pineapple used in an intercropping system. In more recent years the focus

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has shifted to export crops including pumpkin squash and vanilla. The former needs irrigation in dry months. The main practice is still subsistence agriculture, but there are several farmers looking to expand agriculture to a more commercial basis, which involves implementation of larger centralized irrigation schemes and higher groundwater abstractions during periods of drought.

Financial Feasibility Assessment

Tonga has submitted demand for 258 Nos. solar water pumping systems based on L1 prices discovered in International Competitive Bid (ICB) by ISA for various categories of SWPS, the cost of supply, installation, commissioning and 5 years CMC for 258 SWPS including of Cost of Drilling Borewell is USD 2.48 million. Considering 3% of capital cost as Project Management Consultancy cost for EESL to assist Tonga in implementation of SWPS project, the total capital cost is USD 2.56 Million.

Tonga has submitted demand for 258 Nos. solar water pumping systems. Based on cropping pattern, water table depth, rainfall and soil conditions, the annual usage of diesel pumpsets is 919 hours for a 3 HP pumpset. Assuming similar usage for other pumpset capacities, the total avoided annual diesel consumption for 258 pumpsets is 315,237 Liters and accordingly the avoided annual CO_2 emissions is 845 Tons.

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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.

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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
6. Programme for Solar Park

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

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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 demand aggregation of Solar Water Pumps from ISA Member Countries given in the table below:

Sl. No.	Name of the Country	Demand of SWP (Nos)
1	Benin	50,000
2	Cabo Verde	100
3	Democratic Republic of Congo	80,000
4	Djibouti	100
5	Fiji	27
6	Guyana	111
7	Mali	15,000
8	Mauritius	27
9	Nauru	400
10	Niger	15,000
11	Peru	1,750
12	Senegal	4,000
13	Somalia	500
14	South Sudan	6,800
15	Sri Lanka	2,000
16	Sudan	50,000
17	Togo	5,000
18	**Tonga**	**258**
19	Tuvalu	10,000
20	Uganda	30,000
21	Yemen	1,500
22	Zambia	6
	Total	**2,72,579**

Table 2: Demand received from various ISA member countries for solar pumps

Subsequent to the demand aggregation exercise, International 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:

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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
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 3: 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 including Comprehensive Maintenance Contract (CMC) for 5 years

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:

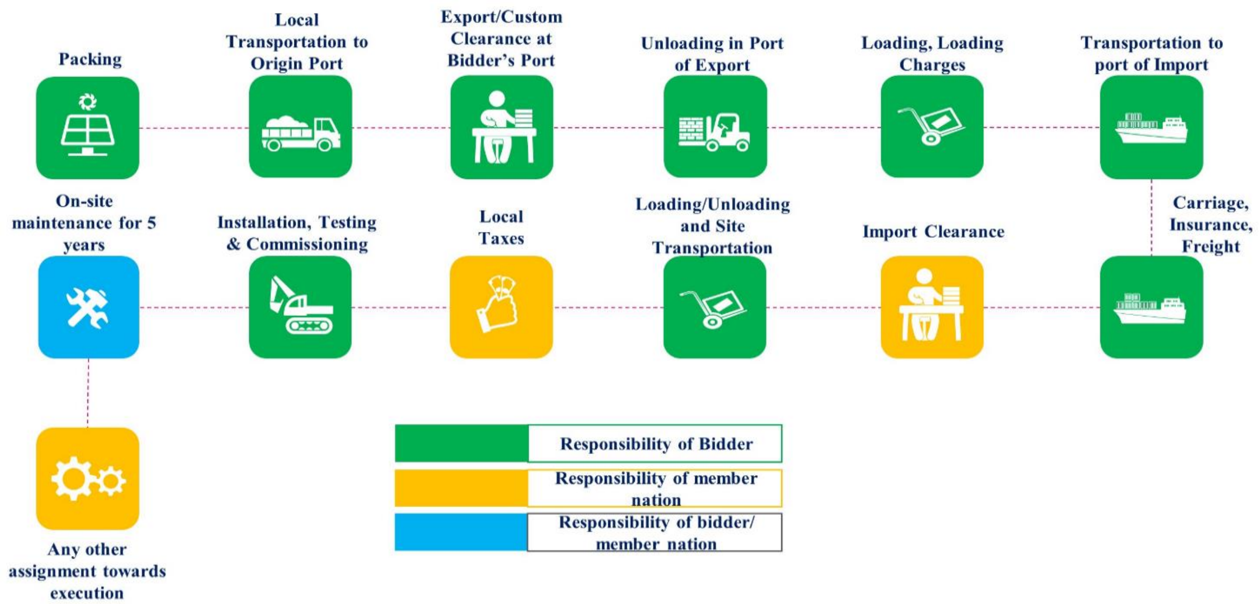

Figure 1: Work Packages and Responsibility Division

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.

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3. Introduction

3.1 About Tonga

The Kingdom of Tonga is a Polynesian country that lies to the south of Samoa, southeast of Fiji and north east of New Zealand. The Tongan archipelago is comprised of 176 islands with a total area of 748 sq. km and an Exclusive Economic Zone (EEZ) of about 700,000 km². The total land area is dispersed between latitudes 15° and 23°S and longitudes 173° and 177°W. The capital, Nuku'alofa, is located on the largest Island, Tongatapu. There are four groups of islands (Tongatapu, Ha'apai, Vava'u and Niuas) comprising 36 inhabited islands. Most islands have a limestone base created from an uplifted coral formation. Some islands have limestone overlying a volcanic base and a few are purely volcanic in origin. The climate is tropical with warm-humid weather during December to May and cooler weather for the remaining months. Winds are seasonal with tropical cyclones most likely between November and March[1].

In 2018, the total population of Tonga is 1,03,197.[2] Tongatapu is the most populous Island with 72,045 inhabitants, which represents 71% of the total Tongan population.[3] About 88% of Tonga's population lives in rural areas, most of the Tonga population depend on agriculture and fisheries.

Tonga is a constitutional monarchy, making it unique in the Pacific. The governing structure comprises the Executive (Cabinet), Legislature and Judiciary, with the Cabinet answering to the Legislative Assembly. The Legislative Assembly comprises 17 People's Representatives, nine Noble Representatives elected from among the holders of Tonga's 33 noble titles, and up to four additional members appointed by the King on the advice of the Prime Minister. The King retains the right to veto legislation. The King appoints the Prime Minister on the recommendation of the Legislative Assembly.

The major macroeconomic parameters of Tonga are as following:

Parameter	Units	Value	Year
Population	Nos.	1,03,197	2018
Country GDP	USD Billion	0.45	2018
GDP growth rate	%	0.3%	2018
Foreign Direct Investment (Net Inflows)	USD Million	15.05	2018
World Bank Political Stability Index	Nos.	0.88	2018
Employment rate	%	98.98%	2019
Retail inflation rate	%	7.44%	2017
Per capita GDP	USD	9,574	2018
Corporate Tax rate	%	27.5%[4]	2017

Table 4: Key Economic Parameters of Tonga[5]

[1] Tonga Energy Road Map 2010 – 2020
[2] World Bank – World Development Indicators
[3] Tonga Energy Road Map 2010 – 2020
[4] multpl.com
[5] World Bank – World Development Indicators

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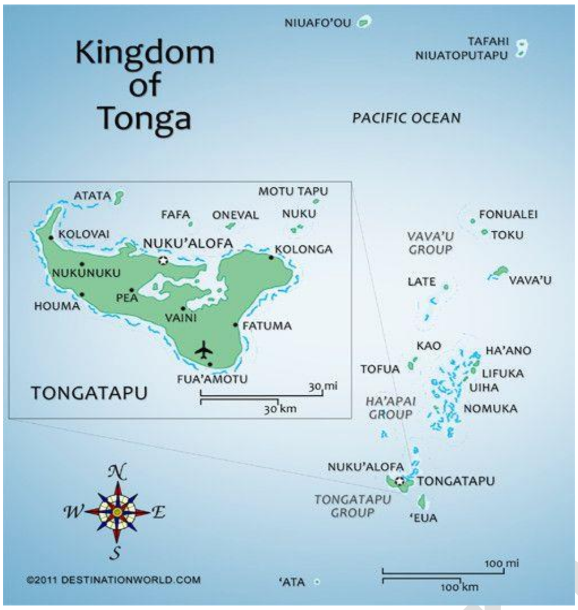

Figure 2: Map of Tonga[6]

3.2 Overview of Energy Scenario

The first Tongan-owned electrification system began operation in Nuku'alofa in 1950. The Nuku'alofa Electric Power Board provided electricity primarily for the port, commodities board, churches and government offices. As the Tongan economy grew during the copra and banana boom so did electricity demand and supply. The Nuku'alofa Electric Power Board became the Tonga Electric Power Board (TEPB) in the 1970's. The islands of Vava'u, Ha'apai and Eua obtained a regular electricity service in 1982, as development began after Cyclone Isaac. In 1995 the TEPB achieved an important milestone when supply, for the first time, reached all communities on Tongatapu.

There are four grid systems owned and operated by Tonga Power Limited (TPL), the major electric utility of Tonga, which generates, distributes, and does retail supply of electricity to three of the four major island groups of Tongatapu, Vava'u, and Ha'apai. The fourth grid is on 'Eua, an island close to Tongatapu. The ownership of electricity assets has changed twice in recent years, first in 1998 when the national utility was bought by Shoreline Power and more recently in mid-2008 when the Government of Tonga (GoT) bought the assets from Shoreline to create TPL as a state-owned enterprise.

The 2018 cumulative installed capacity of the four island grid systems is 24 MW. The installed capacity and energy mix of various power sources is highlighted below:

Values in MW

Installed capacity	2016	2017	2018
Total installed capacity	**21.14**	**24.13**	**24.15**
Total Non-Renewable	**17.70**	**17.70**	**17.70**
Fossil fuels	17.70	17.70	17.70
Total Renewable	**3.44**	**6.43**	**6.45**
Solar energy	**3.22**	**6.21**	**6.23**
On-grid Solar photovoltaic	2.97	5.96	5.98
Off-grid Solar photovoltaic	0.25	0.25	0.25
Wind energy	**0.22**	**0.22**	**0.22**
Onshore wind energy	0.22	0.22	0.22

[6] Destination World

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Values in GWh

Energy Mix	2015	2016	2017
Total generation	58.03	63.59	66.44
Total Non-Renewable	**53.45**	**58.26**	**60.28**
Fossil fuels	53.45	58.26	60.28
Total Renewable	**4.58**	**5.33**	**6.16**
Solar energy	**4.56**	**5.30**	**6.14**
On-grid Solar photovoltaic	4.23	4.96	5.80
Off-grid Solar photovoltaic	0.33	0.34	0.34
Wind energy	**0.02**	**0.03**	**0.02**
Onshore wind energy	0.02	0.03	0.02

Table 5: Installed Capacity and Energy Mix of Tonga[7]

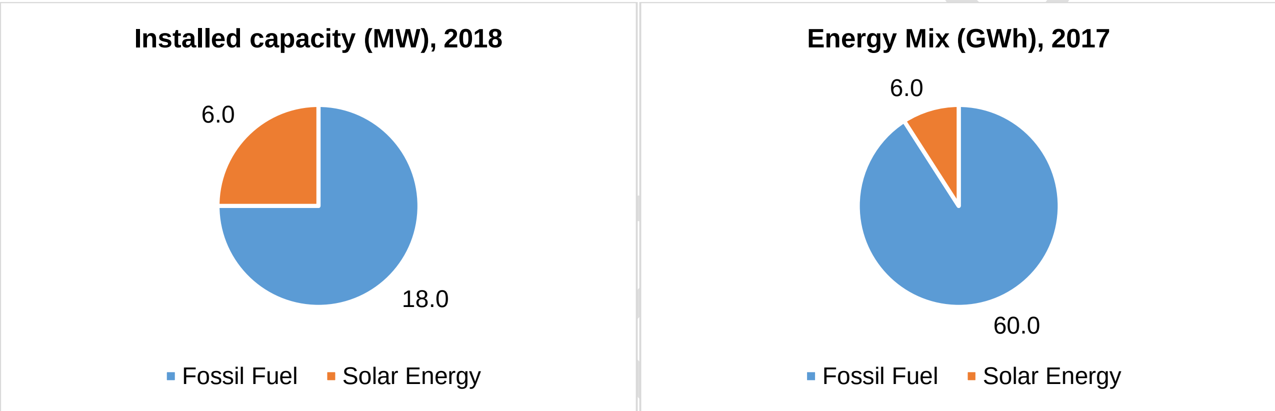

Figure 3: Installed capacity and Power Generation of Tonga[8]

Access to electricity	2013	2014	2015	2016	2017
National	94.48	95.34	96.21	97.02	97.97
Rural	93.41	94.48	95.57	96.53	97.68
Urban	98.00	98.15	98.30	98.63	98.92

Table 6: Access to Electricity of Tonga[9]

50% Renewable Energy Policy: The Tongan Government, in 2009, responded to the twin challenges of global Green House Gas (GHG) emissions reduction and its own energy security by approving a policy to supply 50% of electricity generation through renewable resources by 2012. While the target was ambitious, it represented a clear direction and indication from the Government that reducing the vulnerability of the country to future oil price shocks is a key objective, and that Government had identified a move to renewable energy as a major element of a strategy to provide enhanced energy security for the Kingdom and greater tariff stability.

Financial and Environmental Sustainability in the Energy Sector: The Government of Tonga recognizes that the full benefits of investing in renewable energy can only be realized when it is a part of an overall plan for the energy sector. Such a plan will incorporate improvements in efficiency, reducing environmental impacts

[7] Electricity Sector Development Strategy Note, World Bank
1seniti = 0.00434 USD
[8] IRENA Stat Tool
[9] World Bank – World Development Indicators
1seniti = 0.00434 USD

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both locally and globally with respect to GHG emissions and enhancing energy security while ensuring the sector remains financially viable in the long term.

Shortly after Cabinet approved the 50% target the Prime Minister established a Cabinet Sub Committee on Renewable Energy (CSCRE), which was chaired by himself. The CSCRE was tasked with evaluating renewable options and to pursue possible funding sources with the country's development partners. The membership of the Committee comprised the Prime Minister (Chairman), Minister of Lands (responsible Minister for Energy), and the CEOs of the Ministries of Finance, Lands, and Environment, together with the Chairman of the Electricity Commission, the Prime Minister's Economic Advisor and the Renewable Energy Coordinator.

The tariff rates approved by the Electricity Commission for all 4 Islands viz. Tongatapu, Vava'u, Ha'apai and 'Eua are as following:

New Electricity Tariff (seniti/kWh)	Government Subsidy (seniti/kWh)	Net Price for the first 100 kWh consumed by all Residential Customers per month (seniti/kWh)
85.14	15.14	70.00

Table 7: Electricity Tariff of Tonga as on 2018[10]

[10] Electricity Sector Development Strategy Note, World Bank
1seniti = 0.00434 USD

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4. Technical Feasibility Assessment

4.1 Solar pump Technology Overview

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

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

There are currently three pumping configurations commonly utilized in Africa:

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

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

Term	Description
Array Voltage	Some of the pumping systems have high array voltages. This has the advantage that the array may be further from the borehole without significant voltage drop (dependent on cable size and current). Array positioning may be important where there is potential for theft.
AC Motors	The motor operates on alternating current; the direct current produced by solar panels gets converted to AC using the inverter. The conversion from DC to AC leads to loss of power from generation to consumption.AC motors gain importance in applications where higher output/head combinations are required.
DC Motors	DC motors reach efficiencies of up to 80% and are therefore significantly more efficient than sub-kW three phase motors which have efficiencies in the region of 60% to65%.
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).

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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.
Surface pump	Surface pumps are installed at ground level to lift water from shallow water sources such as shallow wells, ponds, streams or storage tanks. Surface pumps can also be used to provide pressurized water for irrigation or home water systems. These pumps are suitable for lifting and pumping water from a maximum depth of 20 meters.
Submersible pump	Submersible pumps installed where there is a requirement for the submerged in the fluid to be pumped These pumps can be used in areas where water is available at a greater depth and where open wells are not available. Typically, the maximum recommended depth these systems can pumps is 50 meters.

Table 8: Key technology terms in a solar powered irrigation system

4.2 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.

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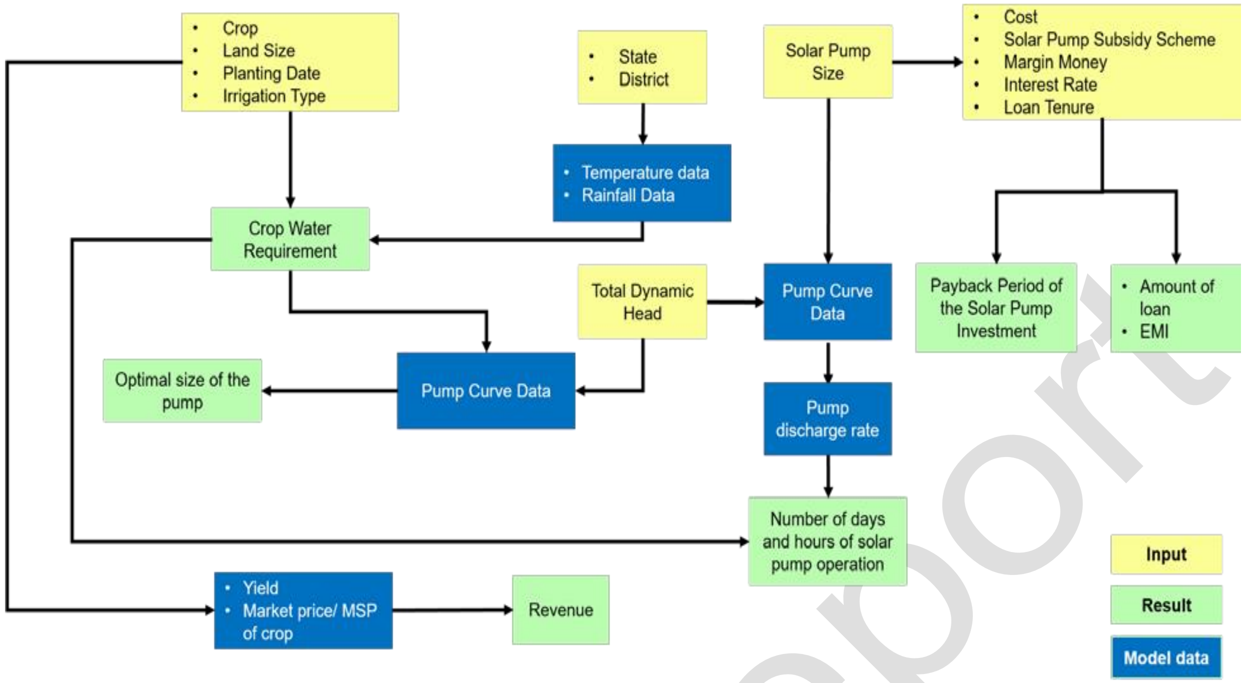

Figure 4: Factors involved in feasibility analysis of solar pump

4.2.1 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.

4.2.2 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[11]. 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[12]:

[11] System Curve and Pump Performance Curve - The Engineering Toolbox
[12] Shakti Pumps (DC pump: 5 DCSSP 2700/3600/4600; AC pump: SSP 5000-100-11)

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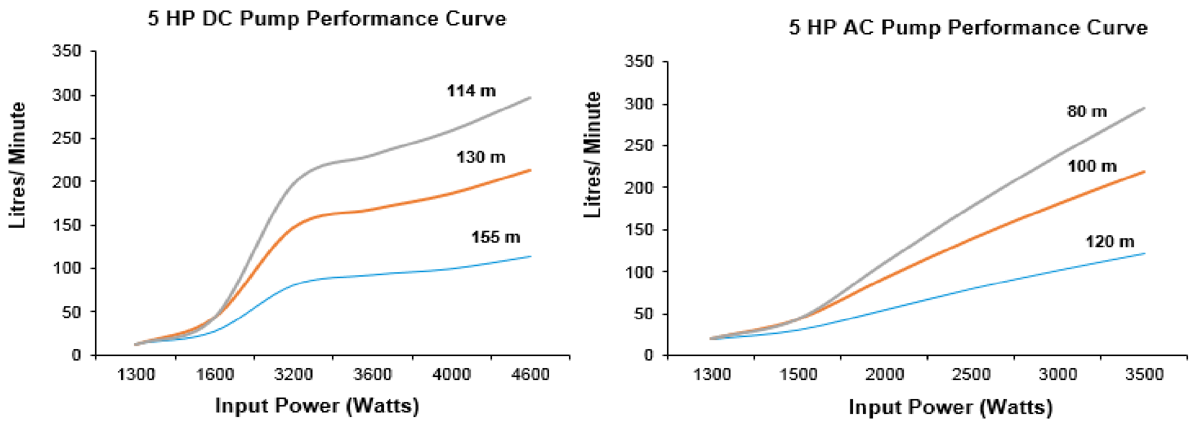

Figure 5: Pump Performance Curves

4.2.3 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)[13]

Table 9: 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[14].

4.2.4 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,

[13] Principles of Irrigation Water Heeds - FAO
[14] Principles of Irrigation Water Heeds - FAO

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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[15].

4.3 Country Assessment

4.3.1 Connectivity and Accessibility

Tonga has an extensive network of 680 km of highways and one of the highest levels of road network density in the region. This network provides good access links to communities in terms of connectivity, but in some areas the condition has deteriorated significantly due to insufficient emphasis on maintenance.

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

	Nuku'alofa	Nukunuku	Ha.atufu	'Utulau	Fua'amotu	Niutoua	Malapo
Nuku'alofa		10	20	19	21	30	15
Nukunuku	10		10	9	25	34	19
Ha.atufu	20	10		17	34	43	28
'Utulau	19	9	17		20	29	14
Fua'amotu	21	25	34	20		19	7
Niutoua	30	34	43	29	19		15
Malapo	15	19	28	14	7	15	

Table 10: Distances from Capital City to Major Towns (km)[16]

There are six airports in Tonga, one airport on each of the main islands. Of these, one has paved runways, the Fua'amotu International Airport on Tongatapu. Of the remaining airports, one has runways exceeding length 1,524m, two have runways longer than 914m, with the remaining two having runways shorter than 914m. Tonga is serviced internationally by Fiji Airlines, Air New Zealand, Virgin Australia, and internally by Real Tonga Airlines.

There are three main ports in Tonga: Neiafu, Nuku'alofa and Pangai. Nuku'alofa is the central hub for transport in Tonga and international import and export cargo shipping. It is also the entry point for international cruise ships. Nuku'alofa Port complies with relevant international and IMO operating requirements.

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[15] Basic Guidelines of SWPS – Sun Connect News
[16] Tonga – Logistics Cluster https://dlca.logcluster.org/display/public/DLCA/2.3+Tonga+Road+Network

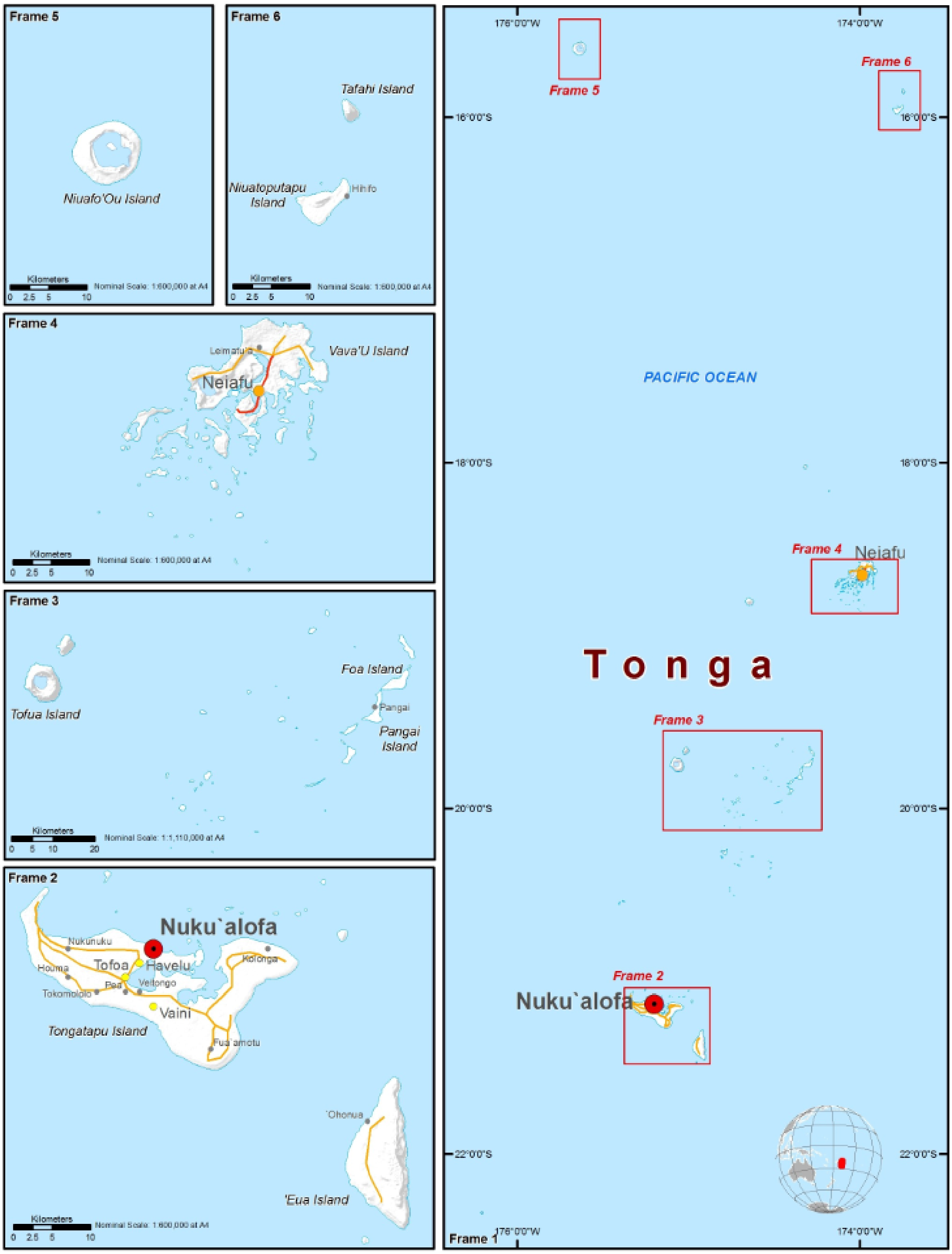

Figure 6: Road Network of Tonga[17]

4.3.2 Climate and Rainfall

The climate of Tonga is humid maritime subtropical with distinct seasonal temperature variations. The temperatures are highest in February and reach their minima in July and August. The relative humidity varies between 65% and 95% on a daily basis but remains rather constant on a monthly basis at 70-80%[18].

[17] Wiki Voyage

[18] DRR-Team Mission Report: Groundwater availability in relation to water demands in Tongatapu; Maarten J. Waterloo / Sjef IJzermans

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature (°C)	25.9	26.3	25.8	25	23.1	22.4	21.2	21.4	22.1	22.7	23.7	24.8
Min. Temperature (°C)	22.5	22.9	22.6	21.8	20.2	19.8	18.6	18.7	19.1	19.6	20.5	21.5
Max. Temperature (°C)	29.3	29.7	29.1	28.2	26.1	25.1	23.9	24.2	25.1	25.9	27	28.2
Precipitation / Rainfall (mm)	190	225	217	157	107	91	90	112	120	122	104	155

Table 11: Temperature Variation in Nuku'alofa, Tonga[19]

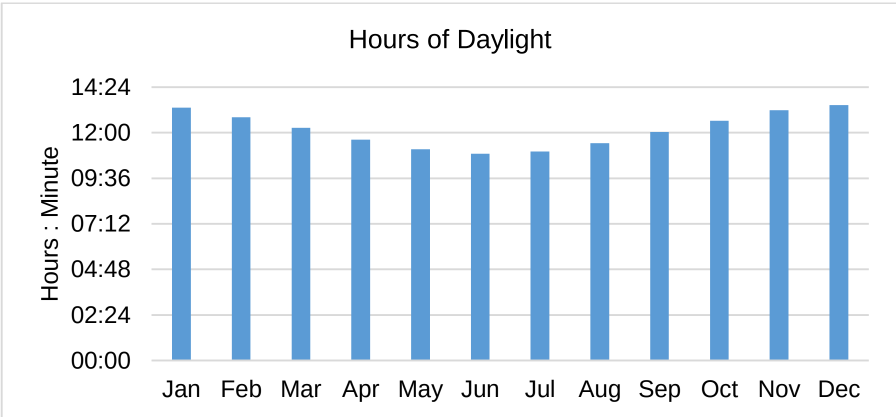

Figure 7: Daylight hours in Nuku'alofa, Tonga[20]

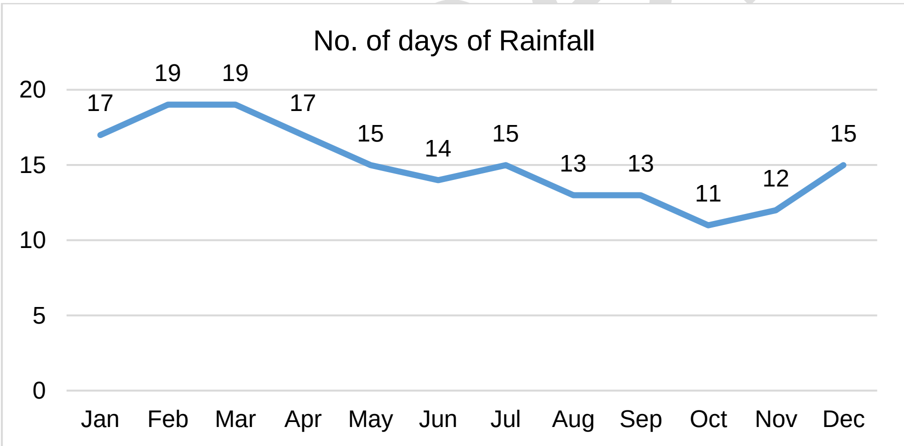

Figure 8: No. of days of Rainfall over the year in Nuku'alofa, Tonga[21]

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4.3.3 Geology and soils

The soils of Tonga are derived from a mixture of volcanic ash and coral. Tongatapu island soil is a coral base covered with around 3 m of volcanic ash. Outer islands area of Tongatapu is also coral base but covered with volcanic ash and coral sand. The main islands of the Vava'u group originated from raised coral. The soils of the group are volcanic ash, up to 9 m thick, overlaying the coral limestone. And shore area and Outer Islands area beach areas are covered with coral based soils.

4.3.4 Groundwater Status

Groundwater is pumped up from the freshwater lens that floats on top of the higher density saline water. When water is pumped from a well, a radial pattern of flow towards the well screen is generated in the aquifer with flow velocities depending on the rate of pumping. The lower pressure caused by pumping in the well also draws

[19] Tonga: Climate Data
[20] World Data - Tonga
[21] Nuku'alofa, Tonga - Weather Atlas

water up from the area below the well, and upconing of saline water may then occur causing salinization of the well. The risk of upconing is related to the thickness of the freshwater lens, aquifer properties (permeability, layering) and the rate of abstraction.

The Tonga Water Board has been very successful in avoiding saltwater upconing even during droughts by using a large number of boreholes from which water is extracted continuously at low rates (3-5 liters^{-1}) from the top of the phreatic aquifer to be stored in several reservoirs for distribution.

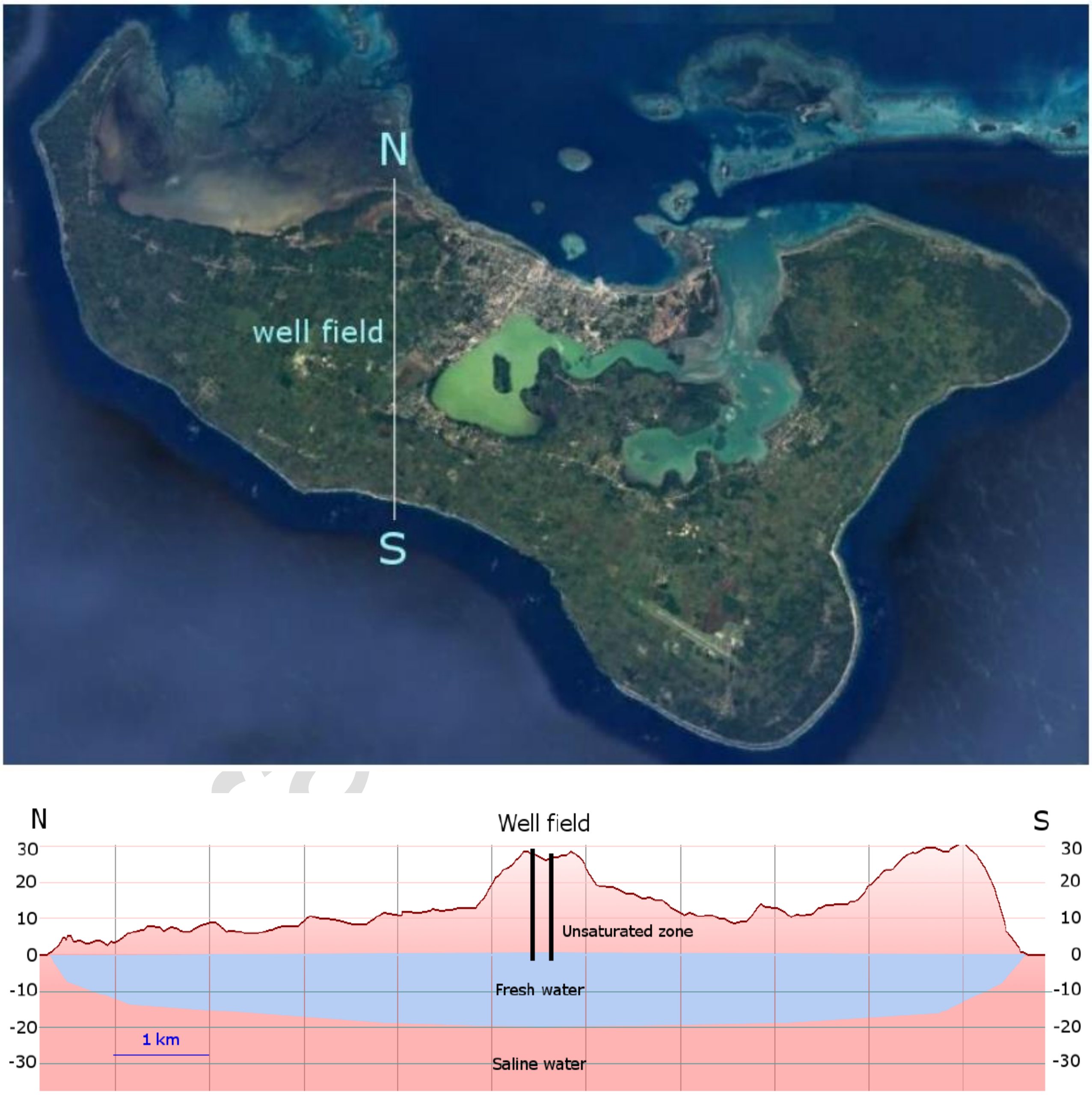

Figure 9: Location of a North South elevation profile and schematic diagram of freshwater lens

4.3.5 Agriculture

The national gross domestic product (GDP) was $450.35 million in 2018. The per capita GDP in 2018 was 9,574[22]. The agricultural sector contributed nearly 14% of the GDP in 2016 employed 34% of the labor force represented over 65% of total exports[23].

Agriculture is the main economic activity after services. Most are smallholder farmers practicing a mix of subsistence and cash crop production, they typically grow root crops, which provide food security, employment and income. The main products exported are kava, squash, pumpkins, root crops, coconuts, and fish[24].

Traditional cash crops include root crops as taro, yams, cassava and sweet potatoes, but also kava, breadfruit, papaya, banana, watermelon and pineapple used in an intercropping system. In more recent years the focus has shifted to export crops including pumpkin squash and vanilla. The former needs irrigation in dry months. The main practice is still subsistence agriculture, but there are several farmers looking to expand agriculture to a more commercial basis, which involves implementation of larger centralized irrigation schemes and higher groundwater abstractions during periods of drought.

4.3.6 Solar Irradiance

Tonga has abundant solar resource potential and it is the most commonly used technology implemented to date. Average insolation of 4.87/kWh/m²/day[25] but the deployment of storage plays a crucial role to increase the penetration.

The solar radiation map for Tonga is shown in the image below.

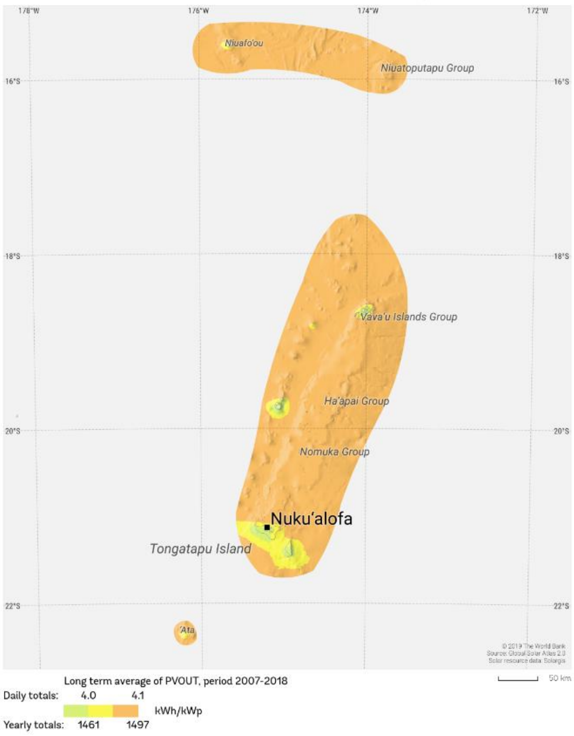

Figure 10: Global Horizontal Irradiation for Tonga[26]

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[22] World Bank – World Development Indicators
[23] Pacific Horticultural and Agricultural Market Access Program, 2016
[24] Tonga Statistics Department, 2017
[25] Preparatory Survey Report - JICA
[26] Solar resource maps – ESMAP Solar GIS

5. Financial Feasibility Analysis

5.1 Solar pumpset demand submitted by Tonga

The following table highlights the prevailing cost of SWPS as shared by Tonga. The supply, installation, commissioning and maintenance of 258 SWPS including the cost of drilling borehole is estimated to be USD 4.45 million

S.No.	Pumpset size (HP)	PV Array Capacity per unit (kWp)	Quantity	Prevailing price/unit (USD)	Cost of Drilling Borehole[27] (USD)	Cost per Pump including Borehole (USD)	Total prevailing cost (USD)
1	3	2.8	60	12,781	2,000	14,781	8,86,886
2	5	5.6	74	14,354	2,000	16,354	1,210,190
3	7.5	8.4	72	16,259	2,000	18,259	1,314,651
4	10	11.2	52	17,918	2,000	19,918	1,035,732
Total			**258**			**Total**	**4,447,459**

Table 12: Prevailing costs for various type of solar pumpsets

Based on L1 prices discovered in International Competitive Bid (ICB) by ISA for various categories of SWPS, the cost of supply, installation, commissioning and 5 years CMC for 258 SWPS including of Cost of Drilling Borewell is USD 2.48 million. Considering 3% of capital cost as Project Management Consultancy cost for EESL to assist Tonga in implementation of SWPS project, the total capital cost is USD 2.56 Million. ISA competitive bidding has effectively reduced the capital expenditure on SWPS by USD 1.89 million (~42% reduction in cost).

S.No.	Pumpset size (HP)	PV Array Capacity per unit (kWp)	Quantity	ISA discovered price/unit (USD)	Cost of Drilling Borehole (USD)	Cost per Pump including Borehole (USD)	Total ISA cost (USD)
1	3	3.0	60	5,594	2,000	7,594	455,641
2	5	4.8	74	6,632	2,000	8,632	638,748
3	7.5	6.75	72	8,428	2,000	10,428	750,804
4	10	9.0	52	10,273	2,000	12,273	638,197
Total			**258**			**Total**	**2,483,390**
						PMC cost for EESL* (@3% of capital cost)	**74,502**
						Total	**2,557,892**

**Optional expenditure, as the EESL Services of PMC is not mandatory for the country to opt.*

Table 13: ISA discovered Prices for various type of solar pump sets

The following tables highlight savings, payback period for representative 3 HP SWPS.

5.2 Indicative Inputs

S.No.	Particulars	Unit	Value		Source
1	Crop to be Irrigated		Cassava, Tomato		
2	Land Size	hectares	0.75 (for each crop)		
3	Planting date		As per cropping calendar of Tonga		
4	Irrigation type		Flood: Lined canal supplied		
5	Annual average yield of crop	Kg/hectare	Cassava	16,705	FAOSTAT
			Tomato	34,333	
6	Market Price	USD/quintal	Cassava	243	

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S.No.	Particulars	Unit	Value	Source
			Tomato 608	FAO: Food Price Monitoring and Analysis
5	Selected Size of Solar Pump	HP	3	
6	Total dynamic head inclusive of friction losses	meters	120	
7	Cost of Solar Pump	USD	5594.0[28]	Average of L1 prices discovered in ISA tender for Various categories of pumpsets
8	Subsidy	%	0 %	
9	Margin Money	%	10 %	
10	Loan Amount	%	90 %	
11	Interest Rate	%	4 %	Assuming concessional financing
12	Loan Tenure	years	7	
13	Cost of diesel pump per HP	USD	117	
14	Cost of diesel	USD/litre	1.3	Published reports and articles[29]
15	Hike in diesel prices (y-o-y)	%	3%	Based on global averages
16	Inflation rate	%	2 %	World Bank Data
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, 2020[30]

5.3 Indicative Crop Water Requirement [31]

Total crop water requirement (m^3)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
110	-	-	-	-	212	527	625	476	50	297	424
Annual crop water requirement (m^3)					2,720						

5.4 Indicative Irrigation schedule

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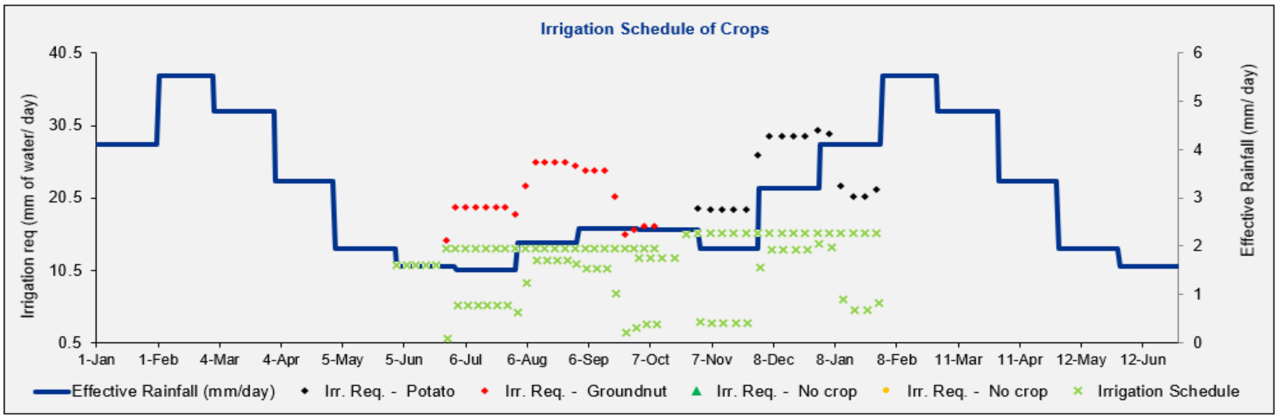
[28] Cost of Solar pumpset includes on-site Comprehensive Maintenance Contract (CMC) for 5 years but exclusive of custom import clearance, duties and local taxes as per ISA International Competitive Bid
[29] mic.gov.to
[30] The toolkit developed by KPMG for Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH was used to undertake the analysis.
[31] 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.



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

5.5 Indicative Outputs

S.No.	Particulars	Unit	Value
1	Amount of subsidy	USD	0
2	Amount of loan to be availed	USD	6,835
3	Yearly installment towards loan repayment	USD	1,139
4	Monthly installment towards loan repayment	USD	95
5	Savings in monthly diesel expenses on an average basis for 20 years	USD	156
6	Number of hours of solar pump operation required	Hours	919
7	Number of days of solar pump operation required	Days	131
8	Payback of solar pump w.r.t. diesel pump	years	5

In subsequent sections, based on annual diesel savings for 3 HP SWPS, the estimated savings for various pump capacities are highlighted.

5.6 Estimated savings due to Solar WPS

Tonga has submitted demand for 258 Nos. solar water pumping systems. Based on cropping pattern, water table depth, rainfall and soil conditions, the annual usage of diesel pumpsets is 919 hours for a 3 HP pumpset. Assuming similar diesel usage for other pumpset capacities, the reduced diesel consumption and accordingly the avoided expenditure on diesel consumption is shown below.

Sl. No	Size of Solar pumpset (HP)	No of Solar Pumpset	Annual Diesel consumption per Pumpset (liters)	Avoided diesel consumption (Liters)	Total Annual Diesel savings (USD)
1	3	60	587	35,244	62,734
2	5	74	979	72,446	128,954
3	7.5	72	1,468	105,732	188,202
4	10	52	1,958	101,816	181,232
Total		**258**	**4,993**	**315,237**	**561,122**

The total avoided annual diesel consumption for 258 pumpsets is 315,237 Liters and avoided annual expenditure on diesel consumption is USD 561,222. The avoided annual CO_2 emissions is 845 Tons[32].

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[32] 2.68 kgs of CO2 released from 1 liter of diesel (Source: https://ecoscore.be/en/info/ecoscore/co2)

6. Advantages of solar powered irrigation

6.1 Advantages of solar power irrigation to various stakeholders

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 14: Advantages of solar powered irrigation

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7. Recommendations for implementation

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

1. **Location of pumps:** Tonga has submitted demand for procurement of 258 solar water pumps. The meteorology of Tonga is characterized as humid maritime subtropical climate with almost consistent rainfall throughout the year. Additionally, the total dynamic head across the country varies from 100 to 200 meters. Considering these parameters, the water requirement can be sufficed by 3, 5, 7.5 and 10 HP pumpsets.
2. **Financing:** Government of Tonga may reach out to MDBs/DFIs such as World Bank, The EXIM Bank, ADB etc. to secure financing for implementation of Solar water pumping systems in the country. The potential savings to farmer due to avoided expenditure on diesel consumption may be utilized to payback debt obligations resulted from financing of solar water pumping systems with an estimated payback period of 5 years.
3. **Knowledge development:** Number of motorized agricultural pumps deployed in Tonga are very limited and farmers have relied on river water, 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 Tonga under the ISA's programme.
4. **Ecosystem availability:** The ecosystem of trained local manpower for operations and maintenance of Solar pumps is to be developed for better realization of benefits envisaged from solar water pumping programme. The mandate to bidder to train every famer and 5 local technicians for every 100 pumpsets installed shall be critical in developing local ecosystem in Tonga.

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8. 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 Tonga. 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**: Identification of foundations/ institutions in Tonga 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. **Supply and project monitoring**: Regular project monitoring for supply and installation of pumps may be undertaken by ISA and NFP Tonga basis field reports and feedback from farmers, suppliers / installers and government agencies.

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