KINGDOM OF TONGA

TECHNOLOGY NEEDS ASSESSMENT

ADAPTATION REPORT

Department of Energy,
Ministry of MEIDECC
(December 2023)

TECHNOLOGY NEEDS ASSESSMENT ADAPTATION REPORT

Prepared by Ms. Lilu Kilisitina Moala

Foreword

The harmful effects of Climate Change constantly challenge the Kingdom of Tonga like most of its Pacific Island neighbors. Every year natural hazards like tropical cyclones become more frequent and severe, ocean acidification as global temperatures continue to rise, and prolonged droughts are only a few of such occurrences that citizens experience annually. The biggest injustice of all is considering that Pacific Island Countries (PICs) contribute very little to global emissions yet are some of the most vulnerable in the world.

However, the response by the Tongan Government has been swift, spearheaded by the Ministry of Meteorology, Energy, Information, Disaster Risk Management, Environment, Communications and Climate Change (MEIDECC) with assistance from the United Nations Framework on Climate Change (UNFCCC). With policy frameworks in place like Tonga's Second Nationally Determined Contribution 2020, Tonga Strategic Development Framework II 2015-2025, and Tonga Energy Road Map (TERM Plus 2021-2035), Joint National Action Plan on Climate Change and Disaster Risk Management (JNAP2) and Tonga's Climate Change Policy. This is a clear indicator that Tonga is willing to do its part to achieve the goal of the Paris Agreement.

This is where the Technology Needs Assessments (TNA) Project plays a vital role by transversing through multiple sectors to meet the demands stated in the policy frameworks mentioned above. Tonga is part of TNA Phase IV meaning that this process has been tried, tested, and successfully implemented in countries before. The key focus of the TNA Project is to identify the Technology Needs of a country to assist in lowering greenhouse emissions. The Department of Energy of the Ministry of MEIDECC has been tapped to take charge of this Project with funding provided by the Global Environment Facility (GEF) in collaboration with the United Nations Environment Programme Copenhagen Climate Change Center (UNEP-CCC) and technical assistance from The University of the South Pacific (USP).

The TNA process is a sector-focused multi-stakeholder consultation making it a truly country- driven initiative because it involves government officials from all line ministries, NGOs, Private organizations, businesses, and technical institutions. Stakeholders involved were identified as key drivers of the four sectors identified for the TNA project—Water and Agriculture (Adaptation) Energy and Transport (Mitigation).

Currently, the Tonga TNA team has completed an Inception Workshop, a Multi-Criteria Analysis (MCA) which is a tool used in the TNA Process to identify and prioritize the top three technologies for each of the Sectors, and the Project is looking forward to the Barrier Analysis and Enabling Framework (BAEF) and also producing a Technology Action Plan (TAP) for the diffusion of these prioritized technologies.

…………………………..

Mr. Sione 'Akau'ola
CEO for the Ministry of MEIDECC

Table of Contents

List of Figures

List of Tables

Acronyms

ADB	Asian Development Bank
DFAT	Department of Foreign Affairs and Trade
ENSO	El-Niño Southern Oscillation
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
JNAP	Joint National Action Plan on Climate Change & Disaster Risk Management
MAFF	Ministry of Agriculture, Food and Forests
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications
NDC	Nationally Determined Contributions
NCDs	Non-communicable diseases
NGOs	Non-government organisations
NIIP	National Infrastructure Investment Plan
TWB	Tonga Water Board
TNC	Third National Communication
TSDF	Tonga Strategic Development Framework
UNEP-CCC	UNEP- Copenhagen Climate Change Centre
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

A technology is defined as ‘a piece of equipment, technique, practical knowledge, or skills for perform a particular activity’ and the three different components of technology are hardware, software and orgware (IPCC, 2000). A Technology Needs Assessment or TNA is a set of country-driven, participatory processes that identifies, selects and implements climate technologies in order to reduce vulnerability to climate change (adaptation) and/or mitigate greenhouse gas emissions (mitigation).

The TNA process consists of three main stages and related objectives:

i. To identify and prioritize adaptation and mitigation technologies for selected sectors
ii. To identify, analyse and address the barriers hindering the deployment and diffusion of the prioritized technologies, including establishing the enabling framework for said technologies
iii. To develop a Technology Action Plan (TAP), based on the inputs from the first two stages, with suggested actions in the form of project ideas.

Tonga’s TNA adaptation focused on Agriculture and Water, as two priority sectors. Agriculture is an integral part of Tonga’s economy and culture. As a primarily subsistence activity, the majority of agricultural products such as yam, taro, sweet potato and cassava, are consumed locally. On the other hand, Tonga also maintains significant exports of squash pumpkins, vanilla, and kava. Tonga’s agriculture sector remains vulnerable to climate change and natural disasters. The increasing variability in weather patterns, coupled with the frequency and intensity of tropical cyclones, poses a threat to agricultural production and intensification throughout Tonga.

Water resources in Tonga include rivers, lakes, underground aquifers, and rainwater. These resources supply fresh water for drinking, sanitation, irrigation, industrial and other purposes in Tonga. The main sources of water in Tonga are rainwater and underground aquifers. The availability of surface and ground water in Tonga is dependent on many natural factors including climate hence the vulnerability to the impacts of climate change. Water supplies for the main urban centres are sourced from groundwater and managed by the Tonga Water Board (TWB). In rural communities, water is sourced from surface and groundwater and supplied by village water committees through their respective distribution pipe networks.

As part of the first TNA stage, technologies are prioritized within the selected priority sectors through a Multi-Criteria Analysis (MCA), where technologies are evaluated using criteria selected by the TNA stakeholders. The prioritisation results will be carried forward to the next two TNA stages, to undergo a barrier assessment for the implementation of prioritised technologies and to develop technology action plans for future deployment.

The prioritised technologies for the Tonga’s Agriculture Sector include Mixed Farming, Food Cubes and Farmer Field Schools (FFS). Scaling up of Rainwater Harvesting (RWH), providing Post-Construction Support (PCS) for Community-managed Water Systems, and implementing Mobile solar-powered desalination units were identified as prioritised technologies for Tonga’s Water Sector.

Chapter 1 Introduction

1.1 About the TNA project

A Technology Needs Assessment, or TNA, is defined as a set of country-driven, participatory activities leading to the identification, selection, and implementation of climate technologies in order to reduce greenhouse gas emissions (mitigation) and/or vulnerability to climate change (adaptation).

The TNA process originated in the Poznan Strategic Programme on Technology Transfer, established during the Fourteenth Conference of the Parties (COP14) to the United Nations Framework Convention on Climate Change (UNFCCC). Its purpose is to scale up investment in technology transfers, enabling developing countries such as Tonga, to address their needs for climate technologies.

The Government of Tonga (GOT), through its National Focal Point to the UNFCCC, signed a Project Cooperation Agreement (PCA) with the UNEP DTU Partnership (DTP) for Tonga's participation in the fourth phase of the Technology Needs Assessments (TNA Phase IV) Project. This PCA was recently renewed between the GOT and the UNEP Copenhagen Climate Centre in March 2023.

The scope and depth of the TNA is well aligned to Tonga's national development objectives, enabling national stakeholders to explore synergies with other national processes. This alignment strives towards the implementation of Tonga's Second Nationally Determined Contributions (NDC), Long-term Low Emissions Development Strategy (LEDS), Climate Change Policy and Joint National Action Plan on Climate Change and Disaster Risk Management (JNAP2).

The TNA process has the following three main steps and related objectives:

1. To identify and prioritize mitigation and adaptation technologies for selected sectors/subsectors.
2. To identify, analyze and address the barriers hindering the deployment and diffusion of the prioritized technologies.
3. Based on the inputs obtained from two previous steps, to draw up a Technology Action Plan (TAP) with suggested actions presented in the form of project ideas.

This TNA Report is the output for the first step of the TNA process. Two more reports will be developed later as the outputs for the last two TNA steps.

1.2 Existing national policies related to technological innovation, adaptation to climate change and development priorities

1.2.1 National Circumstances

The Kingdom of Tonga (Tonga) is an archipelago of 176 volcanic an, d raised/low-lying coral islands in which 36 islands only are inhabited. The capital, Nuku‘alofa, is located on the main island of Tongatapu. There are four main island groups: Tongatapu, Ha‘apai, Vava‘u and the Niuas.

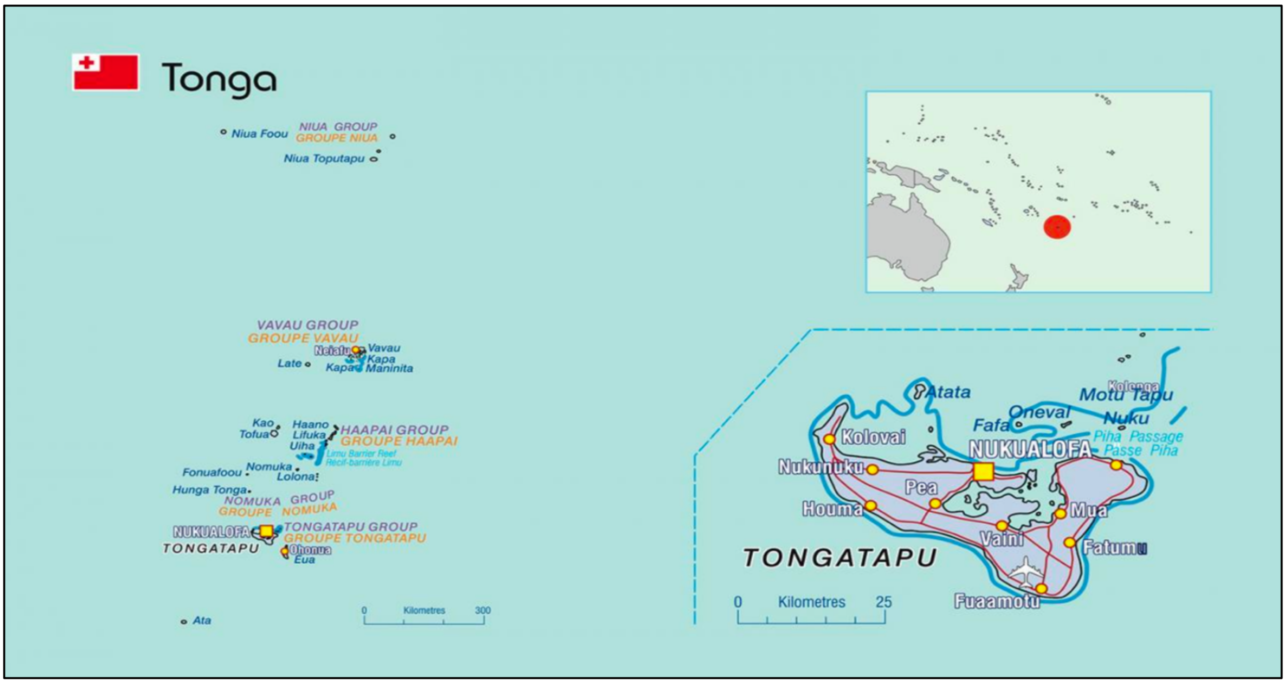

Figure 1: Map of Tonga (Source: Pacific Community, 2023)

According to the latest census in 2021 (Statistics Department, 2022), Tonga's total population was 100,179. Of this total population, 51,430 were females and 48,749 were males, giving a sex ratio of 95 males per 100 females. It was also revealed that 74% of Tonga's total population reside in Tongatapu Island, with the urban population in Nuku'alofa or the villages of Kolofo'ou, Kolomotu'a and Ma'ufanga, making up slightly more than one fifth of the total population.

Tonga is among the countries most vulnerable to climate change due to its geographic location and socio-economic features (GOT, 2020). Sea-level rise, ocean acidification, temperature rise, and the increasing intensity of tropical cyclones continue to pose threats to the people of Tonga and its environment (GOT, 2020).

On average, Tonga experiences 17 tropical cyclones (TC) per decade, with most occurring during the November to April cyclone season (GOT, 2019). Recent tropical cyclones that have devastated Tonga include; TC Gita in 2018 with damages and economic losses of approximately USD 164 million, or the 38% equivalent of Tonga's Gross Domestic Product (GDP); and TC Harold in 2020 with damages and economic losses of approximately USD 124 million, or 23% equivalent of Tonga's GDP (GOT, 2021).

On 15th January 2022, the Hunga Tonga Hunga Ha'apai (HTHH) volcano erupted and generated a tsunami, devastating Tonga and the communities in Tongatapu, 'Eua and the Ha'apai Group. The double disasters of the volcanic eruption and tsunami resulted in four deaths, displacements of approximately 1,525 people from 317 households, damages to 468 houses, disruption, and loss of communications due to the damages to the submarine fibre optics telecommunications cable, damages to the coastal areas and other impacts on the agriculture, fisheries, and tourism sectors (GOT, 2022). The World Bank's post-disaster assessment estimated the economic damages by the HTHH disasters to be USD 90.4 million or TOP 208 million (World Bank, 2022).

Agriculture Sector

Tonga's 2015 Agriculture Census classified agriculture activities in Tonga into subsistence, semi-subsistence, and commercial. The five main types of household agriculture activities were: cropping; livestock; fishery; forestry and handicraft making.

The census concluded with the following key findings:

- Subsistence and semi-subsistence agricultural activities continued to dominate the agriculture landscape in Tonga across all main subsectors, namely, cropping, livestock, fisheries, forestry, and handicrafts. On average, over 95% of the agriculture active households in Tonga engaged mainly in subsistence and semi- subsistence agriculture activities.
- Many agriculturally active households reported that one of the main purposes for their agricultural activity is to meet social obligations such as funerals, weddings, birthdays, church conferences, and other community or extended family events.
- Crop cultivation and livestock raising were the main activities in the subsistence and semi-subsistence agricultural sub-sectors. Food security was one of the main reasons for farmers' continued engagement in crop cultivation and livestock farming.
- Livestock and forestry represent the main commercial activities.

Water Sector

Tonga's water resources are primarily in the form of groundwater. Surface water resources are scarce on most islands, with exceptions such as 'Eua and some of the volcanic islands including Niuafo'ou and Niuatoputapu.

Rainwater is the supplementary source of potable water. Groundwater is normally pumped from drilled wells and occasionally from older dug wells, with depths exceeding 50 meters in some cases. The water supplies for the main urban centers: Nuku'alofa (Tongatapu), Pangai (Ha'apai) and Neiafu (Vava'u), and some villages' water supplies are also sourced from groundwater. Rainwater is primarily collected on rooftops and stored in reinforced concrete, fibreglass, and galvanized iron tanks. The majority of households own one or two of these storage tanks.

The water resources of rural areas or remote islands encompass all water resources available for domestic use within towns, villages and islands situated away from the main urban areas. These areas receive water through piped reticulation systems operated by the Tonga Water Board (TWB). Rural water supplies are managed by Village Water Committees, receiving support and training from the Ministry of Health (MoH).

1.2.2 National Strategies, Policies and actions related to climate change

Over the years, Tonga has made adequate progress in terms of having legislations, policies, and strategies in place for natural disasters and climate change at the national and strategic level, including the:

Tonga Strategic Development Framework 2015 – 2025

The Tonga Strategic Development Framework (TSDF) sets out a results-based framework to guide Tonga's development over a 10-years period. The TSDF's overall focus is on inclusive and sustainable development with a national impact of "A more progressive Tonga supporting a higher quality of life for all" (GOT, 2015).

The TSDF is comprised of the following 7 high-level national outcomes:

A. a more inclusive, sustainable and dynamic knowledge-based economy
B. a more inclusive, sustainable, and balanced urban and rural development across island groups
C. a more inclusive, sustainable, and empowering human development with gender equality
D. a more inclusive, sustainable, and responsive good-governance with law and order
E. a more inclusive, sustainable, and successful provision and maintenance of infrastructure and technology
F. a more inclusive, sustainable, and effective land administration, environment management, and resilience to climate and risk
G. a more inclusive, sustainable, and consistent advancement of our external interests, security and sovereignty.

In support of the 7 National Outcomes, there are 29 Organisational Outcomes, grouped into five Pillars (Institutional Pillars: Economic Institutions, Social Institutions, Political Institutions, and Input Pillars: Infrastructure and Technology Inputs & Natural Resources and Environment Inputs) which, working together, support the National Outcomes.

Government Priorities Agenda 2022 – 2025

Tonga's current government, led by Prime Minister Hon. Hu'akavameiliku, has formulated National Priority Areas (NPAs) to guide the comprehensive approach towards development for Tonga.

The Government Priority Agenda (GPA) is a subset of the TSDF, aiming to focus the Government on key priority areas for 4 years, 2022 – 2025. There are 9 GPAs, grouped into the following 3 major thematic groups:

A. National Resilience

- GPA 1: Building resilience and safer platforms to address natural disasters, meet the ongoing challenges of climate change, and tackle economic crisis.
- GPA 2: Reducing relative poverty and increasing quality of services for social protection; and
- GPA 3: Mobilizing national and international responses to effectively reduce the supply and use of illicit drugs, and address harms reduction processes.

B. Quality of Services and Affordability

- GPA 4: Improving education for all, focusing on safer schools, addressing dropouts, gender equality, and increasing employable training for both local and overseas opportunities
- GPA 5: Improving access to quality and affordable healthcare system, focusing on COVID19, non-communicable diseases and preventative measures; and
- GPA 6: Building quality and easy access to government services and public enterprises focusing on increased access to high-speed broadband technology, more affordable energy, communication, drinking water, and clean environment for Tonga to support inclusive growth.

C. Challenges and Opportunities for Progressive Economic Growth

- GPA 7: Creation of trade opportunities from regional and international trade agreements focusing on agriculture, fisheries, handicrafts, tourism and promoting of value addition and product diversification and simultaneously reduce technical barriers to private sector development and heavy reliance on imports.
- GPA 8: Improving the quality and access to public infrastructure, focusing on the efficiency of land transport for evacuation, marine, and air, to support national resilience and inclusive growth; and
- GPA 9: Strengthen bilateral engagement with accredited partner countries; optimize cooperation with regional and international intergovernmental institutions; strengthen

partnerships with development partners, private sectors, non-government actors, focusing on sound economic investment, to sustain progressive, equitable and vibrant social economic growth.

Tonga Climate Change Policy 2016

The JNAP2 was developed with the vision for 'A Tonga that is resilient to the impacts of climate change and climate-related disaster risks, and is able to protect and safeguard its present and future citizens' (GOT, 2018). The Climate Change Policy (CCP) seeks to achieve this through three strategic goals: strengthened integrated risk management to enhance climate and disaster resilience, low-carbon development, and strengthened disaster preparedness, response, and recovery specific targets.

The purpose of this policy is to provide a clear vision, goal, and objectives to direct Tonga's responses to the effects of climate change and to guide DRR over the years. The objectives of the CCP became the JNAP2's objectives; hence, the achievements of the JNAP2's targets will ultimately fulfil the policy's targets.

Joint National Action Plan on Climate Change and Disaster Risk Management (JNAP2) 2018

Tonga was the first country in the Pacific to have developed a joint action plan for climate change adaptation (CCA) and DRM. The JNAP has helped Tonga refocus its resources on the implementation of CCA and DRM in various sectors throughout the whole of Tonga.

Tonga's Second JNAP2 was endorsed by the Government in 2018 providing a coherent approach to building disaster resilience and strategic actions for climate change and disaster management initiatives for the period of 2018-2028. The JNAP2 is aligned with relevant sector policies and plans, as well as community and island strategic development plans. It is consistent with regional and international development frameworks and agreements such as the Framework for Resilient Development in the Pacific (FRDP), the Sendai Framework, the Paris Agreement, and the Sustainable Development Goals (SDGs).

The JNAP2 provides the strategic action plan for both the TSDF II and the Tonga CCP. Its mission is 'To develop a resilient Tonga through an inclusive, participatory approach that is based on good governance, builds knowledgeable, proactive communications and supports a strong, sustainable development pathway'.

The JNAP2 has a total of 22 targets. JNAP Target 6 and 7 pertain specifically to the agriculture sector; "Resilient low chemical input or organic farming system (Target 6) and "30% of land in Tonga utilized for agroforestry or forestry" (GOT, 2018). Relevant to the water sector is Target 10: "Water security through integrated management and conservation" targeted at the water sector. Target 15, 17 and 20 are all relevant to the two sectors of agriculture and water.

The implementation of the JNAP (and JNAP2) is led by the Department of Climate Change and the JNAP Secretariat, established in 2011 to manage the day-to-day operations of the JNAP and to coordinate implementation activities across various government sectors.

Tonga's Second Nationally Determined Contributions 2020 (NDC)

As 2020 was the year to communicate a new or updated NDC, as requested by the Paris Agreement, Tonga was among the few countries that has already fulfilled its obligation and submitted a second NDC to the UNFCCC on 9 December 2020. Although Tonga's contribution to the global greenhouse gas emissions is negligible (a total of 310.4 Gg CO2-equivalent in 2006, according to the Tonga's Third National Communication), the country has pledged the following ambitious targets in its Second NDC (GOT, 2020) to mitigate the negative effects of climate change:

- "Energy: 13% (16 Gg) reduction in GHG emissions by 2030 compared to 2006 through a transition to 70% renewable electricity as well as energy efficiency measures.
- Agriculture, Forestry and Other Land Use: establishment of a forest inventory as prerequisite to identify a GHG emission target for the 2025 NDC and planting one million trees by 2023.
- Waste: expansion of the formal waste collection system as prerequisite to identify a GHG emission target for the 2025 NDC. 30% of land in Tonga utilized for agro-forestry or forestry by 2025,
- Prevent any permanent loss of land to rising sea levels on Tonga's four main islands (Tongatapu, Ha'apai, Vava'u, and 'Eua),
- Maintenance of the existing stocks of fish and other marine species through a commitment to expand the area covered by Marine Protected Areas (MPAs) and Special Management Areas (SMAs) to 30% of the Tonga's Exclusive Economic Zone (EEZ)."

Tonga's Long-term Low Emissions Development Strategy 2021 – 2050

In line with its second NDC, Tonga also developed its first Long Term – Low Emission Development Strategy (LT – LEDS). The strategy aims to support the country's transition to a low-carbon pathway by establishing realistic targets and short, medium and long-term climate actions for key sectors, including Agriculture, Forestry and Other Land Use (AFOLU), Fisheries, Energy (focused on electricity), Transport (focused on land transport), Waste and Human Settlements.

Tonga's LT-LEDS not only reaffirms Tonga's commitments to the Paris Agreement, ratified on the 21st September 2016, but it also complements the Government of Tonga's existing planning and policy processes by providing a longer-term and more integrated view. Furthermore, the LT-LEDS provides an opportunity for the Tongan government to strategically coordinate with donors and development partners on transformative investments necessary to enhance climate change resilience.

Tonga Agriculture Sector Plan

The Tonga Agriculture Sector Plan (TASP) presents the vision and priorities to maximize the contributions from the agriculture sector to Tonga's economic growth and sustained food security in the face of a changing world economy, looming climate change, and on-going natural disasters in the Pacific.

To establish a policy framework and action plans to "increase and sustain resilient agriculture livelihoods", TASP was launched in 2016 with four strategic objectives: 1) developing a climate-resilient environment; 2) improving the enabling environment; 3) establishing diverse, resilient farming systems for the Kingdom's islands; and 4) increasing and sustaining rural incomes across the Kingdom.

1.3 Vulnerability assessments in Tonga

Tonga has completed three national communications (NC) on climate change since it joined the United Nations Framework Convention on Climate Change (UNFCCC) on 20th July 1998. A NC is a report that each Party to the UNFCCC is obligated to prepare and report to the Convention on its greenhouse gas emissions by sources and removals; national mitigation and adaptation measures; and any other information that the Party considers relevant to the achievement of the objective of the Convention (UNFCCC, 2003). One of the key components of a NC therefore is a report on the vulnerability of the Party, and its adaptation to, climate change.

Tonga's Initial National Communication (INC) was completed and submitted in 2005, Second National Communication (SNC) in 2012 and the most recent, Third National Communication (TNC) in 2019. The Fourth

National Communication (4NC) Project is currently in progress under Tonga's Department of Climate Change, with the 4NC report expected to be completed and submitted to the UNFCCC in 2026.

The most recent vulnerability assessments in the TNC, presented detailed information on specific climatic parameters and risks (rainfall, temperature, wind, tropical cyclones, sea surface temperature, sea level and El Niño Southern Oscillation (ENSO) and results of vulnerability assessments for the following vulnerable sectors: Agriculture, Fisheries, Coastal areas, Water Resources, Lands and GIS, Disasters, Infrastructure, Biodiversity and Health.

For each of the assessed vulnerable sectors, the climate change impacts and vulnerabilities were outlined. Additionally, current adaptation measures including projects were provided with further information on other adaptation options. Furthermore, the results of the TNA conducted during the TNC Project are integrated within the TNC Report, mainly in the Vulnerability and Adaptation Assessment and Mitigation Analysis chapters.

1.4 Sector selection

1.4.1 An Overview of Expected Climate Change and its Impacts in Sectors Vulnerable to Climate Change

Past Observed Trends in Climate Variables

The historical average annual temperature in Tonga shows year-to-year variability, with cooler years such as 2015 and warmer years such as 2011, but it has experienced a warming trend over the 1850 – 2020 period as a whole average (CSIRO & SPREP, 2021). It is likely that all years since 2000 have been warmer than the pre-industrial climate average (CSIRO & SPREP, 2021).

Tonga has a wet season from November to April and dry season from May to October. Nearly two-thirds of Tonga's rainfall occurs during the wet season, with the South Pacific Convergence Zone (SPCZ) controlling the rainfall. The intensity is most pronounced during the wet season. Tonga's rainfall exhibits high variability from year-to-year, primarily due to the El Niño-Southern Oscillation (ENSO). El Niño reduces wet season rainfall and slightly increases rainfall in the dry season (GoT, 2019).

The Australian Bureau of Meteorology and CSIRO (2014) reported that the annual total rainfall in Tonga exhibits large year-to-year variability, partly related to the ENSO, with no significant trends since 1960.

The sea-level rise in Tonga measured from January 1993 to December 2015 is 7.3mm per year, after barometric and vertical ground movement corrections. This is noted to be higher than the global average of 3.2mm (GoT, 2019).

On average, Tonga experiences about 17 tropical cyclones (TC) per decade (calculated from 1970/71 to 2009/10), with most occurring between November and April. The number of cyclones affecting Tonga per decade has increased. Some of the most severe TC to have affected Tonga include TC Waka (Category 4 in 2002), TC Ian (Category 5 in 2014), TC Gita (Category 4 in 2018) and TC Harold (Category 5 in 2020). Tropical cyclones are projected to decline in frequency but expected to increase in intensity in the Southeast Pacific Ocean basin (GoT, 2019).

Climate Projections

In Tonga, observed and projected warming suggests that 2°C global warming relates to 1.1 to 1.7°C in Tonga, i.e. Tonga experiences a warming rate slightly below the global average (CSIRO & SPREP, 2021). However, this doesn't mean impacts are lower than other nations – high temperature extremes emerge faster in the tropics (Frame et al. 2017) and Tonga is vulnerable to climate change in many ways, so risk assessment is needed.

Tonga's TNC (2019) reported that the projections for all emissions scenarios indicate that Tonga's annual average temperate and sea surface temperature will increase in the future. The projected increases in average temperatures will lead to a rise in the number of hot days and warm nights, accompanied by a decline in cooler weather (GoT, 2019).

Uncertainty exists in rainfall projections for Tonga due to inconsistent model results. However, projections generally suggest a decrease in dry season rainfall (May to October) and an increase in wet season rainfall (November to April) over the course of the 21st century.

Sea levels in Tonga are projected to continue rising. Under a High Emissions scenario, the projected sea level rise is expected to be in the range of 3 – 17cm by 2030 (GoT, 2019). This means increasing risks of inundation and flooding for the coastal populations and infrastructures in Tonga.

Projections for Tonga indicate a decrease in the frequency of tropical cyclones by the late 21st century and an increase in the proportion of more intense cyclones. As of 2023, Tonga is in the progress of recovering from the devastating impacts of TC Gita, which caused damages and economic losses of approximately USD 164 million, equivalent to 30% of the gross domestic product (GDP), and TC Harold, resulting in damages and economic losses of approximately USD 124 million, equivalent of 23% of Tonga's GDP (GoT, 2021).

Vulnerable Sectors in Tonga

A. Human Health

Tonga enjoys high levels of access to appropriate health care services with improved water and sanitation over the last few decades. However, the health sector is vulnerable to the vagaries of climate change including the increased temperature, intense rainfall, drought, sea level rise and frequent cyclones.

The projected increase in rainfall and temperature may lead to an increase in vector and water-borne diseases such as dengue, diarrheal illnesses and respiratory infections. There is also a projected increase in injuries, deaths, and mental health problems as a result of extreme weather events, such as tropical cyclones (GoT, 2019). One of the priorities raised in Tonga's TNC was the need to increase understanding of the relationship between climate change and human health. Health impact assessment procedures are suggested to facilitate better understanding of appropriate adaptations to climate change.

Meanwhile, Non-communicable diseases (NCDs) have reached a critical level in Tonga. There have been significant public investments aimed at alleviating NCDs through multi-sectoral approaches, including promoting physical activity, improving nutrition, ensuring availability of healthy foods, restricting access to unhealthy foods, and imposing taxes on tobacco (GoT, 2019b).

B. Agriculture

Tonga's agriculture sector is constrained by its relatively small endowment of land and natural resources, substantial dependence on imports, relative isolation from major markets, high cost of public administration and infrastructure, including transportation and communication (ADB, 2006).

As reported in Tonga's Fifth Report to the Convention on Biological Diversity (2014), there is significant variability in crops and livestock species between Tongatapu, the main island, and other island groups in Tonga. Genetic erosion and loss of crops and livestock genetic resources are high on Tongatapu due to increased specialization for production for local and export markets, particularly in species like squash and watermelon.

The projected climate change is anticipated to significantly impact Tonga's agriculture, a key economic sector. The effects include:

- **Productivity:** Changes in temperature and rainfall patterns.
- **Agricultural Practices:** Increased use of inputs such as herbicides, insecticides, and fertilizers.
- **Soil Health:** Impact on drainage and erosion, leading to a reduction in crop diversity.
- **Land Loss:** Cultivated lands are at risk.
- **Adaptation Capacity:** Organisms may become more or less competitive (GoT, 2019).

C. Water

Tonga primarily relies on groundwater as its main water resource, which is typically extracted through pumped drilled wells and some older dug wells. Only ʻEua and some of the volcanic islands including Niuafoʻou and Niuatoputapu have surface water resources.

Rainwater, harvested from roof tops and stored in tanks made of concrete, fiberglass and galvanized iron, serves as the supplementary source of potable water in Tonga. The water supplied by the Tonga Water Board to urban centers and by the village water committees to rural communities are mostly sourced from groundwater (APCP, 2020).

The primary impact of climate change is expected to be changing rainfall patterns, with compounding effects on Tonga's surface water and groundwater resources. The changes in rainfall patterns will impact stream flows, availability of water in streams and rechange to groundwater (GoT, 2019). The projected increase in rainfall is likely to have positive impacts on water resources in Tonga, leading to increased stream flows and groundwater recharge.

In addition, Tonga's water infrastructure, whether large and small, in both urban or rural settings, is highly vulnerable to extreme weather conditions.

D. Coastal Areas

In Tonga, the majority of villages are situated along the coastal zone, reflecting their close connection with the ocean, marine environment and the resources it provides. Tonga's coastal areas, especially those in low-lying regions, are highly susceptible to the impacts of climate change and extreme weather events.

The majority of Nuku'alofa, the capital city located on the main island of Tongatapu, lies only 1-2 meters above sea level, making it prone to periodic flooding during heavy rain. Settlements to the East of Nuku'alofa (Popua and Patangata) which are on reclaimed areas are also vulnerable coastal zones. Tonga's low-lying areas are exposed and susceptible to the impacts of sea level rise, storm surges, high waves, leading to coastal erosion and inundation issues (Mcue, 2012).

The tourism sector, which is dependent on Tonga's coastal environment is also vulnerable to the impacts of climate change especially extreme weather events. Coastal and beach tourism in Tongatapu were severely affected by TC Gita and Harold, and most recently, by the dual disasters from Hunga-Tonga Hunga-Ha'apai (HTHH).

1.4.2 Process and results of sector selection

Reviews of existing literature, policies and Tonga's national priorities resulted in the Agriculture and Water sectors being chosen as the focus of Tonga's TNA, mainly due to their high vulnerability to climate change impacts and their crucial role in Tonga's development priorities.

As a lower middle-income country, Tonga has a relatively small economy, with a GDP estimated at USD 512 million in 2019 (World Bank, 2021). The Agriculture Sector is the primary economic activity in the Primary Sector, contributing approximately 16.2% to Tonga's GDP (Tonga Statistics Department, 2023). Agriculture is also a key export sector in Tonga, in addition to fisheries and tourism.

Over the years, Tonga continues to prioritise having access to clean and healthy water supplies for all its people, so inevitably, the water sector became a prioritised sector. Climate change and natural disasters pose long-term threats to the agriculture and water sectors in Tonga and their capacities to produce enough food and water for Tonga's population.

Their selection for the TNA process is attributed to the prioritization of both sectors in Tonga's Climate Change Policy, Joint National Action Plan on Climate Change and Disaster Risk Management, Nationally Determined Contributions, Long-term Low Emissions Development Strategy, Tonga Green Climate Fund Country Programme, National Infrastructure Investment Plan and Community Development Plans.

Chapter 2 Institutional arrangement for the TNA and the stakeholder involvement

2.1 National TNA team

Tonga's National TNA Team is made up of the:

1. TNA Project Steering Committee
2. National TNA Coordinator
3. National Consultants – Mitigation & Adaptation
4. Sectoral Working Groups – Mitigation (Electricity & Transport) & Adaptation (Agriculture & Water)

The institutional set up for Tonga's TNA Project is shown in **Figure 2**.

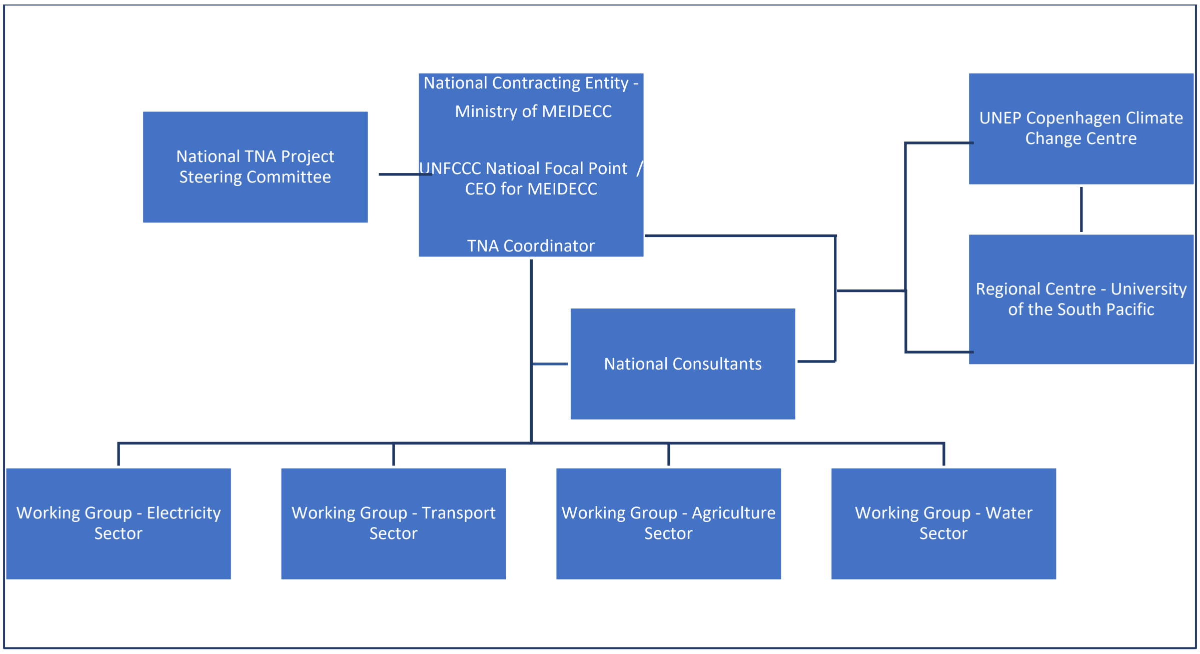

Figure 2: TNA Project Institutional Set Up

TNA Project Steering Committee

The National Steering Committee is the key body that provides high level guidance to the national TNA team. Tonga's TNA Project Steering Committee is Chaired by Tonga's Focal Point to the United Nations Framework Convention on Climate Change (UNFCCC) who is also the Chief Executive Officer of Tonga's Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC). Other members of the committee are senior officials and staff from relevant government Ministries, Departments and Agencies (MDAs), Non-government Organisations and also from the Private Sector.

National TNA Coordinator

The National TNA Coordinator was selected again by Tonga's UNFCCC Focal Point and CEO for MEIDECC, from the Department of Energy. The National TNA Coordinator is responsible for the overall management of the TNA process including the facilitation of the communication and information sharing between the national consultants and the sectoral working groups.

National Consultants

The mitigation and adaptation expert consultants were hired by the UNEP DTU Partnership (UDP), recently changed to UNEP Copenhagen Climate Change Centre (UNEP-CCC), and Tonga's UNFCCC Focal Point/ CEO for MEIDECC through an open and transparent selection process. The national consultants are primarily responsible for preparing the project deliverables, including the Technology Needs Assessment (TNA), Barriers Analysis and Enabling Framework (BAEF) and Technology Action Plans (TAP).

Sectoral Working Groups

Two adaptation sectoral working groups were established with a dedicated working group for each prioritised sector, consisting of relevant representatives from government, NGOs, private and public sectors, utilities, local communities, and technology end-users.

These sector-specific working groups provided technical expertise and input to the technology prioritization, as reported in **Section 3** and **4** of this report. These sectoral working groups will again be utilized for their inputs towards the BAEF and TAP Reports.

2.2 Stakeholder Engagement Process followed in the TNA – Overall assessment

The stakeholders consulted for this TNA report included government MDAs, private sector, non-government organisations, academic institutions, local community and utilities representatives. A list of the stakeholders consulted can be found on ***Annex II: List of stakeholders involved and their contacts***.

This TNA Report was prepared through an extensive stakeholder process. The employed stakeholder engagement methods include:

- Bilateral meetings, in which the consultant engage with sector experts to collect data and information.
- Provision on the Technology Factsheets (TFS) in hard and soft copies to stakeholders for their review, with ample time to provide additional feedback.
- Two national stakeholder consultation workshops with key stakeholders to conduct the technology prioritisation.

2.3 Consideration of Gender Aspects in the TNA process

Tonga has developed a National Women's Empowerment and Gender Equality Tonga Policy (WEGET) along with a Strategic Plan of Action for the period of 2019 – 2025. The vision outlined is "that all women, men, girls and boys as a whole achieve equal access to economic, social, political and religious opportunities and benefits" (MIA, 2019).

The WEGET policy introduces a set of mutually agreed-upon priorities and guidelines aimed at integrating gender perspectives into the development of laws, policies and programmes to address gender issues by ensuring equal rights, opportunities and benefits for women and men. Outcome 5 of the WEGET focuses on creating equal conditions to respond to natural disasters, environmental challenges and climate change.

The WEGET policy was examined during the review of existing planning documents for information for insights into gender dynamics and priorities. This review informed the development of technology factsheets used in the prioritisation of technologies. Gender was also prioritised in both sector and technologies selection and prioritisation. Moreover, the perspectives of both men and women were sought throughout the TNA process, ensuring that equal opportunities were provided to both men and women to voice their opinions on the technologies. In the MCA exercises for both Agriculture and Water Sector, more women than men attended the workshops, including representatives from NGOs, CSOs and the private sector.

Chapter 3 Technology prioritisation for the Agriculture Sector

3.1 Key Climate Change Vulnerabilities in the Agriculture Sector

Agriculture plays a vital role in Tonga's economy and culture, with significant export markets for crops like squash pumpkin, vanilla, and kava. As a primarily subsistence activity, most produce like yam, taro, cassava, and sweet potato are consumed locally in Tonga, with only about 5% of the farmers being commercial producers who engage directly with formal markets (GoT, 2021). Agriculture in addition to fisheries are often the only sources of livelihoods in remote and isolated rural areas and islands in Tonga.

In the past, coconut-based agroforestry was commercially important, and commercial forestry is limited, with subsistence forms of agroforestry including coconut woodlands covering much of Tonga's land mass. In the forestry sector, there are limited private sector initiatives in forestry nurseries and small-scale sawmilling, mainly as part of cyclone response and recovery activities. Additionally, there is a growing number of small, private tree nurseries in Tongatapu, primarily managed by women, cultivating multipurpose trees / plant varieties for landscaping and floriculture.

There are considerable challenges in the agriculture sector which not only impacted agricultural productivity but also resilience to climate change and natural disasters.

The agriculture sector faces considerable challenges, impacting both agricultural productivity and resilience to climate change and natural disasters. According to IFAD (2017, 51% of agricultural land if left fallow due to land rights issues and the high population of Tongan landowners residing overseas.

The increased weather variability makes farming less predictable, and the increased frequency and intensity of tropical cyclones threaten crops and the intensification of agricultural production in Tonga (GoT, 2018). Many farmers therefore strived to maximise production through the use of fertilizers and pesticides, and by expanding their plots, clearing land and forests, causing extensive soil erosion. At the time of this report, Tonga's agriculture sector is still recovering from the massive damages caused by TC Gita in 2018, TC Harold in 2020, and the HTHH volcanic eruption and tsunami in 2022. Recorded damages and losses to Tonga's agriculture sector by recent tropical cyclones is in **Table 1** below.

Table 1: Estimated costs of recent TCs to Tonga's agriculture sector (GOT, 2019)

Year	Tropical Cyclone	Total Costs to agriculture sector in millions (TOP)
2014	TC Ian	$20.6
2018	TC Gita	$97.5
2020	TC Harold	$28.9

Sea level rise has caused loss of agricultural lands on the low-lying coastal areas of Tonga. Devastating impacts of sea level rise include erosion, submergence of shorelines and salinity in the water table. Early surveys in 1980 and 1991 estimated the potential loss of lands due to sea level rise to be about 43 km^2 or 8 % of the total land area, with higher proportion in Tongatapu and the Ha'apai Group (Cowie, 1991). A similar survey in 1997 concluded that 58 km^2 would be inundated if the sea level were to rise by 1 meter (Mimura & Prescott, 1997). Agricultural land areas may be further reduced as a result of sea level rise hence a threat to livelihoods and food security in Tonga.

Droughts also exert considerable influence on agriculture in Tonga, as evidenced by recorded occurrences in 1983, 1998, 2006 and 2015. These events led to the stunted growth of annual crops like squash, yams, sweet potatoes, root crops, and coconuts (GoT, 2019). Moreover, the yields of most traditional crops in Tonga including taro, yams, and cassava experienced significant reductions in these years, impacting the annual export volume of Tongan squash to Japan. According to the MAFF, the estimated vulnerability of agricultural land to drought is 208 km^2 or 39 % of total land areas, with higher proportion for Tongatapu and Vava'u (GoT, 2019).

3.2 Decision context

As discussed in **Section 1.2**, relevant policies and national development plans served as the basis for prioritizing sectors, including the Agriculture Sector.

The issues of agricultural production and intensification is prioritised in different national policies and plans. At the national level, the direction is enshrined in the TSDF II's outcomes: i) urban and regional agriculture development; ii) good governance through the MAFF and; iii) sustainable environment and climate change.

Tonga's Climate Change Policy and JNAP2 outline targets that will contribute to the vision of a Resilient Tonga by 2035. These include climate-smart agriculture, low-chemical-input or organic farming systems and allocating 30% of Tonga's land for agroforestry or forestry.

At the sectoral level, the TASP identifies the vision and priorities to maximise the contributions from the agriculture sector to the country's economic growth and food security, amidst the changing world economy, looming climate change and natural disasters. The TASP acknowledged the factors contributing to the vulnerability of Tonga's agriculture sector including rural poverty, out-migration of rural populations, aging farmer population and the impacts of extreme weather events (MAFF, 2016).

The TASP's four main programmes and sub-programmes are expected to contribute to the plan's overall goal of "Increase and sustain resilient agriculture livelihoods" (MAFF, 2016). The TASP's strategic objectives are as follows:

- Develop diverse, climate resilient farming systems for food/nutritional security and improved livelihoods.
- Increase and sustain rural incomes with rising exports and import substitution.
- Establish climate resilient agriculture system to preserve key natural resources (healthy soils, sustainable water, diverse systems, adaptive communities)
- Improve enabling environment – institutional/service capacity, policies on soil/water, exports/imports & land/rural finance, international relations, regulations, industry organisations, market information.

Tonga's TNC (2019) outlines adaptation measures for the agriculture sector including the need for a stronger focus on natural resources resilience, rural community, commercial production, crop diversification, introduction of new climate-friendly crop varieties, new improve livestock specific, as well as assistance to subsistence farmers to raise crop and domestic animal productivity.

For the Agriculture Sector, the following adaptation options were further identified in Tonga's TNC, 2019:

- Reduce vulnerability to droughts by maintaining soil fertility and productivity, with conservative measures of non-tillage farming practices, long-term bush/planted fallow combine with rotations with crops/livestock, vegetative mulches and planted legume fallow.
- Diversify the livestock species (sheep), breeds (cattle, pigs, chicken, goats), livestock feeds (piggery, layers and broilers) and pasture management strategies.
- Focus on the integrated use of biological control of pest, disease, and weeds with judicious use of pesticides and fertilizers in order to reduce the additional pressure on the environment, as has been the case for the squash industry.

3.3 Overview of Existing Technologies in the Agriculture Sector

The Ministry of Agriculture, Food and Forests (MAFF) is responsible for policy and implementation and various development initiatives for Tonga's agriculture sector.

In partnership with various working partners, MAFF have experiences with various technologies and strategies, as reported in its latest 2021/22 Annual Report, including:

- Soil testing after natural events such as HTHH volcanic eruption and tsunami, to determine the likely impacts of the events on the soil's ability to grow crops
- Establish agronomic crop research such as trial plots for various crops like different cultivars of sweet potato, watermelon and yams using the rain gutters method
- Conduct plant pests and disease research
- Implement smart agriculture practice including demonstration and trial plots of turmeric and ginger.
- Continue research on watermelon and squash as two significant commercial commodities.
- Conduct field research of new varieties of crops with the purpose of improving farmers' access to readily available disease resilient varieties, in partnership with the Pacific Community (SPC)
- Coordinate and facilitate training of farmers and extension officers.
- Conservation of crops and fruits trees including a Cassava and Coconut Seed Banks and plots of fruit trees like avocado, guava, mango and star fruit
- Multiplication plots of resilient planting materials including cassava, dragon fruit, corn and sweet potato
- Implement and support donor funded projects including Tonga Horticulture Competitive Project, Pacific Seed for Life (PS4L), Enhanced Partnership Market Access Program (EPMAP), Plant and Food Research Project, China Aid Project Phase IV, ILAMS R2R Project
- Distribute vegetable seedlings to communities including schools for school garden programs.
- Conduct programs such as: commercial farmers vegetable distribution and monitoring program, happy chicken distribution program, coconut promotion planting program, new vanilla growers' promotion program, dragon fruit & ginger demonstration trial program, pig and sheep selling scheme program, cattle and pig artificial insemination program
- Nursery and seedlings including coconut seedlings for a replanting scheme with registered farmers, kava seedlings and fruit trees seedlings
- Conduct various training and capacity building activities for different stakeholders throughout the whole of Tonga.

Non-government Organisations are also playing key roles in the agriculture sector. MORDI Tonga Trust implements the Tonga Rural Innovation Project (TRIP) across 122 rural communities in Tonga, including rural, remote and isolated outer islands in Ha'apai, Vava'u and the two Niuas. The Tonga Community Development Trust (TCDT) focuses on conserving traditionally useful tree species and promoting home gardening. The Tonga National Youth Congress (TNYC) targets youths. Promoting organic farming and certification. It is actively involved in a number of resilient farming activities nationwide.

3.4 Adaptation Technology Options for the Agriculture Sector and their main adaptation benefits

Table 2 provides a list of technology options for the agriculture sector, in which the TNA stakeholders agreed were relevant for agriculture and would reduce the sector's vulnerability to the impacts of climate change as in **Section 3.1**

Table 2: List of Technology Options for the Agriculture Sector

Technology Category	Technology	Adaptation Benefits for the Agriculture Sector
Planning for Climate Change & Variability	1. Index-based Climate Insurance	Farmers can pay insurance against crop loss due to extreme climatic events such as tropical cyclones, flooding and drought. Insurance can support farmers in years of financial loss due to climatic events.
	2. Decentralized Community-run Early Warning Systems	This technology can contribute to climate change adaptation and risk reduction by improving the capacity of communities to forecast, prepare for and respond to extreme weather events such as tropical cyclones and droughts.
Sustainable Water Use & Management	3. Sprinkler Irrigation	Sprinkler irrigation can make irrigation more efficient by providing a more even application to cultivated plots. It is beneficial especially for where there is limited water supply for agricultural purposes.
	4. Drip Irrigation	Drip irrigation can help farmers adapt to climate change by providing efficient use of water supply, as water will be supplied directly to the plants and fertilizer can also be applied through the same pipes.
Soil Management	5. Integrated Soil Nutrient Management	This can contribute to the reduction of vulnerabilities to climate change through improvements in soil resources which can increase agricultural activity.
	6. Composting of Agricultural Waste	Composting can increase soil biodiversity and at the same time reduces environmental risk associated with synthetic fertilizers.
Sustainable Crop Management	7. Crop Diversification and New Varieties	New varieties can enhance resilience of plants to stresses as a result of climate change like water and heat stress, water salinity and the emergence of new pests.
	8. Integrated Pest Management	Integrating crop, soil and pest management strategies can contribute to sustainable agricultural development, by providing a healthy and balanced ecosystem.
Sustainable Livestock Management	9. Livestock Disease Management	This technology can contribute to reducing livestock diseases, including vector-borne diseases which results from the changing climate.
	10. Selective Breeding via Controlled Mating	Controlled mating can enable the breeding of animals that are more resistant to the impacts of climate change, lowering risks of livestock loss to climate change.

Sustainable Farming Systems	11. Mixed Farming	Diversification of crops and livestock will allow farmers more options and more stable production against the impacts of climate change.
	12. Agro-forestry	Agroforestry can improve the resilience of the agricultural production to climate change. It can also play a crucial role in improving food security.
	13. Food Cubes	This technology uses wicking garden systems for growing fresh, nutritious fruits and vegetables, which is ideal in where top soil and water are limited, like in the Ha'apai Group, which can be further exacerbated by climate change.
Capacity Building & Stakeholder Organisation	14. Farmer-Field Schools (FFS)	FFS can equip farmers with greater understanding of agricultural systems and processes, including agronomic knowledge which can enhance adaptation to the impacts of climate change.
	15. Capacity building for research and extension officers	Enhancing the capacities of research and extension officers can contribute to their support services for farmers, including how to adapt and reduce vulnerabilities to climate change.

These adaptation technologies are classified into seven categories according to the Technologies for Climate Change Adaptation – Agriculture Sector Guidebook (Clement et.al, 2011). Stakeholders decided to focus on technologies for small-scale vulnerable farmers in Tonga. Consequently, a pre-screening process took place, narrowing down the list to eight technologies for further evaluation through the Multi-Criteria Analysis (MCA) process including:

1. Decentralized Community-run Early Warning Systems
2. Sprinkler Irrigation
3. Drip Irrigation
4. Integrated Soil Nutrient Management
5. Crop Diversification and New Varieties
6. Mixed Farming
7. Agro-forestry
8. Farmer-Field Schools (FFS)
9. Food Cubes (Additional technology, added during the MCA exercise)

The technology factsheet for the eight technologies were carried forward to the MCA process is provided in **Annex 1**. It includes information on the technology, it's application potential in Tonga, costs, financial requirements, technical aspects, and various benefits. These factsheets were revised based on additional information received from stakeholders' feedback.

3.5 Criteria and process of technology prioritisation

A set of criteria was selected to help prioritize the adaptation technologies. The consultant prepared a list of criteria, which was validated during MCA exercise by the sectoral working group for the agriculture sector. The final agreed criteria used for the MCA are presented in **Table 3**.

Table 3: Criteria and indicators used in the MCA for the prioritization of adaptation technologies for the agriculture sector

<table>
<tr><th>Criteria</th><th>Indicators</th><th>Scoring Scale</th><th>Preferred Scale</th></tr>
<tr><td>Cost</td><td>Cost to set up, operate and maintain the technology</td><td>USD/yr</td><td>Lowest value</td></tr>
<tr><td>Economic</td><td>Increase farmers income & ability to re-invest, catalyze private investment, create new jobs</td><td rowspan="6"><table><tr><td>0</td><td>Very Low Performance</td></tr><tr><td>1 - 20</td><td>Low Performance</td></tr><tr><td>21 - 40</td><td>Medium Performance</td></tr><tr><td>41 - 60</td><td>High Performance</td></tr><tr><td>61 - 80</td><td>Very High Performance</td></tr><tr><td>81 - 100</td><td>Outstanding Performance</td></tr></table></td><td rowspan="6">81 – 100 Outstanding Performance</td></tr>
<tr><td>Social</td><td>Contribution to social & sustainable development, contributions to GEDSI</td></tr>
<tr><td>Environment</td><td>Protects and safeguards the environment & sustain ecosystem services</td></tr>
<tr><td>Climate related</td><td>Enhance resilience to climate change and reduce vulnerability</td></tr>
<tr><td>Technology related</td><td>Ease of implementation</td></tr>
<tr><td>Political</td><td>Coherence with national development policies & priorities</td></tr>
</table>

At the sectoral working group meeting on 24th October 2023, the stakeholders decided to work in two groups to conduct the MCA so that each and every stakeholder gets to participate, instead of discussing everything as one big group. Each group later presented the results of their MCA and everyone else was given the opportunity to ask questions and/or provide feedback. Further discussions during the meeting eventually led to consensus on the top three prioritized technologies.

Table 4: Weightings assigned by each group to each criterion

		Weightings - Group 1		Weightings - Group 2	
Category	**Criteria**	**Level 1**	**Level 2**	**Level 1**	**Level 2**
Costs	Cost to set up, operate and maintain	15%		40%	
Economic	Increase farmers income & ability to re-invest	5%	33%	5%	50%
	Catalyze private investment	10%	67%	5%	50%
Social	Contribution to social & sustainable development	10%	33%	5%	50%
	GEDSI contributions	15%	67%	5%	50%

Environment	Contribution to protect & sustain ecosystem services	20%		10%	
Climate related	Enhance resilience to climate change	15%		10%	
Technology related	Ease of implementation	5%		5%	
Political	Coherence with national development policies & priorities	5%		15%	

Moreover, the stakeholders determined the weightings for each criterion in their respective group. **Table 4** shows the weightings used in the MCA analysis. Weighting Level 1 represents the primary weighting agreed by stakeholders' consensus and the other two weightings, which were decided by the consultants to consider the difference in opinions amongst the stakeholders during the national workshop, were used for the sensitivity analysis to evaluate the robustness of the MCA analysis.

3.6 Results of technology prioritisation

Group 1's top three ranked technologies (**Figure 3)** are Mixed Farming, Food Cubes and Farmer Field Schools. On the other hand, Group 2's top three technologies (**Figure 4**) were Mixed Farming, Integrated Nutrient Management and Food Cubes. The performance and scoring matrixes are in **Annex III**.

After thorough deliberations between the stakeholders, a consensus was reached and that wrapped up the MCA exercise activity with the following three prioritised technologies to proceed to the BAEF stage:

1. Mixed Farming
2. Food Cubes
3. Farmer Field Schools (FFS) but should include Integrated Nutrient Management in the curriculum / topics for FFS.

Figure 3: Results of Group 1's prioritization exercise using Weighting Level 1 in **Table 4**.

	Costs	Benefits									
		Economic			Social	Environment	Climate related	Technology Related	Political		
	Cost to set up, operate & maintain	Increase farmer's revenue & ability to re-invest	Catalysing private investement	Contribution to social & sustainable development	GEDSI Considerations	Contribution to ptorect & sustain ecosystem services	Enhancing resilience to climate change	Ease of implementation	Coherence with national policies and priorities	Total score	Ranking
Technology 1 (Decentralised Community-run EWS)	1333.3	250	800	700	1500	1400	1500	100	250	7833.3	4
Technology 2 (Sprinkler Irrigation)	833.3	450	1000	700	1200	1600	1200	25	250	7258.3	5
Technology 3 (Drip Irrigation)	1000.0	500	1000	800	1200	1200	750	150	250	6850.0	7
Technology 4 (Integrated Nutrient Management)	1500.0	500	1000	1000	900	800	900	150	250	7000.0	6
Technology 5 (Food Cubes)	1333.3	150	200	1000	1500	2000	1500	500	250	8433.3	2
Technology 6 (Mixed Farming)	1500.0	500	1000	1000	750	2000	1500	500	250	9000.0	1
Technology 7 (Agrofofestry)	0.0	350	700	500	750	1600	1200	400	250	5750.0	8
Technology 8 (Farmer Field Schools)	1166.7	400	800	600	900	2000	1500	500	250	8116.7	3
Criterion weight	15	5	10	10	15	20	15	5	5	100	

Figure 4: Results of Group 2's prioritisation exercise using Weighting Level 1 in **Table 4**.

	Costs	Benefits								Total score	Ranking
		Economic		Social		Environment	Climate related	Technology Related	Political		
	Cost to set up, operate & maintain	Increase farmer's revenue & ability to re-invest	Catalysing private investement	Contribution to social & sustainable development	GEDSI Contributions	Contribution to ptorect & sustain ecosystem services	Enhancing resilience to climate change	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Decentralised Community-run EWS)	3555.6	100	100	300	500	500	900	300	1500	7755.6	4
Technology 2 (Sprinkler Irrigation)	2222.2	300	300	300	300	800	900	100	1200	6422.2	6
Technology 3 (Drip Irrigation)	2666.7	250	250	250	250	700	800	50	1050	6266.7	7
Technology 4 (Integrated Nutrient Management)	4000.0	250	400	450	300	900	900	450	1200	8850.0	2
Technology 5 (Food Cubes)	3555.6	300	300	300	500	1000	1000	300	900	8155.6	3
Technology 6 (Mixed Farming)	4000.0	450	450	450	400	900	900	250	1200	9000.0	1
Technology 7 (Agrofofestry)	0.0	250	250	250	250	800	800	250	750	3600.0	8
Technology 8 (Farmer Field Schools)	3111.1	400	400	400	400	500	500	300	900	6911.1	5
Criterion weight	40	5	5	5	5	10	10	5	15	100	

Chapter 4 Technology prioritisation for the Water Sector

4.1 Key Climate Change Vulnerabilities in the Water Sector

Tonga's freshwater resources consist mainly of groundwater in the form of freshwater lenses. Surface water resources like lakes and springs only exist in some of the high volcanic islands. Crater lakes exist in islands like Niuafoʻou and Tofua and in Niuafoʻou, water from the lakes is used during dry periods. Water from river and cave systems are used as potable water in the island ʻEua.

While water in Tongatapu and Vavaʻu may currently be adequate even during drought periods, water in the other outer islands and low-lying islands of Ha'apai are threatened by drought and potential groundwater salination due to saltwater intrusion (DFAT, 2021).

Rainwater harvesting systems (RWH) are a complementary freshwater resource and a source of potable water in many islands throughout Tonga. In some of the smaller remote islands in Ha'apai and Vavaʻu, RWH sourced the only freshwater for the island populations, thus more vulnerable than other islands to any change in rainfall. Salinity monitoring boreholes (SMB) in Tongatapu, Ha'apai and Vavaʻu indicated brackish groundwater quality, especially in Vavaʻu where the water in then mostly used for non-potable purposes (GoT, 2019) .

In Tonga, most households prefer rainwater from RWH for drinking over piped water from groundwater, which is used domestically for cooking, bathing, washing, watering plants, cleaning the house and vehicles. Where drinking water is unavailable, piped water is boiled before drinking and some drinking water is fetched from neighbours or community water tanks (White, Falkland & Kula, 2020).

The reliance and preference for rainwater in Tonga is risky as rainfall is moderate and variable due to two predominant causes – ENSO and tropical cyclones. Historical data has also shown a general decrease in annual rainfall in central and southern parts of Tonga since 1970 (DFAT, 2020).

The La Niña phase of ENSO generally bring more rainfall in the wet season and El Niño years bring less wet season rainfall or drought conditions, significantly impacting availability of water and increasing the vulnerability of those local communities that rely solely on RWH.

Tropical cyclones pose risks for local communities, particularly those in low-lying areas and high population densities. These risks include road closure, flooding of houses, displacement of families, sewage overflows, contamination of water supplies, disruption of normal activities – work, school and others, and other critical risks to build infrastructure (DFAT, 2021). Tropical cyclones can also cause damages to house and buildings, impacting RWH systems and storage tanks, and can cause contamination by sea spray and partial overtopping by waves (GoT, 2019).

Tonga's TNC Report (2019) outlined the following issues pertaining to the water sector;

- The underground aquifer is liable to contamination from surface activities like farming, household wastewater and sewage within the recharge zone. There are no control measures and om addition to that, the porous nature of the ground offers little protection against contamination.
- A lot of improvement in needed in the storage and treatment of water which include untreated water being distributed to consumers due to insufficient chlorine on site and also the deterioration of the quality of the chlorine because of poor storage.
- Water demand in urban areas exceed the supply from TWB, putting additional pressure on existing water infrastructure.
- Insufficient attention given to staffing and resourcing of water agencies including those involved with water resources management, monitoring, operation and maintenance of water supplies.

Other issues were also identified in a policy paper by DFAT (2021) including;

- Lack of attention to wastewater management in Tonga, leading to pollution and contamination of water sources.
- Lack of nationally accepted framework for water quality and sanitation goals.
- Limited national coordination across jurisdictions and water systems lead to inefficient, siloed decision-making that can hamper resilience.
- While Tonga has established smart groundwater monitoring and water quality monitoring systems, there is an opportunity to improve the integration of the data collected, for better early warning protocols, identification of high-risk areas and coordinated public communication materials.
- Technical capabilities vary within key agencies and village water committees in particular lack the qualified staff, tools, technical expertise and reliable information needed to manage new risks.
- There is significant underinvestment in rural water infrastructure and resilience partly due to lack of widespread community ownership and a reluctance to raise rates.
- Additional rainwater harvesting, storage systems and desalination systems are needed considering Tonga's vulnerability to droughts, but these will need different approaches, noting the differences in service delivery between urban and rural areas
- The Tonga government should also consider exploring more formal commercial arrangements and foster private sector investments in the water sector.

4.2 Decision context

Water remains a top priority for Tonga, alongside with roads and power, especially improvements in the management of delivery of safe water supply for businesses and households, as in Tonga's NIIP 3.

The TSDF II highlights priority issues for Tonga's overall development, with Pillar 5 focusing on the natural resources, environment inputs and organisational outcomes that prioritise improved equitable and inclusive planning for and use of natural resources, and improved resilience to extreme natural events. Considering the water sector, the TSDF outlined various priorities including the improvement of the management and delivery of safe water supply for business and households.

Tonga's Climate Change Policy emphasizes Tonga's commitment towards resilience to the impacts of climate change and climate-related disaster risks. The policy's targets that are relevant to the water sector include Target 3 – Resilient homes, schools and community halls, with a minimum of 30,000L water storage capacity for homes among other requirements, Target 10 – Well-managed water resources and sufficient water for all in times of storage and Target 20 – Sustainable funding for climate change and resilience building needs.

The Hydrology and Water Resources Division (HWRD) Strategic Plan (2020 – 2030) provides information of the water landscape in Tonga with detailed priority actions for future activities, under the vision of "Adequate, accessible, safe and sustainably-managed freshwater throughout the King for the health, well-being, prosperity and continued development of all Tongans. The four strategic goals of the HWRD are:

1. Understand water resources and water-related systems in Tonga.
2. Value our water resources.
3. Manage our water resources sustainably under variable and changing climate and in the face of natural and human-induced hazards.
4. Serve our water-sector stakeholders efficiently and professionally.

The National Infrastructure Investment Plan 3 or NIIP3 has identified programs for the water sector including:

- Centralized TWB and Village Water Supply in Tongatapu
- Improved water supply system in Vava'u (Greater Neiafu)
- Improved 'Eua Water Supply System
- New water and sewage testing laboratory building

The Community Development Plans (CDP) prioritized the most urgent issues in each village. These plans were prepared over an extensive consultative process which resulted in identified priority areas for improvements. The highest overall priority area that all CDPs identified was improvements to village water supply (White, Falkland & Kula, 2020). Over 80% of the CDPs ranked water supply as a priority development issue (DFAT, 2021).

There have been a number of projects throughout Tonga, with activities specifically for the water sector. An overview of these projects is provided in **Table 5.**

Table 5: Some of the most relevant water and climate-related projects in Tonga.

Project	Description
Nuku'alofa Urban Development Sector Project (NUDSP) 2011 - 2020	This ADB project expanded on infrastructure development in Nuku'alofa including the provision of additional water supplies services and the improvement of solid waste management in Nuku'alofa.
Tonga Integrated Urban Resilience Sector Project (TIURSP)	This project by ADB is the next phase for the NUDSP, focusing on the improvement of living conditions in Nuku'alofa area and resilience to extreme natural events and climate change. Two of the project's five outputs are relevant to the water sector: Output 1 – Effective flood risk

	management system implemented (flood mitigation and climate change adaptation) & Output 2 – Improve water supply service in Nuku'alofa including a non-revenue water reduction program.
Strengthening water security of vulnerable island states Project	This project by MAFT conducted assessment of 60 community water supplies, provided community water tanks to priority villages after TC Gita and installed steel water stands in prioritised villages.
Australian Pacific Climate Change (APCC) Tonga Agri-Water Project (Tonga Groundwater Information System – ToGWIS)	Based in Tongatapu, this APCC Project was implemented in Tongatapu and it focused on the development of a smart groundwater management system utilizing climate information in response to shortage of water.
Integrated Water Resource Management (IWRM) Project	This project by the Global Environment Facility (GEF) and it has produced some IWRM Plans for communities in Tonga.
Pacific Resilience Program (PREP)	PREP by World Bank focuses on strengthening early warning, resilient investments, and financial protection of Tonga.
National Water Tank Project	Funded through the Climate Change Fund (formerly the Climate Change Trust Fund) , this project driven by MEIDECC, aims to install water tanks to households that do not have water tanks.
Other Water Tank Projects	NGOs like Live & Learn, MORDI, Caritas and Tonga Red Cross Society (TRCS) also provides water tanks to local communities, together with outreach and relevant training.

4.3 Overview of Existing Technologies in the Water Sector

Drawn from various existing literatures, the following are some of the existing water technologies within Tonga.

- Drought and flood planning
- Integrated Water Resources Management Plans
- Diesel and solar powered water pumps
- Desalination units
- Rainwater harvesting or RWH
- Infiltration galleries
- Water purification
- Water Treatment
- SBMs and rain gauges
- Water Safety Plans
- Consumer Education and Awareness
- Water conservation and plumbing
- Leakage control
- Drainage technologies

4.4 Adaptation Technology Options for the Water Sector and their main adaptation benefits

Table 6 provides a list of existing and/or planned technology options for the water sector, in which the TNA stakeholders agreed were relevant for water and would reduce the sector's vulnerability to the impacts of climate change as in **Section 4.1.**

Table 6: Technology options for the water sector

Technology Category	Technology	Adaptation Benefits for the Water Sector
Diversification of Water Supply	1. Mobile solar powered desalination units	Desalination provides an alternative water supply which can aid adaptation to climate change, especially in places with decreased rainfall. The use of solar will reduce the greenhouse gas emissions from the usual fuel-operated desalination units.
	2. Scaling up of Rainwater Harvesting from rooftops	Scaling up RWH can increase available water for households and the resilience to water quality degradation. Additionally, it can mitigate flooding by capturing rooftop runoffs during rainstorms.
	3. Fog / moisture water harvesting	Fogs have the potential to provide an alternative source of fresh water and can be harvested through the use of simple and low-cost collection systems. The captured water can then be used for agricultural irrigation and other domestic uses.
Groundwater Recharge	4. Water Reclamation & Reuse	This technology contributes to climate change adaptation by allowing water resources to be diversified, conserved and reused for various applications.
Preparation for Extreme Events	5. Post-construction support for community-managed water systems	Support for community-managed water systems can empower local communities to sustain their water resources and adapt to the changing climate and adverse weather events.
	6. Solar water pumps	Solar water pumps for community-managed water systems will be cheaper and also more environmentally friendly, in terms of no greenhouse gas emissions.
Resilience to Water Quality Degradation	7. Water safety plans (WSP)	WSP contributes to climate change adaptation at the catchment level primarily through increase resilience to water quality degradation, by recognizing that water supply systems can be affected by climate change.
	8. Solar disinfection (SODIS) for household drinking water treatment and safe storage	SODIS is cheap and environmentally friendly. It can increase the resilience to water quality degradation especially in remote and rural areas of Tonga.

Stormwater Control and Capture	9. Rainwater collection from ground surfaces	This technology can contribute to the collection and storage of rainwater for dry periods and droughts. Additionally, it can contribute reduce land erosion.
Water Conservation	10. Certification and labeling of water-efficient fixtures and appliances	The use of water efficient appliances and fixtures can preserve water and also slow the onset of water stress.
	11. Leakage management, detection and repair in piped systems	The detection and repair of leaks in water systems can save water, which can be subject to drought and subsequent decreased water availability.
	12. Smart Water Meters	Smart water meters can lead to faster leak detection and leak repairs. It can contribute to conserving water by reducing water waste.

The adaptation technologies in **Table 6** are categorised under six categories as per the Technologies for Climate Change Adaptation – Water Sector Guidebook (Eliott et. al, 2011). It was decided by the stakeholders that the focus will be on technologies for vulnerable households and community-managed water systems in Tonga. After the pre-screening, the list was narrowed down to ten technologies which were then carried forward for the Multi-Criteria Analysis (MCA) process, including:

1. Mobile solar powered desalination units
2. Solar disinfection (SODIS)
3. Post-construction support (PCS) for community-managed water supplies
4. Rainwater collection from ground surfaces
5. Scaling up of RWH from rooftops
6. Water reclamation or wastewater treatment & reuse
7. Smart water meters
8. Certification and labeling of water efficient fixtures & appliances
9. Solar water pumps
10. Moisture / Fog Harvesting

The technology factsheet for the eight technologies carried forward to the MCA process is provided in **Annex 1**, with information on the technology, application potential in Tonga, costs and financial requirements, technical aspects, and various benefits. These factsheets were revised after additional information were received from stakeholders' feedback.

4.5 Criteria and process of technology prioritisation

A set of criteria was selected to help prioritize the adaptation technologies. The consultant prepared a list of criteria, and it was validated and refined during the MCA exercise by the sectoral working group for the agriculture sector. The agreed final criteria which were used for the MCA is in ***Table 7***.

Table 7: Criteria for the prioritization of adaptation technologies in the water sector

Category	Criteria	Scoring Scale	Preferred Scale
Cost	Cost to set up, operate and maintain the technology	0 – Very Low Performance	0 – Very Low Performance
Economic	Improvement in economic performance	1 - 20 – Low Performance 21 - 40 – Medium Performance	81 – 100 Outstanding Performance
Social	Contribution to social & sustainable development, contributions to GEDSI	41 - 60 – High Performance 61 - 80 – Very High Performance	
Environment	Protects and safeguards the environment & sustain ecosystem services	81 - 100 – Outstanding Performance	
Climate related	Enhance resilience to climate change and reduce vulnerability		
Technology related	Ease of implementation		
Political	Coherence with national development policies & priorities		

There were no readily available data or information on the costs to set up, operate and maintain the adaptation technologies, so the sectoral working group evaluated the technologies using a score of 0 – 100, where lower values mean weak performance against the criteria, and the opposite apply to higher values.

Moreover, the stakeholders determined the weightings for each criterion in their respective group. **Table 8** shows the weightings used in the MCA analysis. Weighting Level 1 represents the primary weighting agreed by stakeholders' consensus and the other two weightings, which were decided by the consultants to take into account the difference in opinions amongst the stakeholders during the national workshop, were used for the sensitivity analysis to evaluate the robustness of the MCA analysis.

Table 8: Weightings assigned by each group to each criterion

		Weightings - Group 1		**Weightings - Group 2**	
Category	**Criteria**	**Level 1**	**Level 2**	**Level 1**	**Level 2**
Costs	Cost to set up, operate and maintain	25%		15%	
Economic	Improvement in economic performance	5%		5%	
Social	Job Creation	5%	20%	5%	20%
	Improve Human Health	15%	60%	15%	60%
	GEDSI contributions	5%	20%	5%	20%
Environment	Contribution to protect & sustain ecosystem services	10%		5%	

Climate related	Enhance resilience to climate change	15%	60%	20%	80%
	Water & Energy Efficiency	10%	40%	5%	20%
Technology related	Ease of implementation	5%		20%	
Political	Coherence with national development policies & priorities	5%		5%	
Total Weights		100%		100%	

4.6 Results of technology prioritisation

Group 1's top three ranked technologies were Post-construction support (PCS) for community-managed water supplies, SODIS and Scaling up of RWH from rooftops. On the other hand, Group 2's top three technologies were Scaling up of RWH from rooftops, post-construction support (PCS) for community-managed water supplies and Mobile solar powered desalination units.

The stakeholders deliberated on each group's 3 choices of technologies, with justifications for their selected top 3 technologies. Group 1 prioritised the criteria of; cost to set up, operate & maintain (25%), enhancing resilience to climate change (15%) & improve human health (15%). Group 2 on the other hand prioritised enhancing resilience to climate change (20%), ease of implementation (20%) and cost to set up, operate and maintain (15%) & improve human health (15%).

Although the SODIS technology was ranked highly in terms of costs and ease of implementation, it was agreed amongst the stakeholders that it is quite low on the improve human health criterion and as such should be eliminated from the top 3 technologies due to health concerns over water safety and quality for drinking. Additionally, the mobile solar powered desalination unit was proposed as the top third technology for its adaptation and mitigation benefits, and possible contributions to Tonga's renewable energy targets and aspirations.

A consensus was finally reached and that wrapped up the MCA exercise activity with the following three prioritised technologies for the water sector, to proceed with to the BAEF stage:

1. Scaling up of RWH from rooftops
2. Post-construction support (PCS) for community-managed water supplies
3. Mobile solar powered desalination units

	Costs	Benefits									Total score	Ranking
		Economic	Social			Environment	Climate related		Technology Related	Political		
	Cost to set up, operate and maintain	Improvement in economic performance	Contribution to social & sustainable development	Improve Human Health	GEDSI Contributions	Contribution to protect & sustain ecosystem services	Enhancing resilience to climate change	Water & Energy Efficiency	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Mobile Solar-powered Desalination Units)	1000	300	400	750	250	500	1200	500	225	100	5225	5
Technology 2 (Solar Disinfection)	2250	100	350	300	350	800	900	600	350	100	6100	2
Technology 3 (PCS for community-managed water supplies)	1500	300	300	1200	450	800	1200	600	300	250	6900	1
Technology 4 (Rainwater collection from ground surfaces)	1000	300	400	900	250	500	1050	500	250	250	5400	5
Technology 5 (Scaling up of RWH)	1000	100	350	1050	350	700	1200	700	200	300	5950	3
Technology 6 (Water reclamation)	500	100	300	1050	250	500	900	600	100	200	4500	6
Technology 7 (Smart Meters)	500	300	300	300	250	500	750	800	50	250	4000	7
Technology 8 (Certification & Labeling)	500	300	300	300	250	500	750	800	50	250	4000	7
Technology 9 (Solar Water Pumps)	500	300	300	300	250	500	750	800	50	250	4000	7
Technology 10 (Moisture / Fog Harvesting)	500	300	300	300	250	500	750	800	50	250	4000	7
Criterion weight	25	5	5	15	5	10	15	10	5	5	100	

Figure 5: Results of Group 1's prioritization exercise using Weighting 1 in ***Table 8***.

	Costs	Benefits									Total score	Ranking
		Economic	Social			Environment	Climate related		Related	Political		
	Cost to set up, operate and maintain	Improvement in economic performance	Contribution to social & sustainable development	Improve Human Health	GEDSI Contributions	Contribution to protect & sustain ecosystem services	Enhancing resilience to climate change	Water & Energy Efficiency	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Mobile Solar-powered Desalination Units)	900	350	300	1350	500	250	2000	250	1200	500	7600	3
Technology 2 (Solar Disinfection)	1350	100	250	150	500	400	1600	300	2000	350	7000	4
Technology 3 (PCS for community-managed water supplies)	1050	400	500	1200	500	450	2000	500	1400	500	8500	2
Technology 4 (Rainwater collection from ground surfaces)	300	100	350	750	250	300	1200	250	200	400	4100	9
Technology 5 (Scaling up of RWH)	1500	400	400	1200	500	300	2000	500	1800	500	9100	1
Technology 6 (Water reclamation)	450	300	250	150	250	400	1600	350	800	350	4900	7
Technology 7 (Smart Meters)	450	150	250	900	300	400	1800	500	800	350	5900	5
Technology 8 (Certification & Labeling)	1350	150	200	750	250	400	1800	500	1200	400	7000	4
Technology 9 (Solar Water Pumps)	300	250	300	900	300	400	1200	250	1400	400	5700	6
Technology 10 (Moisture / Fog Harvesting)	300	200	250	600	300	400	1600	250	400	200	4500	8
Criterion weight	15	5	5	15	5	5	20	5	20	5	100	

Figure 6**:** Results of Group *2*'s prioritization exercise using Weighting 1 in ***Table 8***.

The performance and scoring matrix for both Group 1 and 2 can be found in Annex ***III***.

Summary and Conclusions

The technology needs assessment was a nationally driven, gender-inclusive process involving relevant stakeholders from government, non-government and private sector organizations in Tonga. The review of national plans, policies and previous vulnerability assessments led to the prioritisation of the two sectors – Agriculture and Water, for the TNA process of prioritizing technologies for climate change adaptation.

A list of technologies was identified for each of the prioritised sectors and was later shortlisted to a list of only 8 technologies for the agriculture sector and 10 technologies for the Water sector, for prioritisation during a two days' workshop with the sectoral working groups on the 24th and 25th October 2023.

The shortlisted technologies underwent evaluation and prioritisation using the MCA tools. The prioritisation of the technologies was based on various criteria, including costs and benefits, agreed upon by the stakeholders. The TFS were developed for the shortlisted technologies and were validated with amendments as suggested by the stakeholders.

The following technologies were prioritised as the most preferred technology options for the respective sectors:

- **Agriculture Sector**
  1. Mixed Farming
  2. Food Cubes
  3. Farmer Field Schools (FFS)

- **Water Sector**
  1. Scaling up of RWH from rooftops
  2. Post-construction support (PCS) for community-managed water supplies
  3. Mobile solar powered desalination units

List of References

Clements, R., J. Haggar, A. Quezada, and J. Torres (2011). *Technologies for Climate Change Adaptation – Agriculture Sector*. X. Zhu (Ed.). UNEP Risø Centre, Roskilde, 2011

CSIRO and SPREP (2021). 'NextGen' *Projections for the Western Tropical Pacific: Current and Future Climate For Tonga. Final report to the Australia-Pacific Climate Partnership for the Next Generation Climate Projections for the Western Tropical Pacific Project*, Melbourne, Australia

DFAT. 2021. *Identification of Options for a Partnership Program to Strengthen Water Management and WASH Service Delivery in Tonga*, Nuku'alofa, Tonga

Dhar, S., Painuly, J. Nygaard, I., and Rogat, J. (2014). *Organising the National TNA Process: An Explanatory Note*, UNEP DTU Partnership

Dhar, S., Desgain, D., and Narkev, R. (2015). *Identifying and prioritising techologies for mitigation – A hands on guidance to multi-criteria analysis (MCA)*, UNEP DTU Partnership

Elliot, M., Armstrong, A., Lobuglio, J. and Bartram, J. (2011). *Technologies for Climate Change Adaptation— The Water Sector*. T. De Lopez (Ed.). Roskilde: UNEP Risoe Centre

Food and Agriculture Organisation and the Pacific Community, (2019), *Country Gender Assessment of Agriculture and the Rural Sector in Tonga*, Nuku'alofa, Tonga.

Government of Tonga, (2015), *Tonga Strategic Development Framework 2015-2025*, Nuku'alofa, Tonga.

Government of Tonga ,(2016), *Tonga Climate Change Policy*, Nuku'alofa, Tonga.

Government of Tonga, (2018), *Joint National Action Plan 2 on Climate Change and Disaster Risk Management (JNAP 2) 2018-2028*, Nuku'alofa, Tonga.

Government of Tonga, (2018), *Tonga – Green Climate Fund Country Programme*, Nuku'alofa, Tonga.

Government of Tonga, (2019), *Third National Communication on Climate Change*, Nuku'alofa, Tonga.

Government of Tonga, (2021), *Tonga Disaster Risk Financing Strategy 2021-2035*, Nuku'alofa, Tonga.

Government of Tonga, (2022), Government Priorities Agenda 2022 – 2025, Nuku'alofa, Tonga.

Government of Tonga, (2022), *Hunga Tonga-Hunga Haápai Volcanic Eruption and Tonga Tsunami (HTHH Disaster) Recovery and Building Back Better Plan 2022 - 2025*, Nuku'alofa, Tonga.

Ministry of Agriculture, Food and Forests, (2015), *Tonga National Agricultural Census*, Nuku'alofa, Tonga.

Ministry of Agriculture, Food and Forests, (2016), *Tonga Agriculture Sector Plan 2016 – 2020*, Nuku'alofa, Tonga.

Ministry of Agriculture, Food and Forests, (2022), *Annual Report 2021 - 2022*, Nuku'alofa, Tonga.

Ministry of Agriculture, Food and Forests, (2021), *Annual Report 2020 - 2021*, Nuku'alofa, Tonga.

Ministry of Internal Affairs, (2019), *National Women's Empowerment and Gender Equality Tonga Policy and Strategic Plan of Action 2019 – 2025*, Nuku'alofa, Tonga.

Tonga Statistics Department, 2021. *Tonga Census of Population and Housing 2021*, Nuku'alofa, Tonga: Tonga Statistics Department.

Trærup, S and Bakkegaard, R, (2015), Determining *technologies for climate change adaptation – A hands-on guidance to multi criteria analysis (MCA) and the identification and assessment of related criteria*, UNEP DTU Partnership

Annex I: Technology Factsheets for selected technologies

The following TFS are for the top three prioritised technologies for the Agriculture and Water Sector. The information for the TFS were adapted from the TNA Guidebooks for Agriculture (Clement et al, 2011) and Water (Elliot et al, 2011) with contextual information for Tonga, from various sources.

A. Agriculture Sector

Technology: Mixed Farming	
Sector: Agriculture	
Subsector: Sustainable Farming Systems	
Technology Characteristics	
Introduction	Mixed farming is an agricultural system in which a farmer conducts different agricultural practice together, such as cash crops and livestock. The aim is to increase income through different sources and to complement land and labour demands across the year.
Characteristics / highlights	Mixed farming systems can be classified in many ways. They can be based on land size, type of crops and animals, geographical distribution, market orientation, and so on. Three major categories are distinguished here; • On-farm versus Between-farm Mixing - This refers to mixing on the same farm, and between-farm mixing refers to exchanging resources between different farms. On-farm mixing enables the recycling of resources generated on a single farm. Between-farm mixing can be used to resolve waste disposal problems where by crop farmers use waste from animal farms for fertiliser. • Mixing within Crops and/or Animal Systems - This practice involves multiple cropping or keeping different types of animals together. For example, grain- legume association can provide grain with nitrogen. With plant inter-cropping farmers can make the most of the space available to them by selecting plants and cropping formations that maximize the advantage of light, moisture and soil nutrients. Examples of mixed animal systems include chicken-fish production where chicken waste serves as fish fodder. • Diversified versus Integrated Systems - some components exist as independent units. In an integrated system, maximum use is made of resources, making the system highly interdependent.
Institutional and organizational requirements	This technology needs to have qualified technicians both in agronomy and livestock production. The organisations must identify the farmers that are familiar with the technique of multiple crops in the area and develop positive relationships with them.
Operation and maintenance	As for most cases, to estimate the costs of implementing this technology the cost of wages, agricultural tools, and inputs (such as seeds and fertilizers) must be considered. Infrastructure for supporting livestock will be an added cost in crop-animal systems. The main financial needs are associated with credits for the acquisition of inputs, investment in training and in the dissemination of this technology. Investment is needed also to obtain the necessary qualitative and quantitative micro-climate information for managing the synchronisation of mixed crop cycles (phenologies).

Endorsement by experts	Tonga's TNC highly recommend Mixed Farming as an adaptation strategy.
Adequacy for current climate	Mixed farming technology contributes to adaptation to climatic change because the diversification of crops and livestock allows farmers to have a greater number of options to face the uncertain weather conditions associated with the increased climate variability. Mixed farming can also give a more stable production because if one crop or variety fails, another may compensate. Livestock represents a means by which families can save and invest in the future. Livestock is a walking bank of assets that can be sold during periods of need such as if crops fail due to drought or flooding.
Scale/Size of beneficiaries group	Can be for all farmers, subsistence, semi-subsistence and commercial, in Tonga.
Disadvantages	One limitation is that production levels in mixed systems (tons per hectare, milk per animal daily, increase and reproduction rates), can be lower than in specialised systems (monoculture). Another disadvantage is that where farmers depend on wild animal stock rather than domesticated species, they may face increased vulnerability in instances where animal population levels are affected due to climate change (for example, where livestock populations need to be trimmed).
Capital costs	
Cost to implement adaptation technology	As for most cases, to estimate the costs of implementing this technology the cost of wages, agricultural tools, and inputs (such as seeds and fertilizers) must be considered. Infrastructure for supporting livestock will be an added cost in crop-animal systems. The main financial needs are associated with credits for the acquisition of inputs, investment in training and in the dissemination of this technology. Investment is needed also to obtain the necessary qualitative and quantitative micro-climate information for managing the synchronisation of mixed crop cycles (phenologies). The approximated cost to implement a mixed farming by a single farmer in Tonga was set at $10,000 USD per year, noting that this could vary, given varying factors such as land ownership, types of crops and animals, market orientation and so forth.
Development impacts, direct and indirect benefits	
Direct benefits	This technology also allows greater food security and improved household nutrition levels. In addition, farmers can generate a surplus of some products that can be sold at market. Among other benefits, this technology also allows farmers to grow fodder for livestock and poultry.
Reduction of vulnerability to climate change, indirect	
Economic benefits, indirect	
Social benefits, indirect	
Environmental benefits, indirect	
Local Context	
Opportunities and Barriers	The main obstacle for the implementation of this technology is farmers' reluctance since mixed farming is considered to have low productivity in comparison with monocultures which have a high yield in terms of tons per hectare (t/ha). The best way to overcome these barriers is to demonstrate mixed farming systems with better productivity levels; to disseminate the benefits of this technology, and to provide training. This can be facilitated by the MAFF, in addition to their other demonstration activities.

	The main opportunity for implementing mixed farming is that it improves and guarantees the range of products a farmer has available to sell at market. One option to increase productivity while maintaining economic and environmental benefits of mixed farming is specialisation. Partnerships with specialised farms are formed to facilitate the exchange of crops and waste products from manure. For example, the traditional association between nomads and farmers reaping where nomadic cattle converts crop residues into manure for cultivation.
Market potential	Low
Status	Already existed as it used to be a traditional farming practice in Tonga.
Timeframe	Short to Medium term
Acceptability to local stakeholders	High if demonstrations will showcase benefits

Technology: Food Cubes	
Sector: Agriculture	
Subsector: Sustainable Crop Management	
Technology characteristics	
Introduction	Food cubes are technologies that can be distributed to households and established at community garden sites. Each Food cube has the potential to produce up to 25kg of fresh produce per annum and offers significant advantages where access to fresh water and topsoil is limited.
Characteristics / highlights	Using food cubes, crops such as sweet potato, Chinese cabbage, spinach, tomato, taro and chili can be grown effectively using less water and other inputs, less labour and more productively E.g. A pilot project in Tuvalu which aims to revive traditional integrated farming practices and consequently increase land productivity; as well as improving knowledge and awareness of the benefits of local food.
Institutional and organizational requirements	Strong ownership by local stakeholders such as island councils, respective departments of agriculture and communities, including women's and youth groups, will ensure that the intervention is effective and sustainable.
Operation and maintenance	Intensive training in compost production and planting is also being conducted. The program is exploring increased use of animal waste streams to support improved compost production and plant health, training stakeholders on integrated pest and disease management, and assessing the marketing and promotion of diverse nutritious local crops.
Endorsement by experts	Endorsed as an effective climate change adaptation strategy especially for low lying atolls.
Adequacy for current climate	Can be replicated in Tonga given our similarity with Tuvalu in land size and limited agricultural land especially in urban areas.
Scale/Size of beneficiaries group	Small – Large Scale
Disadvantages	Monitoring of food cubes and maintaining the initiative especially with busy households in urban areas.
Capital costs	
Cost to implement adaptation technology	The approximated cost for this technology is $20,000 USD, which was derived from the costs for about 4 food cubes plus accessories

	for 1 farmer in Tonga, if sourced from Food Cube, Biofilta Pty Ltd, Australia (supplier of food cubes for the Live & Learn Project). The cost may vary depending on where the food cubes will be sourced from – NZ, Australia, USA or China.
Development impacts, direct and indirect benefits	
Direct benefits	Farming at home / villages, without having to travel far.
Reduction of vulnerability to climate change, indirect	Can also support MoH's efforts towards healthy eating, active lifestyles and combating NCDs.
Economic benefits, indirect	
Social benefits, indirect	
Environmental benefits, indirect	
Local Context	
Opportunities and Barriers	Opportunities for backyard gardening which can involve all members of families / communities. Also ideal for those without any bush or tax allotment for farming.
Market potential	High especially if it gets the buy-in from donors and development partners.
Status	Already trialed in Tonga, in Ha'apai and 'Eua Island, by Live & Learn Tonga. Looking at replicating to other parts of Tonga not covered by the Live & Learn Tonga's Project.
Timeframe	Short – Medium-term
Acceptability to local stakeholders	Can use success stories from the Live & Learn's Project to raise awareness on the benefits of the technology and also to obtain stakeholders acceptance. Can also work together with Live & Learn Project's partners such as DFAT, SPC, ACIAR, CSIRO and other research organisations

Technology: Farmer Field Schools	
Sector: Agriculture	
Subsector: Capacity building and stakeholder organisation	
Technology characteristics	
Introduction	The Farmer Field School is a group-based learning process that has been used by a number of governments, NGOs and international agencies originally to promote integrated pest management (IPM). The first FFS were designed and managed by the Food and Agriculture Organisation (FAO) in Indonesia in 1989. They were developed in response to perception that small farmers were not managing agrochemical-based agriculture well, particularly pest management through the use of pesticides. Many farmers did not have the resources to use pesticides, and sometimes wrong uses and storage caused the problems of poisoning. Furthermore, many pests seemed to rapidly develop resistance to the pesticides. FFSs bring together concepts and methods from agroecology, experimental education and community development, as a group-based learning process. Overall, FFSs look to reinforce the understanding of farmers about the ecological processes that affect the production of their crops and animals, through conducting field learning exercises such as field observations, simple experiments and group analysis. The knowledge

	gained from these activities enables participants to make their own locally-specific decisions about crop management practices. Although FFSs were initiated as a training process for pest control in field crops, the principles have now been adapted to all agricultural production systems from livestock to coffee production.
Characteristics / highlights	The FFS approach represents a radical departure from earlier agricultural extension programmes, in which farmers were expected to adopt generalised recommendations that had been formulated by specialists from outside the community.
Institutional and organizational requirements	The curriculum of the FFS was built on the assumption that farmers could only implement integrated crop management once they had acquired the ability to carry out their own analysis, make their own decisions and organise their own activities. The process of empowerment, rather than the adoption of specific management techniques, is what produces many of the developmental benefits of the FFS.
Operation and maintenance	FFS require facilitators to have abilities in developing understanding of the participants of agroecological processes, but not through 'lecturing' on these processes, but through facilitating the farmers in discovery exercises to find out and understand these processes. Subsequently management options are defined through the integration of local knowledge of the farmers and ecological knowledge gained through the FFS.
Endorsement by experts	High
Adequacy for current climate	Climate change brings many complex and unpredictable changes that affect the viability and management of farming systems. Not only are there trends in the change of temperature and rainfall, but also increased climate variability especially in the duration and intensity of the seasons. This affects a whole range of conditions relating to the performance and management of different farming systems, from planting time, to flowering, to the prevalence of different pests and diseases. To cope with this increased variability farmers will need a greater understanding of the processes that affect the performance of the different production systems they manage and undergo constant experimentation and adaptation of these production systems. More so even than the agronomic knowledge that farmers acquire from participating in farmer field schools, the habits and abilities of constant adaptation are essential for farmers to be able to cope with climate change.
Scale/Size of beneficiaries group	Depends on target group / communities. Can be a whole-country initiative.
Disadvantages	Educating farmers through FFS requires more time from both farmers and extensionists than simple technology transfer or technical recommendations. The experimentation conducted may initially generate more failures than successes, but so too have technical recommendations in the contexts of small farmer agriculture. In the medium-term farmers participating in FFS leads to more sustainable impacts.
Capital costs	

Cost to implement adaptation technology	Fundamental to the success of FFS is the training of the trainers of facilitators of the FFS. This often requires re-training of extension personnel in a range of skills and attitudes that were not part of their initial training. Extension personnel have typically been trained in technology transfer rather than adult education and participatory learning. The estimated cost to conduct a FFS in Tonga for about 20 – 25 farmers, for a season-long field school is about $30,000. The cost may also vary depending on the crops that the FFS may focus on, the availability of trainers / facilitators and the geographical scope of the FFS, noting it is more expensive in the main island of Tongatapu than further out in the smaller and remote islands.
Development impacts, direct and indirect benefits	
Direct benefits	Farmer field schools represent an effective mechanism for group training that can reach thousands of small-scale farmers with knowledge and technical content that each can adapt to their own unique circumstances. Beyond this, as has been indicated, these processes empower farmers, both individually and collectively, to more effectively participate in the processes of agricultural development.
Reduction of vulnerability to climate change, indirect	More so even than the agronomic knowledge that farmers acquire from participating in farmer field schools, the habits and abilities of constant adaptation are essential for farmers to be able to cope with climate change.
Economic benefits, indirect	
Social benefits, indirect	
Environmental benefits, indirect	
Local Context	
Opportunities and Barriers	Farmer field schools require substantial changes to the capacity of agricultural extension services, both in terms of the policies of agricultural development and the abilities of those who execute it. Re-training of agricultural extension services both represents an investment, but also resistance at all levels can be a significant impediment. Also, since FFS has become a popular concept, there is the danger that the name is used for any kind of group training, but that does not really follow the concepts of building the learning capacity of the participants.
Market potential	High
Status	Already exist in Tonga to some extent but needs strengthening and replicating. May also need to strengthen the capacities of the MAFF to support FFS.
Timeframe	Medium – Long-term
Acceptability to local stakeholders	High

B. Water Sector

Technology: Scaling up of Rainwater Harvesting from Rooftops (RWH)	
Sector: Water	
Subsector: Diversification of water supply; Resilience to water quality degradation; Stormwater control and capture	
Technology characteristics	
Introduction	RWH is the collection of rainwater from rooftop catchments for household and institutional water supply.

Characteristics / highlights	This scaled-up technology calls for the add on or incorporation of water quality protection measures and other additions to the existing RWH including; • Filtration/ screening with tank screens / mesh • Chemical disinfection like rainwater tank chlorination on a regular basis • First flush diverters • Gauges • May also include ensuring the tank in the RWH is positioned so that it's accessible to people living with disabilities
Institutional and organizational requirements	The government may consider establishing RWH standards and modifying the building codes to include the new standards with accompanying guidance. Noted that different standards will be needed for different levels of implementation – household, schools, churches, public facilities etc
Operation and maintenance	Maintenance of the RWH systems plus improvements to some rooftops may be costly for poor households. RWH for dual piped systems requires professional plumbers who are trained to install and maintain such systems. Capacity building for local plumbers will be needed.
Endorsement by experts	These additional items are endorsed to add value to water quality.
Adequacy for current climate	RWH contributes to climate change adaptation at the household level primarily through two mechanisms: (1) diversification of household water supply; and (2) increased resilience to water quality degradation. It can also reduce the pressure on surface and groundwater resources (e.g. the reservoir or aquifer used for piped water supply) by decreasing household demand and has been used as a means to recharge groundwater aquifers. Another possible benefit of rooftop RWH is mitigation of flooding by capturing rooftop runoff during rainstorms.
Scale/Size of beneficiaries group	Can be for all RWH systems at households to community to public places.
Disadvantages	It may be costly to assess what exists and what needs scaling up at each RWH system, like a baseline survey for all RWH systems in Tonga.
Capital costs	
Cost to implement adaptation technology	The cost of the additional RWH elements may vary depending on the size of the storage containers / water tanks and also the existing features at each RWH system. Transportation costs will also be needed if technology will be diffused to outer islands throughout Tonga. The minimum approximated cost for the application of one or some additional features of this technology to one household in Tonga is about $500 USD.
Development impacts, direct and indirect benefits	
Direct benefits	Scaling up existing RWH can contribute to development by saving money and time. It can also reduce expose to waterborne pathogens by ensuring high potable water quality for drinking and other household purposes such as hygiene, bathing etc.
Reduction of vulnerability to climate change, indirect	

Economic benefits, indirect Social benefits, indirect Environmental benefits, indirect	Scaling up RWH can also increase per capita water availability, increasing the sustainability of water resources and reducing public and private expenditures associated with water infrastructure.
Local Context	
Opportunities and Barriers	Opportunities for investment in scaled-up RWH will be greatest when locals buy-in that it's investment for improved water quality and health gains. Barriers to implementation include inadequate or unsuitable roofing, lack of space for storage containers / water tanks and extreme air pollution.
Market potential	Potential is high as capital costs maybe lower due to existing RWH systems and numerous potential suppliers in Tonga.
Status	RWH is a common technology in Tonga for the collection of rainwater for drinking but it is becoming increasingly used for other domestic non-potable use as well. RWH systems in Tonga vary from residential rooftops to schools, churches and other institutions collecting water through the same system. There's also an increase in household dual piped systems where households use both piped water from TWB or village water sources together with water from RWH.
Timeframe	Implementation can be immediate if building on existing RWH systems.
Acceptability to local stakeholders	Subsidization of these add-on elements to the RWH may contribute to uptake. Again, if subsidization goes towards piped water systems, then this proposed technology will not be as popular.

Technology: Post-construction support (PCS) for community-managed water supplies	
Sector: Water	
Subsector: Diversification of water supply; Preparation for extreme weather events; Resilience to water quality degradation.	
Technology characteristics	
Introduction	Rural water supply interventions such as post-construction support (PCS) are needed in Tonga to ensure success and sustainability of community-managed or village-managed water systems. PCS is typically carried out through government programs, municipalities, multilateral donors, and various NGOs. Types of PCS can include, but are not limited to: • Technical training for water system operators • Technical and engineering support, including provision of technical manuals • Financial and accounting assistance (e.g., setting tariffs) • Help settling disputes (e.g., bill payment or water sources) • Help with maintenance, repairs and finding spare parts • Help finding external funding for operations and maintenance (O&M), expansion or repairs • Help assessing the sufficiency of supply for expansion or in the case of drought

	• Household visits to residents to discuss water system use, etc.
Characteristics / highlights	PCS can either be demand-driven (solicited) or supply-driven(non-solicited). Non-solicited PCS like providing free repairs and free technical assistance have been proven futile and do not lead to improved system sustainability or user-satisfaction. Solicited programs on the other hand have proven more successful as the decision to pursue PCS is initiated by the community / village.
Institutional and organizational requirements	There are four basic PCS institutional models and hybrids combining aspects of more than one: • Centralized Model: where support services are provided by a government agency or ministry operating from a centralized point, directly engaging with community management structures in rural areas • Deconcentrated Model: under which support services are provided by a central government agency operating, with a degree of autonomy, through regional or departmental level offices • Devolution Model: where the authority and responsibility for provision of support services is transferred from a central government agency to a decentralized tier of government, usually at the municipal level • Delegated Model: where the responsibility for provision of support services is delegated from a central or local government agency to a third party, which could be an NGO, a private sector company or a relevant user association Regardless of the model, it is important that the roles and responsibilities among PCS staff are well defined. More crucially, perhaps, it is imperative that community water committees understand clearly which operation, maintenance and administration tasks are the responsibility of the community. The respective roles of all stakeholders involved should be recorded and widely disseminated.
Operation and maintenance	Non-solicited PCS can include; • Non-technical financial and managerial training for committees or system operators • Non-technical support visits to help village water committees with administrative functions and resolution of disputes
Endorsement by experts	It is widely accepted that PCS support is needed to broaden membership and increase capacity and capability base of rural village water committees in Tonga, to maintain their community-managed water supplies.
Adequacy for current climate	Community-managed water supplies are typically more vulnerable to extreme weather events and less able to assess water resource sustainability in comparison to utility-managed systems like those in urban areas by TWB.

	PCS can empower community water committees and operators to access the financial, management and technical resources to prepare for and adapt to adverse weather events like droughts.
Scale/Size of beneficiaries group	Local villages in rural areas and outer / remote islands in Tonga whereby water systems are managed by village/island water committees.
Disadvantages	Previous successes in PCS led many to the incorrect assumption that, if best practices were followed during implementation, PCS would be unnecessary. The successes of PCS may also vary as there's no one size fits all, nothing that local communities vary in circumstances.
Capital costs	
Cost to implement adaptation technology	PCS need reliable source of funding for costs like salaries, office overhead expenses, training costs and transportation for field staff. Contributions from authorities within Tonga's water governance structure such as TWB, MOH and NRD (MLNR) are also critical for PCS. The minimum approximated cost for the application of one or some of the PCS activities for one village in Tonga is $5,000 USD, with costs to be higher, if taken further outwards to the outer islands.
Development impacts, direct and indirect benefits	
Direct benefits	PCS can contribute to improving the performance and sustainability of community-managed water systems.
Reduction of vulnerability to climate change, indirect	Increasing the resilience of rural communities to climate change and disasters Communities benefit from other developments from the funds collected from water fees / bills. Ownership of community-managed water systems leading to maintained social cohesion and overall well-being.
Economic benefits, indirect	
Social benefits, indirect	
Environmental benefits, indirect	
Local Context	
Opportunities and Barriers	PCS is sometimes viewed as a waste of resources by organizations that prefer projects with clearer or more tangible metrics of success like number of people provided with clean water / water tanks. Politicians may also prefer unveiling / ceremonies for new water projects than PCS and this goes to show that not all stakeholders are aware of the importance of PCS. There are opportunities for trialing PCS in pilot sites and replication later throughout the country, but need to document the successes and lessons learned for improvement to future PCS activities.
Market potential	There's potential for PCS to be led and conducted by local experts as this will not only contribute to the ease of acceptance of the technology but also PCS can also benefit from the integration of local knowledge / contexts from the planning to the impementation stages.
Status	The rural water supplies are operated by village rural water supplies with support and training provided by the Ministry of Health. The water supplies for most of the villages and outer islands are sourced from groundwater which is normally pumped from drilled wells and some old dug wells. Water resources for households are supplemented harvesting of rainwater from roof catchments. On the island of Eua, small streams flowing from caves are for the primary

	water supply. On the island of Lifuka where the groundwater resource (freshwater lens) is limited, water supply improvements have been implemented by constructing infiltration galleries to replace earlier boreholes. Most of the islands in Tonga fall into the category "very small island" usually have a width of an area not greater than 100 square meters or a width greater than 3 km the water resources on these islands are primarily dependent on rainwater and supplemented by underground water.
Timeframe	Implementation can be immediate, if building on previous and existing activities and if concerned government MDAs are committed to supporting PCS for local villages / communities.
Acceptability to local stakeholders	Awareness of the importance and ownership of PCS efforts by local communities are critical for acceptance and prioritisation of the technology.

Technology: Mobile solar powered desalination units for desalination of seawater	
Sector: Water	
Subsector: Diversification of water supply, Resilience to water quality degradation	
Technology characteristics	
Introduction	Seawater desalination is a process in which salt and other constituents are removed to produce pure water. Over 97% of the water on earth is unsuitable for human consumption due to its salinity. The vast majority (about 99%) of this is seawater, with most of the remainder consisting of saline groundwater. Purification of this saline water holds the promise of nearly unlimited water resources. However, purification of seawater is expensive, energy intensive and often has large adverse impacts on ecosystems. Despite these drawbacks, desalination can be an appropriate technology for Tonga as technological advancements continue to decrease the economic and environmental costs of desalination.
Characteristics / highlights	Two streams of water result from desalination: (1) a pure product water and (2) a high-concentration waste stream or brine. The principal desalination methods fall into two categories: thermal processes and membrane processes. Thermal treatment uses heat to evaporate the water, leaving behind the dissolved salts, or waste stream, and separating it from pure water. Membrane processes use reverse osmosis and high pressure to force saltwater through very fine, porous filters that retain the salts, leaving pure water on one side of the membrane and the waste stream on the other side.
Institutional and organizational requirements	Desalination should be incorporated into existing water governance structures in Tonga. Key recommendations for exploring development of desalination include: • Develop a clear water policy using an integrated water resources management (IWRM) approach to determine

	accurately renewable freshwater resource potential, demand and consumption. Only when the adequacy of conventional water resources is understood should development of nonconventional (e.g. saline) water resources be pursued. • Implement conservation and water demand management in all sectors. Key methods include reduction of non-revenue water in piped systems, use of only limited targeted subsidies, and prevention of groundwater pollution. • Consider desalination in combination with other non-conventional water sources including reuse of treated wastewater, importation of water across boundaries, rainwater harvesting and others.
Operation and maintenance	Training and formal education requirements for desalination are needed so that locals can operate and maintain desalination technologies in Tonga.
Endorsement by experts	There is significant potential for desalination technology to resolve water supply problems in Tonga. Experts acknowledged that research and development leading to improved efficiency of desalination (reverse osmosis or other methods), primarily to reduce the operational costs, is needed. Tonga's TNC (2019) also proposed the use of desalination technologies for Tonga's water sector.
Adequacy for current climate	Desalination creates an opportunity for coastal communities to access virtually unlimited freshwater sources. In addition, desalination techniques can be used to purify brackish water in areas with seawater intrusion like in the Ha'apai Group of islands. In light of climate change adaptation, this is also a crucial resource for areas where existing freshwater resources can no longer support local populations or be rehabilitated to meet the freshwater demands.
Scale/Size of beneficiaries group	Desalination can benefit local coastal villages and island communities throughout Tonga.
Disadvantages	The major drawbacks of current desalination processes include costs, energy requirements and environmental impacts. The environmental impacts include disposal of the concentrated waste stream and the effects of intakes and outfalls on local ecosystems.
Capital costs	
Cost to implement adaptation technology	Costs for desalination are very much site-specific and the cost per volume treated can vary widely. Also depends on where (country) the technologies will be sourced from. The cost for this technology is approximated at $40,000 USD per unit, drawing form the approximated costs for the solar desalination technologies that the Australian National University (ANU) and PHAMA Plus is working to pilot in Tonga. This cost is approximated to be inclusive of the desalination unit plus transportation to Tonga and installation at community site. Cost may also be higher if applying to outer islands in Tonga.
Development impacts, direct and indirect benefits	
Direct benefits	Desalination can greatly aid climate change adaptation, primarily through diversification of water supply and resilience to water quality degradation. Desalination technologies also provide resilience to water quality degradation because they can usually produce very pure product water, even from highly contaminated source waters.

Reduction of vulnerability to climate change, indirect	Diversification of water supply can provide alternative or supplementary sources of water when current water resources are inadequate in quantity or quality, reducing the vulnerability to climate change.
Economic benefits, indirect	Alternative source of water for irrigation of commercial crops and other economic activities.
Social benefits, indirect	Alternative source of water for various uses in overcrowded urban areas like Nuku'alofa. Can also contribute to hygiene and sanitation needs.
Environmental benefits, indirect	Desalination paired with other water conservation and management projects.
Local Context	
Opportunities and Barriers	In the case of low-lying islands, additional rainwater harvesting, storage systems, and desalination systems are needed considering the country's vulnerability to droughts and climate change. These will need different approaches for different locations that acknowledge the differences in service delivery between urban and rural locations.
Market potential	Mobile solar powered desalination units are likely to decrease the costs of desalination so the market potential is High.
Status	Desalination is not new in Tonga. It has been implemented at various places like Ha'apai and Tongatapu. There are several portable reverse osmosis units in reserve which are deployed in response to national emergencies, for example, to the Ha'apai Islands after damage by Cyclone Ian in 2014. In 2015, three reverse osmosis (RO) plants were donated by Japan to the GoT for disaster relief and there is one desalination unit available for mobile deployment as required. Several agencies in Tonga own a single unit with a capacity similar to the 18TS Portable desalination units distributed by Citor Desalinisation, Australia at a unit cost of TOP$90,000.00 (approx. AUD$51,000).[i] Those agencies include Tonga National Emergency Management Office (NEMO), His Majesty's Armed Forces (HMAF), Tonga Water Board (TWB) and the Tonga Red Cross Society (TRCS). Latest development in desalination is a project in Tonga by the ANU and the PHAMA Plus Project, which will pilot a solar-powered desalination unit, providing a reliable source of water for Tongan farming communities. The desalination unit will use reverse osmosis to produce clean, fresh water from seawater for irrigation of local farms and other agricultural activities in Tonga.
Timeframe	Short – Medium term
Acceptability to local stakeholders	Desalination is acceptable but the cost in many parts of Tonga could be prohibitive. Can be prioritised in priorities for collaborations with donors and development partners.

Annex II: List of stakeholders involved and their contacts

Stakeholders for the Agriculture Sector

Name	Gender	Organisation	Email
Sione Tausinga	M	Department of Energy, MEIDECC	sl_tausinga@yahoo.com
Fe'auini Laumanu	F	Department of Energy, MEIDECC	feauini@gmail.com
Filimone Fifita	M	Department of Energy, MEIDECC	monefifita@gmail.com
Vika Fusimalohi	F	Tonga Growers Federation	vfusimalohi@gmail.com
'Ana Tonga	F	Civil Society Forum Tonga	-
'Ilaisaane Vakatapu	F	MAFF	nanevakatapu@gmail.com
Natia Seni Lokotui	F	Civil Society Forum Tonga	naniseni@gmail.com
Tiana Matoto	F	Civil Society Forum Tonga	tmatoto14@gmail.com
Robert Vivili	M	Phama Plus Program	r.vivili@phamaplus.com.au
Leopino Fa'asolo	M	Ministry of Health	alakihihifofaasolo@gmail.com
Sifa Palelei	M	Prime Minister's Officer	spalelei@gmail.com
Kaati Hakaumotu	F	Live & Learn Tonga	kaati.hakaumotu@livelearn.org
'Anaseini Tu'ineau	F	Live & Learn Tonga	anaseini.tuineau@livelearn.org
Loiloi Latu	F	Department of Climate Change, MEIDECC	leroy.latu@gmail.com
Lu'isa Nau	F	Department of Environment	luisamaukakalanau@gmail.com
Lilu Moala	F	TNA Project	lilumoala@gmail.com

Stakeholders for the Water Sector

Name	Gender	Organisation	Email
Sione Tausinga	M	Department of Energy, MEIDECC	sl_tausinga@yahoo.com
Fe'auini Laumanu	F	Department of Energy, MEIDECC	feauini@gmail.com
Filimone Fifita	M	Department of Energy, MEIDECC	monefifita@gmail.com
Fatuimoana Langilangi	M	Tonga National University	flangilangi@gmail.com
'Ilaisaane Vakatapu	F	MAFF	nanevakatapu@gmail.com
Meleseini Makaafi	F	Live & Learn Tonga	meleseini.makaafi@livelearn.org
Natia Seni Lokotui	F	Civil Society Forum Tonga	naniseni@gmail.com
Tiana Matoto	F	Civil Society Forum Tonga	tmatoto14@gmail.com
Robert Vivili	M	Phama Plus Program	r.vivili@phamaplus.com.au
Leopino Fa'asolo	M	Ministry of Health	alakihihifofaasolo@gmail.com
Seini Tolu	F	Department of Climate Change	seinitolu21@gmail.com
Lu'isa Nau	F	Department of Environment	luisamaukakalanau@gmail.com
Lilu Moala	F	TNA Project	lilumoala@gmail.com

Annex III: Scoring Matrix and Normalised Matrix for the Technology Prioritisation

A. Agriculture Sector

Group 1

	Costs	Benefits									
		Economic			Social	Environment	Climate related	Technology Related	Political		
	Cost to set up, operate & maintain	Increase farmer's revenue & ability to re-invest	Catalysing private investement	Contribution to social & sustainable development	GEDSI Considerations	Contribution to ptorect & sustain ecosystem services	Enhancing resilience to climate change	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Decentralised Community-run EWS)	88.9	50	80	70	100	70	100	20	50		
Technology 2 (Sprinkler Irrigation)	55.6	90	100	70	80	80	80	5	50		
Technology 3 (Drip Irrigation)	66.7	100	100	80	80	60	50	30	50		
Technology 4 (Integrated Nutrient Management)	100.0	100	100	100	60	40	60	30	50		
Technology 5 (Food Cubes)	88.9	30	20	100	100	100	100	100	50		
Technology 6 (Mixed Farming)	100.0	100	100	100	50	100	100	100	50		
Technology 7 (Agrofofestry)	0.0	70	70	50	50	80	80	80	50		
Technology 8 (Farmer Field Schools)	77.8	80	80	60	60	100	100	100	50		
Criterion weight	15	5	10	10	15	20	15	5	5	100	should add to 100

Group 2

	Costs	Benefits									
		Economic		Social		Environment	Climate related	Technology Related	Political		
	Cost to set up, operate & maintain	Increase farmer's revenue & ability to re-invest	Catalysing private investement	Contribution to social & sustainable development	GEDSI Contributions	Contribution to ptorect & sustain ecosystem services	Enhancing resilience to climate change	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Decentralised Community-run EWS)	88.9	20	20	60	100	50	90	60	100		
Technology 2 (Sprinkler Irrigation)	55.6	60	60	60	60	80	90	20	80		
Technology 3 (Drip Irrigation)	66.7	50	50	50	50	70	80	10	70		
Technology 4 (Integrated Nutrient Management)	100.0	50	80	90	60	90	90	90	80		
Technology 5 (Food Cubes)	88.9	60	60	60	100	100	100	60	60		
Technology 6 (Mixed Farming)	100.0	90	90	90	80	90	90	50	80		
Technology 7 (Agrofofestry)	0.0	50	50	50	50	80	80	50	50		
Technology 8 (Farmer Field Schools)	77.8	80	80	80	80	50	50	60	60		
Criterion weight	40	5	5	5	5	10	10	5	15	100	should add to 100

B. Water Sector

Group 1

		Benefits										
	Costs	Economic	Social			Environment	Climate related		Technology Related	Political		
	Cost to set up, operate and maintain	Improvement in economic performance	Contribution to social & sustainable development	Improve Human Health	GEDSI Contributions	Contribution to protect & sustain ecosystem services	Enhancing resilience to climate change	Water & Energy Efficiency	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Mobile Solar-powered Desalination Units)	40	60	80	50	50	50	80	50	45	20		
Technology 2 (Solar Disinfection)	90	20	70	20	70	80	60	60	70	20		
Technology 3 (PCS for community-managed water supplies)	60	60	60	80	90	80	80	60	60	50		
Technology 4 (Rainwater collection from ground surfaces)	40	60	80	60	50	50	70	50	50	50		
Technology 5 (Scaling up of RWH)	40	20	70	70	70	70	80	70	40	60		
Technology 6 (Water reclamation)	20	20	60	70	50	50	60	60	20	40		
Technology 7 (Smart Meters)	20	60	60	20	50	50	50	80	10	50		
Technology 8 (Certification & Labeling)	20	60	60	20	50	50	50	80	10	50		
Technology 9 (Solar Water Pumps)	20	60	60	20	50	50	50	80	10	50		
Technology 10 (Moisture / Fog Harvesting)	20	60	60	20	50	50	50	80	10	50		
Criterion weight	25	5	5	15	5	10	15	10	5	5	100	should add to 100

Group 2

		Benefits										
	Costs	Economic	Social			Environment	Climate related		Related	Political		
	Cost to set up, operate and maintain	Improvement in economic performance	Contribution to social & sustainable development	Improve Human Health	GEDSI Contributions	Contribution to protect & sustain ecosystem services	Enhancing resilience to climate change	Water & Energy Efficiency	Ease of implementation	Coherence with national policies and priorities		
Technology 1 (Mobile Solar-powered Desalination Units)	60	70	60	90	100	50	100	50	60	100		
Technology 2 (Solar Disinfection)	90	20	50	10	100	80	80	60	100	70		
Technology 3 (PCS for community-managed water supplies)	70	80	100	80	100	90	100	100	70	100		
Technology 4 (Rainwater collection from ground surfaces)	20	20	70	50	50	60	60	50	10	80		
Technology 5 (Scaling up of RWH)	100	80	80	80	100	60	100	100	90	100		
Technology 6 (Water reclamation)	30	60	50	10	50	80	80	70	40	70		
Technology 7 (Smart Meters)	30	30	50	60	60	80	90	100	40	70		
Technology 8 (Certification & Labeling)	90	30	40	50	50	80	90	100	60	80		
Technology 9 (Solar Water Pumps)	20	50	60	60	60	80	60	50	70	80		
Technology 10 (Moisture / Fog Harvesting)	20	40	50	40	60	80	80	50	20	40		
Criterion weight	15	5	5	15	5	5	20	5	20	5	100	should add to 100