NAURU

TECHNOLOGY NEEDS ASSESSMENT

FOR

CLIMATE CHANGE MITIGATION

Barrier Analysis and Enabling Framework

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BARRIER ANALYSIS AND ENABLING FRAMEWORK FOR CLIMATE CHANGE MITIGATION TECHNOLOGIES

REPORT II

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Foreword

Climate change is a "crisis multiplier" that has profound implications for international peace and stability according to the United Nation Secretary-General António Guterres (February 2021). Undoubtedly, it is one of the greatest threats to human existence in this 21st century. For example, for Republic of Nauru, it is a colossal challenge to achieve its sustainable development goals without compromising on its socio-economic development needs. Due to its exposure to the recurrent episodes of sea level rise, coastal flooding, heatwaves, cyclones and droughts in the past few decades, the country is consistently ranked by multiple climate change vulnerability indices as being one of the most vulnerable to the impacts of climate change. With such back drop the country is in dire need of innovative mitigation technologies to lessen damage to life, property, natural eco-systems, and its economy.

I am confident that the Technology Needs Assessment (TNA) process initiated by the Department of Climate Change and National Resilience (DCCNR) in partnership with the United Nations Environment Program (UNEP), University of the South Pacific (USP) and Technical University of Denmark (DTU) will play an effective role as the country finds effective technologies towards mitigating the impact of climate change through transfer and diffusion of prioritized technologies within the energy and waste sectors. I am pleased to note that the entire process to set preliminary targets for transfer and diffusion of technologies, identify barriers and suggest an enabling framework for overcoming those respective barriers in this phase-II of the TNA project has been country-driven despite of the impact of the current covid 19 pandemics. Being highly consultative, it involved a number of stakeholders and experts from the government, private sector, and non-government organisations. I strongly believe that the implementation of mitigation technologies prioritized in TNA Adaptation Report Phase-II will help the country in its mitigation objective including the reduction of its greenhouse gas emissions.

I would like to thank the members of the TNA Team and my colleagues in the Department and experts of the Mitigation Working Group for their invaluable contributions to the preparation of this Report. I also thankfully acknowledge the contributions of Dr. Michael Otoara Ha'apio, Adaptation national consultant, Abraham Aremwa, Mitigation national consultant and other experts of USP, United UNEP, UNEP-DTU Partnership and the Asian Institute for Technology (AIT) for their constant support and guidance for implementation of the TNA project.

Reagan Moses

Permanent Secretary for Climate Change and National Resilience

List of Abbreviations

ADB	Asian Development Bank
BESS	Battery Energy Storage System
CTCN	Climate Technology Centre & Network
DCIE	Department of Commerce, Industry and Environment
DCCNR	Department of Climate Change & National Resilience
GEF	Global Environment Fund
GCF	Green Climate Fund
GGP	Grant Assistance for Grassroots Human Security Projects
GHG	Greenhouse Gas
GoN	Government of Nauru
kWh	Kilo-watt hour
LPG	Liquefied Petroleum Gas
MJ	Mega-joules
MW	Mega-watt
NDC	Nationally Determined Contributions
NEPF	Nauru Energy Policy Framework
NERM	Nauru Energy Roadmap
NRC	Nauru Rehabilitation Corporation
NSDS	National Sustainable Development Strategy
NSWMS	National Solid Waste Management Strategy
NUC	Nauru Utilities Corporation
OTEC	Ocean Thermal Energy Conversion
PPA	Pacific Power Association
PHES	Pumped Hydro Energy Storage
PT	Problem Tree
PV	Photo-voltaic
RE	Renewable Energy
SGP	Small Grants Programme
SWM	Solid waste management
TA	Technical assistance
TNA	Technology Needs Assessment
UNIDO	United Nations Industrial Development Organization

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Executive Summary

With the completion of the TNA report, the second phase of the TNA project is to identify barriers hindering the acquisition and diffusion of prioritised technologies and to develop enabling frameworks to overcome the barriers and facilitate the transfer, adoption, and diffusion of selected technologies in Nauru.

Stakeholders have prioritised energy and waste sectors for Nauru's Technology Needs Assessment (TNA) project as they are the highest greenhouse (GHG) emitting. The choice of prioritising the energy sector is aligned with Nauru's Nationally Determined Contributions (NDC), National Sustainable Development Strategy (NSDS) 2005-2025; Second National Communication (SNC) 2014; and the Nauru Energy Roadmap (NERM) 2014-2020. The waste sector is aligned with the NSDS and SNC.

In this second TNA report, barriers hindering the transfer and diffusion of prioritised mitigation technologies for energy and waste sectors have been identified, and measures to overcome the barriers and facilitate the transfer, adoption and diffusion of these technologies are explained.

To facilitate the identification of root causes of the main barriers, expert working groups for energy and waste sectors were taken through exercises on creating Market Mapping, Problem Tree (PT) and Objective Tree (OT) for each of the energy and waste technologies. The outcome of these exercises is provided in the annexes.

The whole process of technology barrier identification was drawn from various literature reviews, stakeholder meetings, stakeholder bilateral meetings, mitigation expert working group and respective technology experts. Mitigation consultant also seek reference to the TNA barrier analysis guideline, resources, information, and templates provided by specialists UNEP-DTU Partnership and USP during and after regional capacity building workshops.

Energy Sector

Ocean Thermal Energy Conversion (OTEC) – The main barrier facing the uptake of this technology is the viability and very high capital costs despite Nauru having the resources and potential for implementing a small-scale plant with 1 MW capacity. The technology is capital intensive and unviable at small scale of power output but can become viable when approached as a sustainable integrated solution to co-generate electricity and freshwater. The effects of not being able to take up this technology will be continued reliance on fossil fuel use for power generation and water production. However, the potential and funding availability of a feasibility study will only determine the viability of OTEC technology in Nauru as a provider for base load and sustainable power and water. OTEC is categorised as a capital good as well as a publicly provided.

Grid-connected Rooftop Solar PV – Despite the great viability of solar PV systems in Nauru, the main barrier identified for this technology; especially when connected to the grid, is lack of institutional arrangement where there is the need for policies and regulations to be developed and enforced. Some notable technical challenges associated with solar-grid integration include problems of voltage stability, frequency stability, and overall power quality. The two viable but rather capital-intensive energy storage systems include battery energy storage (BESS) and pumped hydro energy storage (PHES) systems. Grid-connected roof top solar PV systems are categorised as a consumer and capital goods.

Biogas – The main barriers identified for this technology is the high capital cost especially in building and maintaining a pig farm sufficient for the size of digester to be installed. Some advantages of biogas technology include eco-friendly, reduces soil and water pollution, produces organic fertiliser and good alternative for electricity. Biogas is categorised as capital goods and publicly provided goods.

PHES – Like OTEC, the main barrier for this technology is high capital cost. However, its viability given the land topography of Nauru is positive. PHES is an exceptional substitute for BESS due to its lifespan where BESS life is estimated at 15 years and PHES up to 50 years. If not taken up, the installed capacity of grid-connected rooftop solar PV system will be limited. This limited penetration will only affect the reduction in fossil fuel. However, when technology is taken up, it can provide energy-balancing, stability, storage capacity, and ancillary grid services such as network frequency control and reserves. The current barrier to the uptake of this technology is funding availability for a feasibility study. The intent of the feasibility study is to determine the feasibility of PHES for either New Zealand Ministry of Foreign Affairs and Trade (NZMFAT) or other agencies assisting with the further development of the system potentially through to construction (GHD, July 2020). PHES is categorised as a capital goods and a publicly provided goods.

Waste Sector

Composting – At community level, the main barriers identified are lack of public awareness, behaviour and skilled personnel in making compost and understanding the benefits. At National level, there has been attempts to set up big scale composting which has not been very successful due to lack of institutional arrangement and a segregation process. This results in organic wastes ending up at landfill causing build-up of methane gas. Promoting segregation at community level creates access to compost material for home gardening and reduces GHG. Composting is categorised as a capital and consumer goods.

Segregation – The main barriers identified for the diffusion of segregation at community level is lack of institutional arrangement and resources, public awareness and behaviour. This causes all types of wastes ending up at landfill that will eventually rot, but not all, and in the process it may smell, or generate methane gas, which is explosive and contributes to the greenhouse effect. Leachate produced as waste decomposes may cause pollution. Development and enforcement of policies, strengthening of institutions and educating segregation practices will result in a controlled and better managed landfill thus reducing GHG. Segregation technology is categorised as a capital and consumer goods.

Semi-aerobic landfill – The main barriers identified with the construction of a semi-aerobic landfill is lack of funding for the development of a Master Plan and Policies due to weak institutional arrangement in the waste sector. There are also financial and technical barriers that will be faced during the construction stages for the supply of heavy machinery and knocking down of pinnacle rocks. Development of a Master Plan and Policy and strengthening of institutional capacity will provide the financial support required to access funding. An uncontrolled landfill is an environmental problem. If integrated with segregation technology, they will support composting and recycling. Semi-aerobic landfill technology is categorised as a capital good and can also be a publicly provided goods or other non-market goods.

Bailing – The main barriers identified in the effective operations of a baling process is the lack of institutional arrangement and the absence of segregation practices. A non-functional baling process will result in recyclable wastes ending up in the landfill. Segregation of dry and wet wastes from source of generation, strengthened institutional capacity with developed and enforced policies will only enable a controlled and environmental free landfill, as well as opening up opportunities in waste recycling technologies.

Chapter 1: **Energy Sector**

1.1 Preliminary targets for technology transfer and diffusion

The energy sector in Nauru has been prioritised for technical assistance under the Technology Needs Assessment (TNA) project as it is considered the highest greenhouse gas (GHG) emitting sector. Nauru relies greatly on imported fossil fuel for power generation and transportation. Because of this high dependence on imported fossil fuels, Nauru is vulnerable to international fuel market prices. Nauru Utilities Corporation (NUC); a state-owned enterprise (SOE) and the sole provider of electricity on Nauru, currently provides services to over 3,500 electricity customers with a total firm electricity production capacity of 11.6 MW that comprises 5.6 MW of medium speed diesel generation and 6 MW of high-speed diesel generation. The current maximum demand is 5.7 MW hence NUC has a security level: for production of electricity of N-2. The yearly demand recorded from July 2017 to June 2018 was 28.090 GWh.

Within the context of climate change mitigation, targets for reducing GHG are mainly guided by National reports such as the First and Second National Communications (FSNC), Nationally Determined Contributions (NDC), National Sustainable Development Strategy (NSDS), Nauru Energy Policy Framework (NEPF) and the Nauru Energy Road Map (NERM 2018-2020).

Nauru's NSDS 2005-2025 outlines the long-term plan for Nauru's development. This was revised in 2009, then further reviewed and updated in 2017/18. Table 1 illustrates the energy strategies and goals that were developed in the NSDS.

Table 1: NSDS 2009 energy strategy and goals

Strategies	Short-term Milestones 2012	Medium-term Milestones 2015	Long-term Milestones 2025	Responsibility
Increased use of renewable energy and other alternative	Use of renewable energy and solar photovoltaic promoted widely and implemented	Renewable energy comprised 50 percent of total energy supply in Nauru	Other alternative forms of energy explored and their feasibility examined	Nauru Utilities Corporation and Department of Commerce

forms of energy	Wind power feasibility study completed and its findings/ recommendations implemented	Wind power energy piloted in Nauru for wider application		

The NEPF was endorsed by the Government of Nauru (GoN) in 2009 which outlines a policy framework that builds on the energy priorities outlined in the NSDS.

The NERM is the implementation plan for activities to facilitate Nauru's energy sector development agenda. The main targets of the NERM 2014 - 2020 were that by 2020, Nauru would have:

a) 24/7 grid supply with minimal interruptions.
b) 50% of grid electricity supplied from renewable energy sources by 2020.
c) 30% improvement in energy efficiency in the residential, commercial and government sectors.

Although these targets are very broad, these will be revised in the updated NERM. The outcomes the NERM 2018 - 2020 aimed to achieve were:

a) A reliable, affordable and safe power supply and services.
b) A reliable and safe supply of fossil fuels.
c) Universal access to reliable and affordable energy services.
d) An efficient supply and use of energy.
e) A significant contribution from renewable energy towards electricity supply.
f) Financial sustainability of the energy sector.
g) Efficient, robust and well-resourced institutions for energy planning and implementation.

To make progress towards these targets, the NERM 2018 - 2020 have six Action Plans and 19 Strategies that are provided below.

Capacity: Efficient, robust and well-resourced institutions for energy planning and implementation.

i) Establish appropriate policies, regulations and legislation for the energy sector.
ii) Facilitate development of appropriate local skill base to meet ongoing demand in energy sector.
iii) Improve governance and accountability in the energy sector.

iv) Foster a culture of partnerships between public and private sectors including the community.

Power: A reliable, affordable and safe electrical power supply and services.

i) Upgrade assets.
ii) Improve planning and management.
iii) Improve supply-side energy efficiency.
iv) Move toward full recovery of operating and maintenance costs.
v) Develop and safeguard NUC staff.

Renewables: 50% of electricity used in Nauru comes from renewable energy sources by 2020.

i) Phased implementation of large-scale solar.
ii) Investigation and implementation of other renewable energy sources.
iii) Build in-country capacity to operate and maintain solar PV systems.

Efficiency: An efficient supply and use of energy.

i) Data collection and analysis for preparation for Demand Side Management implementation.
ii) Implementation of demand side energy efficiency.
iii) Introduction of energy labelling and Minimum Energy Performance Standards.

Fuels: A reliable and safe supply of fossil fuels.

i) Establish an economically efficient, secure and safe National Fuel Terminal and fuel supply.
ii) Investigate ways to reduce use or find alternatives to liquid fuels.

Transport: Policy to be developed as part of road map implementation.

i) Implementation of energy efficiency in transport.
ii) Investigate substitutes to diesel and petrol for transport.

The following tariffs are applied within Nauru:

a) $0.22/ kWh for pre-paid residential customers up to the first 200 kWh (Lifeline tariff rate);
b) $0.47/ kWh for pre-paid residential customers over 200 kWh including post-paid residential customers;
c) $0.75/ kWh for commercial, industrial and government customers.

In 2016, NUC made comparison with its tariff rates with regional power providers placing it in the top 5 for lowest rates at domestic level and amongst the top 5 with highest rates at commercial level.

Figure 1: Comparison of electricity monthly bills (Source – NUC)

The four mitigation and RE technologies in the energy sector that were prioritised in the first TNA report are fully supported by the NSDS under its Long-term Milestone where by 2025 other alternative forms of energy will have been explored and their feasibility examined (Table 1.) These four technologies are as follow.

- **i) OTEC**
- **ii) Grid-connected Rooftop Solar PV**
- **iii) Biogas**
- **iv) PHES**

All these technologies will be considered for this barrier analysis and enabling framework study that is supported by stakeholder consultations, literatures and desktop reviews. However, the penetration levels of these four mitigation technologies in the energy sector were not defined by stakeholders as these targets would normally be developed by a consulting firm that is engaged to carry out a feasibility study.

1.2 OTEC – Barrier analysis and possible enabling measures

1.2.1 General description of OTEC technology

OTEC is an RE technology that produces clean baseload (24/7) electricity using the temperature differential (>20ºC) between warm surface water and cold deep water in the world's tropical oceans. OTEC is a promising renewable energy technology to generate electricity and has other applications such as production of freshwater, seawater air-conditioning, marine culture and chilled-soil agriculture. (Muralidharan, 2012)

The warm seawater at depth of 1,000 meters is used to produce a vapour that acts as a working fluid to drive turbines. The cold water is used to condense the vapour and ensure the vapour pressure difference drives the turbine. OTEC technologies are differentiated by the working fluids that can be used. Open Cycle OTEC uses seawater as the working fluid, Closed Cycle OTEC uses mostly ammonia. A variation of a Closed Cycle OTEC, called the Kalina Cycle, uses a mixture of water and ammonia. The use of ammonia as a working fluid reduces the size of the turbines and heat exchangers required.

Most pilot project tests have focused on ammonia as a working fluid in a closed Rankine cycle (except for Nauru, 1981 where Freon was used) due to its superior thermodynamic and thermal characteristics. The material used for the cold water pipe was polyethylene. This project tested the load response characteristics, turbine, and heat exchanger performance tests. The results were fairly satisfactory with the efficiency of the turbine recorded at over 80%. The plant achieved a continuous power generation of 31.5 kW and an operational record of 10 days. (Muralidharan, 2012)

OTEC can also be used for ocean water desalination. The dominant natural desalination is the evaporation/condensation distillation process. The theoretical energy requirement for making 1 cubic meter of fresh water from ocean water is 1 kWh (3,6 MJ). Even though reverse osmosis is able to get 1 cubic meter of fresh water from ocean water at 3 kWh energy. The energy need to be in the form of electrical energy or some mechanical form. A better desalination procedure using the ocean is to use ocean thermal energy directly. The warm ocean surface water can provide the thermal energy to generate water vapours at the evaporator. The cooler deep ocean water can condense the vapour into water. The energy required to move the heating and cooling ocean water through the heat exchangers can be much less than the theoretical energy requirement of 1 kWh for each cubic meter. Ocean thermal energy can easily provide 40 MJ of thermal energy to get 1 cubic meter of fresh water. The cost of desalinate ocean water can be less than 10 cents for each cubic meter[1].

The technology is capital intensive and unviable at small scale of power output but can become viable when approached as a sustainable integrated solution to co-generate electricity and freshwater, especially for island nations in the OTEC resource zones with supply constraints on both these commodities. (Muralidharan, 2012)

1.2.1.1 Technology status in Nauru

One of the first OTEC plants was built on Nauru in 1981. This project was not intended to replace the existing fossil fuel generation that was already providing 100% electrification on the island, nor a need at the time for conversion to renewable energy. This was merely a pilot or experiment project that was considered to be most efficient in tropical waters and within the equatorial boundary of 20°N and 20°S. This plant produced 31.5 kW to the national grid. The experiment was widely successful however a hurricane eventually wiped it out[2].

The construction and operation of the 100 kW (gross) OTEC test facility on the island of Nauru in 1981 significantly increased the momentum of the Japanese OTEC program and furnished a much needed data base for the design of commercial-scale pilot plants[3].

The Institute of Ocean Energy, Saga University, (IOES) together with the Overseas Environmental Cooperation Center (OECC), were recently awarded to carry out an OTEC pre-feasibility study project on Nauru.

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[1] https://www.climatecolab.org/contests/2015/harnessing-the-power-of-mit-alumni/c/proposal/1325332

[2] https://coastalenergyandenvironment.web.unc.edu/2012/07/22/otec-the-only-option-for-japan/

[3] https://nsuworks.nova.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1067&context=nsudigital_otec-liaison/

An OTEC demonstration facility built in 2013 on Kume Island, Okinawa Prefecture, which succeeded in generating the first electricity in its second phase of research and development worldwide, has attracted international attention with more than 10,000 people from 67 different countries having visited the facility so far. This 100 kW demonstration facility has been selected as the best model to build from and adapt to Nauru's needs and situation. Under the current circumstances, the OECC team believes that the most feasible option would be to consider the installation of an OTEC plant capable of generating a constant baseload of 1MW in Nauru. Since the size of the plant is scalable, it is recommended to start with a plant with this capability. A picture of this OTEC demonstration facility that is located in Kumejima on Kume Island is shown in Figure 2.

Figure 2: Kumejima OTEC demonstration plant, Okinawa, Japan[4]

1.2.1.2 Technology category and market characteristics

To facilitate the barrier analysis process and reporting, technologies are not categorized according to their technical properties, but according to both the types of goods and services they belong to or contribute to, and the markets or non-markets in which they are transferred

[4] Source: https://www.pacificnote.com/single-post/2018/11/15/kumejima-model-an-island-move-toward-self-sufficiency

and diffused (Ivan Nygaard, 2015). OTEC technology was identified by the energy expert group as a capital goods when described as a plant used in the production of electricity and water, and also as a publicly provided goods when owned and operated by an SOE. Market characteristics are provided in Table 2.

Table 2: OTEC technology category and market characteristics

Technology	Category	Description	Market Characteristics
OTEC	Capital goods [market good]	Plant used in the production of electricity and desalinated water.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven
	Publicly provided goods [non-market good]	Publicly-owned and operated by a state-owned enterprise to produce electricity and desalinated water to the public.	• large investment, government/donor funding • public ownership • simple market chain; technology procured through government or donor-approved tendering process. • decided at the government level and heavily dependent on National sustainable development strategies

1.2.2 Identification of barriers for OTEC

Preliminary barrier identification

An initial desktop-review for the viability of this technology was carried out by the mitigation consultant and has come up with a list of the common barriers relevant for discussion with the expert working group to identify the root causes of these barriers.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;
- Human capacity barriers;
- Public awareness and information barriers.

Screening of barriers identified

The core problem; as identified by the energy expert group for OTEC development, transfer and diffusion is *its uptake as an RE source for power generation.*

The above barrier categories were decomposed by the energy working group using Problem Trees (PT) to identify the root causes of each barrier, and an Objective Tree (OT) that mirrors the PT was developed to further identify possible measures to overcome the root causes. The outcome of the desktop-review and problem and objective tree exercises are produced in the annexes. These are briefly discussed below.

1.2.2.1 Economic and financial barriers

a) *High capital and maintenance cost* – The main economic and financial barriers that hinders the uptake of OTEC on Nauru is the extremely high cost of capital, maintenance and access to funding. According to OECC, it is estimated that a 1 MW OTEC plant alone will cost around USD33 million which does not include cost for the seawater intake pumping facility. A separate intake facility is estimated to cost between USD40-80 million bringing the total cost of a functional OTEC plant to USD73-113 million (CTCN, 2020).

   OTEC systems are limited by the high infrastructure costs involved and low net efficiencies that can be achieved along with significant maintenance costs in the pumping and piping infrastructure (CTC-N, n.d.).

1.2.2.2 Non-financial barriers

Technical

a) *Technology components are still being improved* – According to the CTCN website, maintenance of OTEC systems is hard to determine at such an early stage of development. As it stands OTEC systems have not necessarily overcome the issues of biofouling, heat exchanger degradation and sealing. Makai Ocean Energy Research Center is in the process of scaling up a design for a low-cost, compact, corrosion-resistant design that could revolutionize OTEC heat exchangers.

Institutional arrangements

a) *Land tenure policy* – Access to land for OTEC plant construction need to go through a number of consultations with major stakeholders – GoN Cabinet Ministers and Departments, NGO's, SOE's, Community Leaders and most important land-owners. There is a regulatory framework – Lands Act 1976, that regulates all land matters in Nauru. This Lands Act states that the government has the right to lease land for public interest, as well as be granted easement, way leave or other right to the land.

Social, cultural and behaviour

a) *Land tenure system* – The Nauruan land management system can be a major roadblock for any development activity because the government do not or cannot own land but can only lease it for public interest and national development purposes. This favours the private landowners, and national development plans are often undermined by politics and personal relationships. (Tsiode, 2018).

b) *Land lease disputes* – Unclear and inconsistent land lease policies and rates can often lead to non-agreement of land owners wanting to lease out their land for development projects.

Environmental

a) *Tropical storms* – The potential sites for OTEC on Nauru is around the South-Western part of the island where the reef lengths are short and therefore requiring shorter runs of piping system. However, this same part of the island is known to be commonly affected by the West Pacific Monsoon. This occurs when the persistent monsoon westerly winds reach as far east as western Kiribati (PACCSAP, 2015).

b) *Marine life* – The environmental impacts of OTEC systems are largely unknown. The main concerns around the technology would be the effect on the local ocean surface ecosystem due to the release of large volumes of cooler water and the possibility that marine creatures can be drawn into the piping that feeds the OTEC plant. Only during the course of further development, EIA studies and larger projects will the marine energy community be able to gain a firmer idea of any potential impacts on marine life. (CTCN, n.d.)

Human capacity

a) *No skilled personnel* – OTEC technology; given its scale and technical complexity, will require a high level of local expertise engagement to be trained during the construction and commissioning stages as well as the operation and maintenance of the plant.

Public awareness and information

a) *Lack of public awareness* – There is lack of information sharing and awareness raising to the public in regards to, and the progress of Nauru's energy targets as provided in the NERM 2014-2020 report. Hence land owners can be reluctant in supporting a project if they are not informed in advance of what has been prioritised or in the pipeline.

1.2.3 Identified measures for OTEC

1.2.3.1 Economic and financial measures

a) *Pre-feasibility study* – Full support from the GoN and stakeholders is paramount in supporting an ongoing OTEC pre-feasibility study that is being conducted by OECC through CTCN and UNIDO. The outcome of this study will determine the implementation of a feasibility study.

b) *Co-financing* – Theoretically, OTEC output is not more than the solution that meets Nauru's most essential needs in terms of sustainable supply of electricity and water. The technology may be capital intensive and unviable at small scale of power output but can become viable when approached as a sustainable integrated solution to co-generate electricity and freshwater, especially for island nations in the OTEC resource zones with supply constraints on both these commodities (Muralidharan, 2012). An open-cycle OTEC plant is capable of co-generating electricity and water. Nauru's ongoing commitments to co-financing development projects is key to achieving its sustainable development goals.

The core anticipated result of having a functional OTEC plant is less reliance on fossil fuel burning. Access to funding an OTEC plant can be considered as the difference between Nauru having a long term functional and sustainable supply of energy and water or not.

1.2.3.2 Non-financial measures

Technical measures

a) *Technology is proven* – Conducting a feasibility study to analyze and justify the present viability of OTEC technology on Nauru; especially with its failing components, is key to its uptake that reflects Nauru's commitment to reducing its emissions and supporting the ongoing development of experimental technologies. The purpose of the OTEC trial carried out in 1981 was to allow engineers to do practical research into the problems of OTEC including design, behaviour and plant operation, biofouling and the efficiency of heat-exchangers. Lessons learnt from this installation is to build a more robust OTEC facility to withstand tropical cyclones which caused much damage to this demonstration facility.

Institutional arrangements

a) *Landowner agreement* – Collaboration between NUC and landowners to obtain a mutual agreement on the lease terms and condition is paramount to securing land for project development.

Social, cultural and behaviour

a) *Land tenure evaluation periods* – In a situation of rapid economic and social change, land tenure should be periodically evaluated (perhaps every five years) to ensure it continues to meet the current and expected needs of the people.

Environmental

a) *Feasibility study* – A systematic approach is key to designing a robust and sustainable OTEC plant while reducing impacts to marine life.

Human capacity

a) *Local capacity development* – Building the capacity of locals to effectively operate and maintain an OTEC plant is paramount. Despite the limited number of local expertise, engaging as many skilled locals during the construction phase of an OTEC plant is key to building capacity of locals and to have that sense of ownership. The provision of training institutions in the fields of plant operations; mechanical, electrical and control system engineering will be an advantage.

Public awareness and information

a) *What information to share* – Minimum information should include (i) project name and contact details of key local project representatives; (ii) Short summary of the project to include objectives, activities, timescale and intended beneficiaries; (iii)

Rights of project beneficiaries; (iv) What to do and who to contact in case of a complaint, including definition of complaint, and (v) employment opportunities.

b) *How to share information* – There are a number of ways in which information may be shared with communities that include (i) community meetings or outreach programs where community members have the opportunity to make comments or share concerns on projects; (ii) Radio and local television; (iii) Posters and flyers; (iv) Focus group discussions; etc. Engaging all relevant stakeholders prior to and during project implementation is key to obtaining public confidence and support.

1.3 Grid-connected Rooftop Solar PV Systems – Barrier analysis and possible enabling measures

1.3.1 General description of Rooftop Solar PV systems

Solar photovoltaic, or simply photovoltaic (SPV or PV), refers to the technology of using solar cells to convert solar radiation directly into electricity. Solar PV systems can either be installed on stands on a flat ground surface or on rooftops of any building that has good exposure to sunlight.

Photovoltaic solar systems comprise devices and equipment like photovoltaic modules, charge controllers, inverters, batteries or battery bank. Their design and cost estimation, depend on installation site, building design, required load profile and type of solar module. Depending on application and usage, they can be classified as stand-alone (off-grid) systems or grid-connected solar power systems.

Stand-alone PV systems are not connected to the grid, hence will require some form of a battery energy storage system whereas a grid-connected system is coupled to the grid and does not require a battery energy storage system. Although stand-alone systems may be more expensive due to high cost of batteries, grid-tied systems are limited to the capacity of the grid power producers in order to maintain stability. If not regulated, the power producers will require some form of energy storage systems. Grid-connected roof top solar PV installations are becoming more common in Nauru.

Solar energy is one of the cleanest sources of energy, and it's an extremely effective way of making your household more efficient and sustainable. Solar panels don't use any water to generate electricity, they don't release harmful gases into the environment, and the source of their energy is abundant and sustainable. However, according to (Nugent & Sovacool, 2014), when viewed in a holistic manner, including initial materials extraction, manufacturing, use and disposal/decommissioning, studies show that both wind and solar systems are directly tied to and responsible for some GHG emissions over their lifecycle. They are thus not completely emissions free technologies.

1.3.1.1 Technology status in Nauru

The abundance of solar radiation in Nauru gives great potential for rooftop and ground solar PV systems. Current RE solar PV capacity is 2.456 MW which comprises 0.831 MW of roof top solar PV and 1.625 MW ground mounted solar farms operated and maintained by NUC. The amount of solar PV installed as a percentage of the total available diesel generation is 13%. The following table sets out the potential diesel fuel offset and avoided cost due to solar generation exports to the grid for the period April 2021. The specific fuel consumption for the period is 4.05 kWh/ litre.

Table 3: Diesel fuel offset due to solar generation exports to the grid

Energy production	April 2021	Comments
Solar PV (kWh)	261,999	Exported to grid in the period
Diesel generation (kWh)	3,101,421	Average generated for the period
Fuel consumption – diesel (litres)	765,689	Total fuel consumed for diesel generation for the period
Fuel offset (litres)	62,562	Avoided fuel assuming 100% solar penetration into grid
% Solar penetration	8.1	Percentage of total energy generated
% Diesel offset	8.2	Percentage of total diesel fuel used in the period

Source: NUC April 2021 Report

Figure 3: Typical rooftop solar PV panel and inverter installation in Nauru

The following are some of the installed and on-going donor-funded grid-connected solar PV projects in Nauru.

i) UAE-funded 500 kW ground-mounted grid-connected solar PV farm. In service.
ii) NZMFAT-funded 1 MW ground-mounted grid-connected solar PV farm. In service.
iii) ADB-funded 6 MW ground-mounted grid-connected solar PV farm with battery back-up. Yet to be installed and commissioned.
iv) Taiwan-funded 130 kW grid-connected rooftop solar PV at USP Nauru Campus. In service.
v) Taiwan-funded 150 kW grid-connected rooftop solar PV at Nauru International Airport. Installation in progress.

The situation in Nauru which has set an ambitious target of 50% of renewable electricity to be achieved by 2020 has been delayed due to the pandemic. This target is now expected to be achieved by end of 2022. However, there is concern of rapid and unplanned solar PV installations that were not taken into account in the feasibility study[5] for the 50% target in solar penetration that was done back in 2019. If grid-connected solar PV installations are not controlled, this will impact the integrity, reliability and stability of the grid should cloud coverage occurs.

[5] ADB 6MW Nauru Solar Power Development Feasibility Study Report by GHD.

1.3.1.2 Technology category and market characteristics

Grid-connected rooftop solar PV technology is categorised by the energy expert working group as a consumer and capital goods. When purchased by the private or business sector on a small scale for installation on their rooftops to reduce electricity bills, this technology is referred to as a consumer goods, whereas bigger scale solar PV arrays installed on Government and commercial building rooftops merely to support the grid are considered to be capital goods. The market characteristics for grid-connected rooftop solar PV's is tabulated in Table 4.

Table 4: Grid-connected solar PV category and characteristics

Technology	Category	Description	Market Characteristics
Grid-connected Rooftop Solar PV	Consumer goods	Goods specifically intended for the mass market; households, businesses and institutions.	• a high number of potential consumers • interaction with existing markets and requiring distribution, maintenance and installer networks in the supply chain • large and complicated supply chains with many actors, including producers, assemblers, importers, wholesalers, retailers and end consumers • barriers may exist in all steps in the supply chain • demand depends on consumer awareness and preferences and on commercial marketing and promotional efforts
	Capital goods	Equipment used in the production of electricity.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make

1.3.2 Identification of barriers for Rooftop Solar PV systems

Preliminary barrier identification

For this process, the following list of broad barrier categories will be addressed whether or not they impact the development, transfer and diffusion of grid-connect rooftop solar PV systems.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;

- Human capacity barriers;
- Public awareness and information barriers.

Screening of barriers identified

The screening of the barriers identified above was carried out by the same energy expert working group and the outcome of this discussion and information gathered is produced in the market mapping, problem tree and solution tree tables in the annexes. These are further explained below.

1.3.2.1 Economic and financial barriers

a) *High upfront cost* – to the private investor, the cost of importing rooftop solar PV systems is considered high due mainly to import duties (20%) and the very high shipping cost; dry 20ft containers cost AUD5,500 and AUD7,500 from Suva and Brisbane respectively[6]. The lack of adequate port facilities and long waiting times is the result of high operating costs associated with servicing Nauru. Unloading shipping containers is a lengthy and costly processes exacerbated by fuel costs which are transferred to the customers (ADB, 2017). The cost for a 20 foot container from Fiji is almost AUD6k and around AUD7k if from Australia (Brisbane).

b) *Feed-in-tariff*[7]– In January 2017, a feed-in-tariff rate of AUD0.2005 was approved by the Cabinet which has remained unchanged to this date (August 2021). The current arrangements expose NUC to financial and commercial risks which may negatively impact on its commercial sustainability (Piantedosi, August 2021).

1.3.2.2 Non-financial barriers

Technical

a) *Grid instability* – Some notable future challenges associated with high penetration of solar-grid integration; if not properly planned or managed can lead to serious instability on grid voltage and frequency stability and overall power quality, in the

[6] https://info.naurushippingline.com/latest-news/freight-rates/

[7] A feed-in tariff (FiT) is a credit customers receive for any unused electricity that their solar power system sends back to the power grid. It's usually a set rate per kilowatt hour and paid as a credit on electricity bills.

event of cloud coverage. To overcome these issues, energy storage systems like BESS are normally provided to maintain grid stability, however the main issue with BESS systems is that they are very costly and only have a lifespan 10 to 15 years.

Institutional arrangements

a) *Feed-in-tariff* – The lack of legislation and regulations with reference to the feed-in-tariff scheme; if not addressed will have a negative impact on the financial viability of NUC.
b) *Grid stability* – Lack of regulations to control solar PV installations will impact grid stability.

Social, cultural and behaviour

a) *Power Purchase Agreement* – The Feed-in-Tariff policy that was approved by the Cabinet on 27 January 2017 states that NUC will buy excess electricity generated from residential rooftop solar PV system at the tariff of $0.2005 / kWh. For these same customers, their tariff rates will be increased from $0.25 to $0.50. For some, this policy discourages the people to invest
b) *Motivation* – There are no incentives in place to encourage residential customers to import and install rooftop PV systems. There are no rebate schemes to import solar PV systems.
c) *Affordability* – It is noted that very few households are able to afford to have rooftop PV installations due to costs.

Environmental

a) *Pinnacle rocks* – Roof top solar PV installations are known to have no negative impact to the environment as compared to ground mounted solar farms. Environmental barriers faced with installation and diffusion of ground mounted systems is the land availability and pinnacle rocks. On the other hand, impacts with land clearing will cause vegetation degradation and displacement of wildlife habitats including that of invertebrate fauna, reptiles and birds.

Human capacity

a) *Lack in skilled personnel* – There is a notable increase in the number of households that have opted to invest on grid-connected rooftop solar PV systems. However, there is limited number of skilled technicians trained in the installation and commissioning of these systems. This has caused delays on a number of solar PV systems that are waiting to be installed. Noted also is the number of installed systems that are not performing 100% for some technical reasons that would require a skilled technician in troubleshooting to identify and rectify faults. NUC only has a few skilled personnel, hence will not be able to meet demand.

Public awareness and information

a) *Limited awareness* – There is no awareness or information that encourages the public to invest in grid-connected solar PV systems due to issues related to over penetration and grid stability.

1.3.3.1 Economic and financial measures

a) *Low cost solar PV systems* – The completion of the new ports facilities is anticipated to bring down the cost of imported goods. Financial incentives for solar PV systems could be established in a form of exemptions from import duties or a rebate system.
b) *Feed-in-tariff* – NUC management will need to establish the necessary policy, rules and guidelines for the implementation of the Electricity Feed-in-Tariff Solar Scheme in order to be commercially sustainable (Piantedosi, August 2021).

1.3.3.2 Non-financial measures

Technical

a) *Grid stability* – Proper planning and management of solar penetration levels is key to grid voltage and frequency stability. To avoid grid instability issues due to over penetration, an energy storage system will be required.

Institutional arrangements

a) *Policy formulation* – Clear and enforceable regulations, codes and rules are required to ensure economically sustainable solar PV generation into the grid, grid stability, reliability and security of supply to all customers. Investigating public awareness, acceptance, and attitude towards renewable energy are thus critical for providing insights necessary for an effective policy formulation.

Social, cultural and behaviour

a) NUC need to review and amend related policies that will reduce its financial and commercial risks and to ensure that rates are ideal and affordable to the public. The government should support customers by introducing rebate schemes for imported solar PV systems. Where needed, the government should provide subsidies that financially secures NUC operations and encourage the use of solar PV systems.

Environmental

a) *Limited land availability* – Future land clearing for further solar farm development projects should be limited to the already existing solar farm sites. For future solar expansion projects, rooftop installations should be considered.

Human capacity

a) *Capacity building* – Assess training needs and develop the necessary training programs for small businesses, technicians and tradespeople. Inclusion of renewable energy sources and technology topics into the school curriculum.

Public awareness and information

a) *Grassroots perception* – I Public opinion of solar and other RE is critical for the planning of future energy portfolios. The public has an active role to play in the development of energy policy and operation of the energy market. The public strongly approves the development of RE technologies and still believes that this will reduce the cost of electricity.

1.4 Biogas – Barrier analysis and possible enabling measures

1.4.1 General description of Biogas

Biogas is the mixture of gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. Biogas is a modern form of bioenergy and renewable energy source that can be produced through anaerobic digestion or fermentation of a variety of biomass sources. It is a versatile fuel that can be used for cooking, heating, lighting, power generation and combined heat and power generation, as well as, when upgraded to boost its methane content, in transport applications.

Biogas contains roughly 50-70 percent methane, 30-40 percent carbon dioxide, and trace amounts of other gases (U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy, 2014). The energy content of 1.0 m^3 of purified biogas is equal to 1.1 L of gasoline, 1.7 L of bioethanol, or 0.97 m^3 of natural gas. Digestion is a slow process and it takes at a minimum of three weeks for the microorganisms to adapt to a new condition when there is a change in substrate or temperature (Dieter & Steinhauser, 2008).

The implementation of the technology leads to the reduction of GHG's emission due to the substitution of fossil fuel based energy with renewable energy and reduction methane emissions from animal manure management.

The benefits of small-scale biogas plants provide an opportunity to solve manure management problems and simultaneously generate energy for cooking. The size of these digesters varies between 1 and 150 m^3. The common designs include fixed dome, floating drum and plug flow type. For tropical countries, it is preferred to have digesters underground due to the geothermal energy as this is reported to help in maintaining the temperature in the digester when buried underground. (Rajendran, Aslanzadeh, & Taherzadeh, 2012).

The choice of substrate in Nauru will depend on the availability of the raw material, type of digester, and its operating conditions. Although kitchen wastes and crop residues are some underexploited substrates for domestic biogas production, the high fat content of kitchen waste; in the form of animal fat and cooking, are known to enhance the biogas production. Pig manure which is known to have a high content of methane, around 60% will be used in this report as a source of substrate.

The amount of biogas used for cooking purposes usually varies between 30 and 45 m^3 per month. This number can be compared with other commonly used fuels such as kerosene where the consumption is between 15 and 20 litres, and Liquefied Petroleum Gas (LPG) between 11 and 15 kg per month, respectively. The energy equivalent was around 300, 200, and 150 kWh for biogas, kerosene, and LPG, respectively (Rajendran, Aslanzadeh, & Taherzadeh, 2012).

Biogas systems are also a waste management solution that solve multiple problems and create multiple benefits.

1.4.1.1 Technology status on Nauru

There is currently no biogas plant nor a working demonstration system on Nauru. Therefore, it should be noted that this technology is totally new to Nauru who have relied greatly on LPG and electricity as an energy source for cooking. However, through the GEF/ UNDP Small Grants Program (SGP); that is being coordinated by EcoNauru[8], two districts in Nauru – Ijuw and Denig, will be awarded a maximum of up to USD50k each to establish piggery farms that will also enhance renewable energy through demonstration of collecting manure to produce biogas. This program is yet to commence.

Figure 4: Biogas digester

1.4.1.2 Technology category and market characteristics

Biogas technology is categorised by the expert working group as a capital goods in a situation where a relatively large capital is invested into the building of a big biogas plant to produce electricity and/ or gas for cooking. As a publicly provided goods, technology may be owned by the public that produces gas for cooking, say in a public hospital. Market characteristics are listed in Table 5.

[8] EcoNauru - Formally established in 2016, EcoNauru consists of members with backgrounds in Environmental Science, Climate Change (Vulnerability & Adaptation, Greenhouse Gas accounting, and Mitigation practices), Water conservation and management, Land Management, the sustenance and preservation of natural biodiversity, and Fisheries Management.

Table 5: Biogas category and characteristics

Technology	Category	Description	Market Characteristics
Biogas	Capital goods	Equipment used in the production of gas for cooking or generating electricity.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make
	Publicly provided goods	Publicly owned and SOE operated to produce gas for electricity generation to the grid.	• very few sites • large investment, government/donor funding • public ownership or ownership by large companies • simple market chain; technology procured through national or international tenders. • investments in large-scale technologies tend to be decided at the government level and heavily dependent on existing infrastructure and policies.

1.4.2 Identification of barriers for Biogas

Preliminary barrier identification

Being a new technology to Nauru, the same list of common barrier will be used to analyze which barrier(s) may or may not impact the development, transfer and diffusion of this technology given the available resources and capacity.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;
- Human capacity barriers;
- Public awareness and information barriers.

Some of the main variables known to affect biogas production include the digester type; digester size (measured either as volume or expected production level); the type and amount of feedstock used in the digester; feedstock retention time; and temperature (IRENA, 2016).

Screening of barriers identified

1.4.2.1 Economic and financial barriers

a) *High capital and operating costs* – The costs needed to build and maintain a fully functional biogas system using pig manure is determined by the size of the digester – the bigger the digester, the more pigs that must be farmed. To date, biogas use on-farm are known to be most economical for larger piggeries (1000+ sows farrow-to finish). However, the cost to maintain a large piggery farm can be very costly. Household digesters are cheap, easy to handle, and reduce the amount of organic household waste. The effect of not having a biogas system for cooking will mean continued reliance on costly LPG[9].

1.4.2.2 Non-financial barriers

Technical

a) *Design and operation* – Maintaining correct operating parameters are very critical for obtaining the maximum biogas yield from the digesters. Some of the known technical reasons for failed biogas systems include:

- Poor design and construction
- Low quality construction materials
- Poor operation (improper feeding, more water, more feed)
- Ineffective maintenance or no maintenance service available
- Non-availability of spare parts
- Natural/ man-made disasters
- Slurry entered in to the gas pipe
- Water collected in pipe, clogging
- Higher water level/ overflowing during rainy season

Leakage from biogas digesters increases emissions of methane and carbon dioxide into the environment. Fire explosions in households are another disadvantage when methane leaks from the digester.

[9] Nauru 13kg LPG retail = AUD82 vs Fiji 13kg LPG retail = FJD38.

Institutional arrangements

a) *No framework* – The institutional barrier relates to the lack of regulatory framework for environmental control over the use of organic waste and enforceable mitigation measures.

Social, cultural and behaviour

a) *Behaviour* – Increased waste recycling in a household waste management system to support biogas is a challenging task that involves both social and technical aspects. The change of culture or behaviour from utilising electricity or LPG for cooking will be a challenge considering the standard of living in Nauru and needs in terms of access to and establishing a biogas facility at home as compared to other readily available and accessible sources for cooking.

Environmental

a) Literature on biogas installations indicate that there are no known environmental barriers to the uptake of biogas technology.

Human capacity

a) *No skilled worker* – The capacity barrier relates to insufficient personnel with the practical experience in biogas plants construction and biogas production. There are no professional training programs in Nauru preparing operators of domestic and commercial biogas plants and other personnel specific to biogas production.

Public awareness and information

a) *Public acceptance* – some of the limiting factors involve public acceptance of the biogas facilities diffusion, as well as lack of a reliable coordination between different stakeholders. Furthermore, normative and legislative inadequacies and deficiencies haven't facilitated the implementation of these technologies within the national context.

1.4.3 Identified measures for Biogas

1.4.3.1 Economic and financial measures

a) *Low capital cost* – Financial incentives for biogas digester systems could be established in a form of exemptions from import duties. Small experimental biogas systems should be set up and trialled out first before it is promoted. If cost to setup, operate and maintain is affordable, this can prove to become a more sustainable form of energy for cooking.

1.4.3.2 Non-financial measures

Technical

a) *Good practices* – The maintenance of a biogas plant is an essential step in its operation. For the project developer, this is a major investment that he must include in the operational costs of the biogas plant, and paying special attention to certain aspects such as technical equipment, anaerobic digestion biological process and safety.

Institutional arrangements

a) Regulatory framework – One of the key goals of biogas is to reduce negative environmental impacts associated with animal manure waste. To foster the implementation of biogas, it is recommended to develop, adopt and enforce the regulatory framework.

Social, cultural and behaviours

a) *Cultural change* – To promote biogas within a community will require a lot of information sharing and most important financial and technical support. A built and functioning pilot biogas plant will have a potential to change people's initial negative mind-set.

b) *Participatory process* – A participatory process model must be developed as the main project's approach to include all actors in an important common decision-making process.

Environmental

a) The uptake of biogas technology on Nauru does not pose any environmental issues.

Human capacity

a) Coordination – As a newly introduced technology to Nauru, it is essential for local project developers to coordinate with technology suppliers to provide training in operating a biogas plant. Trialling of a biogas system is essential for initial collection of relevant data to determine personnel confidence and viability of technology.

Public awareness and information

a) Communicate – There is the need for construction of a communication model oriented to spread balanced information, based on environmental and economic benefits, between all the actors potentially involved in biogas implementation.

   The attention should be focused on some high energetic potential communities where the diffusion of this technology struggles to be realized and the effects of project actions on awareness and acceptance will be evaluated.

   A specific decisional participative model need be implemented and applied in one of the selected districts, as case study.

1.5 PHES – Barrier analysis and possible enabling measures

1.5.1 General description of PHES

PHES entails using surplus electricity (for example, on windy/sunny days or during off-peak periods) to pump water from a lower reservoir to an upper reservoir through a pipe or tunnel. Later, the stored water can be released through a turbine to recover most of the stored energy (Blakers, Mathews, Bin, Kirsten, & Anna , 2017). The main applications of pumped hydro are for energy management, frequency control and provision of reserves.

Pumped hydro is the most developed energy storage technology, with facilities dating from the 1890s in Italy and Switzerland. Currently, there is over 90 GW of pumped storage capacity in operation worldwide, which is about 3% of global generation capacity. Pumped storage plants are characterized by long construction times and high capital expenditure. However, with rising electricity prices and increasing use of intermittent energy sources, it can be very economic to store electricity for later use.

The advantages that a PHES system has over battery storage is that the pumped hydro has a lifetime 50 years compared with 8-15 years for batteries (Blakers, Mathews, Bin, Kirsten, & Anna , 2017).

The use of fresh water rather than salt water is preferred to reduce corrosion of turbines, pumps and pipes and to minimise the risk of salt contamination of the land environment. The largest drawcard for a seawater PHES is the opportunity to eliminate the lower reservoir, saving capital cost. This cost saving must be balanced against the increased cost and risk of exposing the system to corrosive seawater. Most suppliers suggested the repairs and maintenance requirements, including downtime for routine maintenance, would be twice that as compared with a freshwater PHES (EnergyAustralia & Aru, 2020). Typically, about 85% of the stored water is available for use in a PHES system. The majority of modern pumped storage hydropower projects use reversible pump/turbine units that act as both a pump and a turbine.

This technology allows for a long lasting energy storage system; in place of batteries, that will be supported from any RE excess power generated and in return will support the grid when there is no RE source.

1.5.1.1 Technology status on Nauru

The concept of pumping seawater to higher grounds for storage and gravitational use is not a new concept to NauruSeawater reservoirs have been used to supply seawater for engine cooling, firefighting and for non-potable use. This system has been decommissioned.

Due mainly to its great potential as an alternative for BESS, GHD; through NZ MFAT funding, have prepared a feasibility study proposal back in 2019. This technology has drawn the attention and interest of the Department for Climate Change and National Resilience in making this study possible.

1.5.1.2 Technology category and market characteristics

PHES technology was identified by the energy expert group as a capital good when described as a plant used in the production of electricity, and also as a publicly provided goods when owned and operated by an SOE. Market characteristics are provided in Table 6.

Table 6: PHES category and characteristics

Technology	Category	Description	Market Characteristics
PHES	Capital goods	A water reservoir with machinery and	• a limited number of potential sites/consumers • relatively large capital investment

		equipment used in the production of electricity.	• simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make
	Publicly provided goods	Technology is publicly owned and operated by NUC to store energy for load shifting and maintaining grid quality.	• very few sites • large investment, government/donor funding • public ownership or ownership by large companies • simple market chain; technology procured through national or international tenders. • investments in large-scale technologies tend to be decided at the government level and heavily dependent on existing infrastructure and policies.

1.5.2 Identification of barriers for PHES

Preliminary barrier identification

Since PHES technology is new to Nauru, the core problem in prioritizing its development, transfer and diffusion as identified by the energy expert group is lack of knowledge of technology as a proven and widely used energy storage technology; over BESS, that is also viable for its development on Nauru. PHES technology is commonly used for power grid management where intermittent renewable energy technologies are used such as wind and solar..

An initial desktop-review for the viability of this technology was carried out by the mitigation consultant and has come up with a list of the common barriers for discussion with the expert working group to identify what may be the root causes of these.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;
- Human capacity barriers;
- Public awareness and information barriers.

PHES technology is a capital good that will require a high capital cost and a big mass of land for the construction of a reservoir, hence the leasing of land may certainly become a potential barrier if land-owners do not agree to the terms provided. As a new technology for Nauru, there is lack of skilled personnel to operate and maintain the system therefore capacity building is key.

Screening of barriers identified

1.5.2.1 Economic and financial barriers

a) *High capital and running cost* – Commercially, the use of seawater adds additional costs to a PHES project compared with a freshwater solution. Depending on if the system pre-treats the water prior to filling the reservoir, the additional costs are either through costs associated with higher grade materials that can withstand higher concentrations of corrosive chloride or with the additional capital and operating costs required for a water treatment process plant. Some of the key design inputs impacting on the capital cost include head (the difference in elevation between the upper and lower reservoir), penstock length (the distance between upper and lower reservoir), transmission length and storage time (storage volume). Other variables that will impact on cost include land tenure, local topography, geological conditions, available site construction material, available water source (and quality), environmental and approval issues and flood risk (EnergyAustralia & Aru, 2020).

1.5.2.2 Non-financial barriers

Technical

a) *Seawater source* – Technically, utilizing seawater systems represents an interesting challenge. Largely the viability of utilizing seawater for PHES comes down to the chloride concentration of the water and potential rate of corrosion of associated equipment which influences material selection and operational life.

   Biofouling, or the build-up of biological matter such as algae and other organisms, can occur on the submerged surfaces of piping and equipment in a marine environment. This can cause issues with operability and performance if left unaddressed.

b) *Freshwater source* – Freshwater is a solution to the technical challenges faced with using seawater. Freshwater from rainwater harvesting, reverse-osmosis, existing natural freshwater sources and ground water are potential sources of water identified in the MFAT report[10].

Institutional arrangements

a) *Weak institutional support* – Due to lack of knowledge on concept, benefits and potential of PHES technology in Nauru, there is little interest and support for PHES development.

Social, cultural and behavior

a) *Land access* – Unlike OTEC plants, PHES require a bigger portion of land area to accommodate an upper reservoir, and a lower reservoir; if freshwater was to be used. An estimated land area being proposed for a feasibility study on Nauru is 3.2 hectare. Hence, similar barriers for OTEC in this regard will need to be addressed also for PHES.

Environmental

a) *Lack of legislation on seawater use and impacts* – The use of seawater for PHES project will need to comply with relevant environment legislation where impacts on the receiving environment (during construction, operation and maintenance) may also need to be sufficiently understood and addressed. Examples of potential impacts may include:

- impacts to local coastal processes and marine water quality
- impacts to marine ecology, including National listed species
- impacts to surface water or groundwater water quality from seepage of saline water from the reservoirs
- impacts to community amenity and values.

Land clearing will cause vegetation degradation and displacement of wildlife habitats including that of invertebrate fauna, reptiles and birds.

Human capacity

a) *No skilled personnel* – There is significant capacity building required within Nauru to allow for the successful and sustainable operations and maintenance of PHES plant equipment – in particular the turbine and pump.

[10] MFAT Proposal for Nauru Pumped Hydro Power Energy Storage Feasibility Sturdy report (GHD – July 2020)

Public awareness and information

a) *Lack of public awareness* – There is lack of information sharing and awareness raising to the public in regards to, and the progress of Nauru's energy targets as provided in the NSDS and NERM 2014-2020 reports.

1.5.3 Identified measures for PHES

1.5.3.1 Economic and financial measures

a) *Feasibility study* – Being a newly introduced technology to Nauru, and with potential to serve its purpose as a renewable source for energy storage to support in this case grid stability, the only recommended measures that will ascertain its economic viability is to carry out a feasibility study.

1.5.3.2 Non-financial measures

Technical

a) *Seawater PHES Model* – Given Nauru's limited water resources on land, the abundance and access to seawater as a water source for PHES use is more viable, but faces greater challenges to corrosive effect of saltwater on plants' electromechanical and water conveyance structures. The Okinawa Yanbaru Seawater Pumped Storage Power Station is the world's first experimental pumped-storage facility to use seawater that was decommissioned in 2016 (Okinawa Yanbaru seawater pumped storage power station, 2020). The Okinawa Yanbaru plant operated successfully for the subsequent 16 years, only closing because of a lapse in regional electricity demand growth (Hydrowires, 2020). The Yanbaru experience can be used as model to build from and adapt to Nauru's need and situation with real-world data and studies already completed.

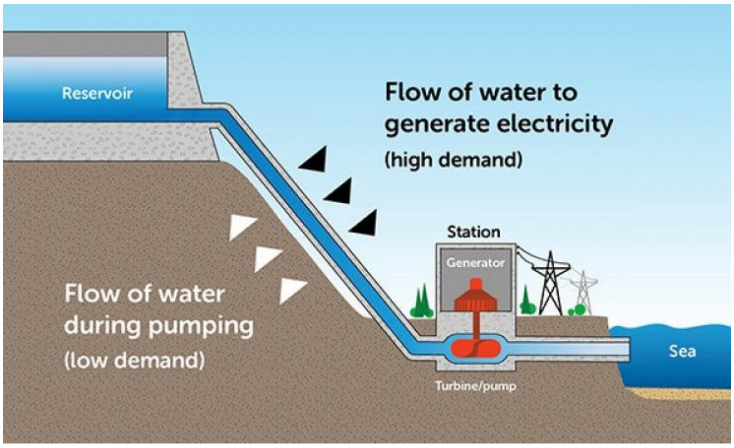

Figure 5: Typical seawater pumped hydro scheme[11]

Institutional arrangements

a) *Institutional strengthening* – If taken up, this PHES facility will be operated by NUC. Hence, a series of reform measures will need to be identified and recommended to provide institutional strengthening. Recommended reform measures identified include:

i) Develop relevant policy and legislation for land tenure;
ii) Develop and implement an asset management and maintenance plan;
iii) Improve accounting systems through integration of the asset registry and the financial management information system;
iv) Implement performance management systems for lower level NUC staff;
v) Review the corporate governance of the organization.

Setting the necessary framework conditions and ensuring that public institutions work effectively and efficiently with the rest of society is essential to achieving sustainable development.

Social, cultural and behaviour

a) *Land tenure evaluation periods* – In a situation of rapid economic and social change, land tenure should be periodically evaluated (perhaps every five years) to ensure it continues to meet the current and expected needs of the people.

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[11] Source: http://www.esru.strath.ac.uk/EandE/Web_sites/17-18/cumbrae/Seawater%20pumped%20hydro.html

Environmental

a) *Development of legislation on seawater use and impact*s – This is a must have document that will provide the best practices and guidelines for transporting and storing seawater inland effectively with minimal or no seepage or impacts to marine life.

Human capacity

a) *Training* – building specialised local capacity in the operations and maintenance of turbine and pumping equipment for continued and effective operations. Specialist to be flown in to provide certified trainings to as many locals as possible.

Public awareness and information

a) *Television* – TV is a powerful persuasive mass communication medium that attract the audiences of all age groups, literate and illiterate and of all the strata of the society. Sharing of information on energy-related technologies that are either in their stages of a feasibility study or in the construction stages should be encouraged to keep the public informed and updated. These awareness programs will obtain the full support from the public who are also the main stakeholders as landowners. It informs the public on government capacity, initiatives and responsibilities to achieving its energy goals as outlined in the NSDS.

1.6 Linkages of the barriers identified

This section discusses the barriers common to OTEC, grid-connect rooftop solar PV, biogas and PHES. These four prioritised technologies in energy sector serve the common goal in providing an alternate source of energy that can be fed into the grid and thus reducing the reliance on fossil fuel for generating electricity. These four technologies all have different sources of fuel that are available and accessible locally to generate electricity to the grid. Both OTEC and PHES generate mechanical energy that is converted to electrical energy.

A review of the barriers shows a concern for costs, whether capital or operational costs. OTEC is currently in the pre-feasibility stage with PHES still in the stage of sourcing fund for a feasibility. Solar PV technology is well developed however the shipping cost and custom duties to import are very high.

OTEC technology is considered to be still in its early stages in terms of its economic viability. However, its purpose to (i) reduce GHG is rated high; (ii) meet National socio-economic goals in terms of renewable and sustainable sources of electricity and water, this too is rated high. There is also minimal environmental impact. However, the major barrier for the uptake of OTEC technology is its high capital cost and lack of skilled personnel. With its past experience with OTEC technology; that is further supported by its potential given its location, Nauru continues to embrace this technology as the most recommended technology given its capability to produce baseload electricity and in desalinating sea water.

Grid-connected rooftop solar PV technology is certainly a viable technology that has increased its penetration level dramatically in a short period of time. Although the cost of panels has decreased, the cost of shipping on Nauru is very high, hence the high cost of living. A major technical issue; if solar penetration is not controlled, is grid instability. The technical solution to resolve this issue is to have an energy storage system. Energy storage systems are purposely installed and designed to maintain grid power stability; during cloud coverage, for certain period of time that allows the power plant to start up its diesel generators and connect to the grid. Therefore, an increase in grid-connected solar PV systems; regardless whether ground or roof-mounted, will require sufficient capacity of the energy storage system. In order to control or limit installation of solar panels, policies must be developed. By the end of 2022, Nauru will achieve its energy target of 50% energy to be produced through RE thus reducing its GHG. Major barriers that will hinder the expansion of this technology therefore are high costs, weak institutional capacity and unclear policy to control over penetration.

Biogas technology is viable both technically and economically at household level. However, there is lack of public awareness and information, donor support and capacity. Technology acceptance by the community may also take some time. Biogas is a new and interesting technology to Nauru which if never encouraged or funded, will never have existed.

PHES is a proven technology that is viable in countries with hills and mountains. With its highest elevated point of 70 meters, a high level study has shown potential for the viability of this technology in Nauru. If adopted, it will enhance the viability of grid-connected solar PV systems in terms of providing a reliable form of renewable energy back-up system that can be used freely as needed. An estimate in the reduction in GHG emission can be determined by the PHES electrical rating with respect to the equivalence of diesel power generation. The major barrier for the transfer and diffusion of PHS technology on Nauru is its high capital costs.

1.7 Enabling framework for overcoming the barriers in the Energy Sector

The penetration level of rooftop solar PV systems to the grid is anticipated to increase dramatically if not controlled in terms of institutional strengthening with development and enforcement of policies by NUC. Measures to include a review and adjustment of feed-in tariff rates to safeguard NUC from financial and commercial risks that may negatively impact its commercial sustainability. It is forecasted that by the end 2022, Nauru's renewable energy mix would have reached well over 50%.

Biogas technology is yet to be piloted and anticipated to take some time to fully develop before it can be accepted and taken up by the community.

OTEC and PHES technologies have been highly prioritised for feasibility studies to determine their economic viability and contribution to reducing GHG.

Chapter 2: **Waste Sector**

2.1 Preliminary targets for technology transfer and diffusion

The waste sector has been prioritised for technical assistance under the Technology Needs Assessment (TNA) project as it is considered as one of major GHG emitter if not managed properly. GHG emissions from the waste sector in Nauru are estimated for following subsectors:

- Solid Waste Management and Disposal
- Domestic and Commercial wastewater handling

Waste management sector emissions has been estimated using data from open source, Nauru census and pacific specific waste generation and composition, due to lack of reliable data on waste generation (Republic of Nauru, 2014) . Waste is considered as any unwanted substance from human life. The term “waste” in general, could be used in different descriptive terminologies such as garbage, trash, rubbish, refuse, by-product, a rest product and discards. No matter which terminology is used, waste is ever ingrained and inseparable from human life, and it requires proper handling for a better tomorrow.

Collection and disposal of municipal solid waste are managed by two privately-owned businesses through a GoN waste management funding program. Household waste is normally disposed of in 204 litre plastic wheelie bins that are collected three times a week. Skip bins are also available for hire at $75 and $150 for 3 and 6 cubic meter capacity bins respectively.

The NRC is responsible for the waste management program in Nauru which includes control of landfilling at the dumpsite and some resource recovery activities that include separation and stockpiling of tyres, white, garden waste, cardboard and scrap steel. Asbestos are placed in shipping containers (Tonkin and Taylor, 2018). Segregated waste are also stockpiled separately for composting and recycling. Unsegregated waste is disposed of freely at the dumpsite and bulldozed for landfill.

There have also been numerous strategies to improve waste management in the Republic, through improving Reduce, Re–use and Recycle projects. A few initiatives include: Clean and Green Project, composting, the scrap metal scheme, privatization of recycling, pick up of wheelie bins, and compost toilets. There is an existing and growing community awareness of the importance of waste management (Republic of Nauru, 2014).

The Government of Nauru through the Department of Commerce, Industry & Environment (CIE) is responsible for the strategic planning and regulatory aspects of waste management.

Nauru has very limited legislation relevant to waste management and governance, and no specific legislation on this topic. An Environment Management Bill 2006 and 2011 are discussed in the National Solid Waste Management Strategy 2017-2026, Waste and Dumpsite Management Report 2018, the Solid Waste Management in the Pacific: Nauru Country Snapshot 2014 and the Stockholm Convention Initial National Implementation Plan 2012. To date, the Environment Management bills have not been passed into law. It appears that the Litter Prohibition Act is still, therefore, a major piece of legislation regulating solid waste management in Nauru (The University of Melbourne, Nov. 2020).

The Litter Prohibition Act (1983) makes provision for the abatement of litter, and repeals section 15 of the Public Health Ordinance 1967. Section 2 of the Act makes it an offence to throw, drop or deposit litter, refuse or rubbish of any kind in a public place. Those found guilty will be liable to a fine of three hundred dollars.

The National Solid Waste Management Strategy (2017-2026) contains a range of actions intended to improve solid waste management in Nauru. The strategy sets out a range of targets as follow (Tonkin and Taylor, 2018).

- Practical and enforceable regulations for waste management enacted by 2019, and enforced beginning in 2020.
- Increase the percentage of the population aware of and engaging in good solid waste management practices by at least 10% yearly over the 2017 levels.
- Solid waste management integrated into the Nauru school curriculum by 2017.
- By 2017, adequate numbers of trained staff are effectively implementing the National Solid Waste Management Strategy, and there is a plan in place for continuous staff development.

- Improved operation and management of the NRC-managed dumpsite by 2017 in order to extend the operational life and minimize the pollution risks and other environmental impacts (odours, pests, fires, etc).
- An efficient and sustainable collection system in place by 2018.
- 30 % reduction in the amount of solid waste requiring disposal to landfill by 2020 compared to 2017 baseline data
- 75% reduction in bulky waste stockpiles by 2020.
- Fair application of the polluter pays principle – i.e., those who cause pollution should pay the cost of managing that pollution.
- At least 15% of the waste management budget generated from sustainable means by 2020, and 30% by December 2023.

The vision for the NSWMS is identical to the strategic goal identified in Nauru's NSDS 2005-2025: ***Effective management of waste and pollution that minimizes negative impacts on public health and environment***. This vision is underpinned by three goals:

a) To reduce environmental pollution from the generation and disposal of solid waste
b) To increase economic benefits and efficiency by reusing and recycling wastes where possible
c) To reduce the costs to society of managing waste through efficient and responsible management and equitable distribution of costs

Waste entering the dump site from community or business collections is recorded and billed each month. Communities are billed $2.50 per cubic meter and businesses at $20 per cubic metre (Tonkin and Taylor, 2018). There is known to be some form of daily logging information available on waste quantity or composition with the dumpsite site office that was not accessible when this report was being prepared. However, based on materials received at the dump site in the week of 26 February 2018, an estimated 26,000 m3 or 4 to 5,000 tonnes of material is received each year. Visual observation of waste material entering the Nauru dump site indicates that cardboard, plastic bottles and plastic bags are a significant portion of the waste stream. Aluminium cans, food tins, nappies and a wide range of broken items were also present (Tonkin and Taylor, 2018).

The application of sustainable waste management (SWM) principles in SIDS is critical because it has direct impact on the state of the environment, well-being of humans and ultimately the economy. Despite the importance of SWM, implementation is impeded by a combination of social, economic and environmental challenges. Awareness raising should be conducted as much as possible in the native language. Success of waste management in SIDS depends on how much the community can engage in them, rather than sophisticated technologies imported from other countries. Indeed, oftentimes residents of SIDS cannot afford to maintain advanced technologies, even if the capital expense has been covered via grants or low interest loans (Periathamby & Herat, 2014).

The four mitigation technologies that were prioritised in the first TNA report for the waste sector include:

- **(i) Composting**
- **(ii) Segregation**
- **(iii) Semi-aerobic Landfill**
- **(iv) Baling**

2.2 Composting – Barrier analysis and possible enabling measures

2.2.1 General description of Composting

Composting is the natural process of recycling organic matter, such as leaves and food scraps, into a valuable fertilizer that can enrich soil and plants, hence the basis of all sustainable agricultural system is a fertile and healthy soil.

The term composting is defined as biological degradation of waste under controlled aerobic conditions. Composting enriches soil, helping retain moisture and suppress plant diseases and pests. Reduces the need for chemical fertilizers. Encourages the production of beneficial bacteria and fungi that break down organic matter to create humus, a rich nutrient-filled material. The waste is decomposed into CO2, water and the soil amendment or mulch. In addition, some carbon storage also occurs in the residual compost.

Three composting techniques available are windrow, aerated static pile and in-vessel composting. Supporting techniques include sorting, screening and curing also. Each technique varies in procedures and equipment’s needs.

Generally, there are two major approaches to compositing. Active and passive. Active (hot) compositing is compositing close to ideal conditions allowing aerobic bacteria to thrive. To achieve good results, the composite material must be kept warm, insulated and moist. Passive composition is compositing in which the level of physical intervention is kept to a minimum. Most industrial compositing operations use active compositing techniques while home compositing operations use passive techniques.

2.2.1.1 Technology status on Nauru

Nauru soils are generally poor and suffer major deficiencies of key elements (particularly nitrogen and potassium). Use of fertilizer and composting is not common due to costs and lack of farmer skills. But given resources, these problems can be rectified. As the people of Nauru become aware of the need to improve their food security and nutrition status, agriculture is beginning to grow in importance as more people are now starting to plant crops.[12] However, the warm, wet (average 2000 mm rain per year) climate on Nauru is well suited to composting of organic materials.

The operation of the current dump site includes some resource recovery activities that include garden waste - collected in hook bins periodically and transported to NRC Workshop for shredding and composting with cardboard and garden waste.[13] NRC who manages the dumpsite, uses a Red Roo CMS100 and Vermeer BC1500 shredders that can handle green waste and cardboards.

[12] http://www.fao.org/fileadmin/user_upload/sap/docs/Nauru.pdf

[13] 2018 – Nauru Waste Report

Figure 6: NRC shredding machineries

The Nauru Ridge to Reef (R2R – 2015 to 2020) GEF project promotes sustainable use of all resources, including agrobiodiversity. The improvement of soil, including proper composting technique, has contributed to families being able to growth vegetables and fruits.

At community level, there are some form of composting activities going on but at a very small scale. The Taiwan Technical Mission on Nauru is the main producer and provider of compost soil that are made available to the community for free.

2.2.1.2 Technology category and market characteristics

Composting technology was identified by the waste expert group as a consumer goods when used as a form of topsoil for growing lawns; and capital goods when used to grow crops for consumers. Market characteristics are shown in Table 7.

Table 7: Composting category and characteristics

Technology	Category	Description	Market Characteristics
Composting	Consumer goods [Market goods]	Used as topsoil for growing lawn.	• a high number of potential consumers • interaction with existing markets and requiring distribution, maintenance and installer networks in the supply chain • large and complicated supply chains with many actors, including producers, assemblers, importers, wholesalers, retailers and end consumers • barriers may exist in all steps in the supply chain • demand depends on consumer awareness and preferences and on commercial marketing and promotional efforts

	Capital goods [Market goods]	Used in the production of crops.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make

2.2.2 Identification of barriers for Composting

Composting of solid waste could yield some odorous by-products such as CH4, N2O and NH3 that are detrimental to the environment and can cause secondary environmental pollution. Emission of odour from composting plants could cause discomfort to the public especially those residing around composting facilities. This makes odorous emissions a matter of serious concern to bio-waste treatment facilities/plants. These emissions might not directly cause health problems, but they could be associated with negative health effects which may thus lead to defensive reactions of people due to psychological effects.

Preliminary barrier identification

For this process, a list of common barriers will be used although some may or may not impact the development, transfer and diffusion of composting. These barriers are provided below.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;
- Human capacity barriers;
- Public awareness and information barriers.

Screening of barriers identified

2.2.2.1 Economic and financial barriers

a) *Residential vs commercial composting* – Household composting effectively reduces waste quantities for collection, thereby improving efficiency and reducing operating costs. Commercial composting is done at the dumpsite hence the need for transporting of wastes to the site and the need for mulching machineries. There is also the need for paid workers.

2.2.2.2 Non-financial barriers

Technical

a) *Lack of resource availability* – There is lack of composting activities being carried out at the resource recovery site due to limited availability of sorted organic and green waste which would normally end up at the landfill.

Institutional arrangement

a) *Lack of policy enforcement* – There is lack of institutional arrangements in place that supports and encourages the uptake of composting both at community and commercial levels.

Social, cultural and behaviour

a) *Lack of incentives* – composting is not widely encouraged at community level although there are several groups of growers who have developed an interest to promote and provide training to those interested not only in making composts but also in kitchen gardening.

Environmental

a) *Improper composting* – Composting can generate odours if the compost facility is not well designed and processes do not operate properly or efficiently. Flies and insects can breed in and around composting facility. The inappropriate disposal of contaminants and residues removed from the composting process can adversely impact the environment.

Human capacity

a) *Lack of skilled personnel* – There is certainly lack of locals who are interested to learn how to make composts, hence the lack of skilled personnel.

Public awareness and information

a) *Lack of collaboration* – failure to share information and knowledge.

2.2.3 Identified measures for Composting

2.2.3.1 Economic and financial measures

a) *Residential composting* – Composting at home can be started with very little capital and operating costs. It should be promoted especially when a significant number of homes have individual or collective yards or gardens and there is sufficient space. Composting units can be easily made out of locally available materials such as wood or wire mesh.

2.2.3.2 Non-financial measures

Technical

a) *Technical Assistance* – Composting at home is highly encouraged to be able to manage kitchen and garden waste effectively and to be able to have a fertile home garden for food security. Technical assistance at community level to understand the composting process (know-how) and building own compost bins (equipment) should be encouraged. To support composting at the resource recovery site, there is certainly the need to have in place an integrated SWM process where segregation is effectively carried out at the source.

Institutional arrangement

a) *Home composting* – Community awareness and workshops on concepts of segregation and composting should be highly promoted. Even if composting is not an interest, it is the understanding of the segregation process that will ensure that organic wastes reaches the resource recovery site.

Social, cultural and behaviour

a) *Kitchen gardening* – Government should support kitchen gardening not only as a source for food security but also for competitions – as an incentive based project aimed to stimulate interest in home gardening and encourage families to get active.

Environmental

a) *Composting techniques* – Key factors to effective composting must be followed. For example, optimal moisture content for composting should be 45% to 60% which can be regulated either by adding water or fresh material with higher water content. Other factors include process time, space requirements and climatic conditions.

Human capacity

a) *School activity* – Gardening and composting should be introduced into school curriculums as an outdoor activity that will teach students how the environment works and how to reduce waste. This will help students understand the three environmental r's (recycle, reuse and reduce). This builds capacity of students to practice their own home gardening and composting. This activity can be promoted as an annual event

Public awareness and information

a) *Benefits of composting* – Education and awareness are essential components of a good waste management programme. A sustained and integrated effort is required in order to influence the value system of people, and achieve a positive behavioural change. This must include educating the young and the old (National solid waste management strategy, 2017-2026). Information on the benefits of composting should be shared through media.

2.3 Segregation – Barrier analysis and possible enabling measures

2.3.1 General description of Segregation

"Waste segregation" means dividing waste into dry and wet. Waste segregation is different from waste sorting[14]. Effective segregation of wastes means that less waste goes to landfill which makes it cheaper and better for people and the environment. It is also important to segregate for public health. The following five categories of waste are common in Nauru:

i) Dry/ recyclable waste
ii) Organic waste
iii) Reject/ sanitary waste
iv) Biomedical wastes
v) E-waste

14 https://en.wikipedia.org/wiki/Waste_sorting#:~:text=%22Waste%20segregation%22%20means%20dividing%20waste,is%20different%20from%20waste%20sorting.

vi) Hazardous waste

Dry/ recyclable waste normally include plastic, paper, foam, metal, wood and glass. Organic waste includes wet waste (left-over foods, etc) and garden waste. Reject wastes can include sharp objects, broken glass and used cloth, beds, etc. Sanitary wastes include diaper, used tissues and tissue paper from the toilets. Biomedical waste are generated from hospitals such as needles, syringes, cotton/ bandage with body fluids, etc. E-waste include discarded computers and accessories and other electronic waste like fax machines, copiers, printers, mobiles, cameras, TV and some of which are hazardous including batteries, bulbs and tubes. Hazardous waste includes solvents, chemicals, waste oil, paints, etc.

Waste segregation at the source is mandatory. Effective segregation of wastes at the source will mean that less waste goes to landfill which makes it cheaper and better for people and the environment. It improves collection efficiency and leads to better efficiency in processing of waste and resource recovery.

2.3.1.1 Technology status on Nauru

Neither household nor industrial waste is segregated at the point of collection. There is no waste transfer station in Nauru; hence, NRC attempts to extract recyclable wastes at the landfill before the rest of the rubbish is bulldozed into the site. Because of a lack of staff and equipment, very little recyclable materials are salvaged (ADB, 2014).

2.3.1.2 Technology category and market characteristics

Segregation is categorised as a consumer goods when referred to as a hardware component (segregation bins) for segregation purposes and a capital goods as a process for segregating dry and wet waste for recycling purposes.

Table 8: Segregation category and characteristics

Technology	Category	Description	Market Characteristics
Segregation	Consumer goods [Market goods]	Segregation bins.	• a high number of potential consumers • interaction with existing markets and requiring distribution, maintenance and installer networks in the supply chain • large and complicated supply chains with many actors, including producers, assemblers, importers, wholesalers, retailers and end consumers • barriers may exist in all steps in the supply chain

			• demand depends on consumer awareness and preferences and on commercial marketing and promotional efforts
	Capital goods [Market goods]	Process for producing dry and wet wastes.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make

2.3.2 Identification of barriers for Segregation

Preliminary barrier identification

For this process, a list of common barriers that may or may not impact the development, transfer and diffusion of segregation technology are provided below.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;
- Human capacity barriers;
- Public awareness and information barriers.

Screening of barriers identified

2.3.2.1 Economic and financial barriers

a) *Lack of resource availability* – There are no resources available to implement segregation as there is no incentive to enable this process. These in particular include proper segregation or colour-coded bins that informs the public where wet and dry wastes should be disposed of. The main issue identified by the waste expert group is lack of financial support due to weak institutional arrangements. The absence of a segregation process will result in increased landfill and GHG emission.

2.3.2.2 Non-financial barriers

Technical

a) *Lack of resource availability* – Lack of financial support will only result in non-availability of the hardware components needed for a segregation process to take place.

Institutional arrangement

a) *Lack of policy* – There are no laws or other instruments requiring segregation of organic waste from waste disposed at the rubbish dump (The University of Melbourne, Nov. 2020). Some laws that address waste originate from outdated and fairly generic legislation, such as the Litter Prohibition Act – 1983.
However, there exists some form of waste separation; in particular, being practiced adjacent to the dumpsite area that include stockpiling of huge plant steel beam structures and equipment, used ruined vehicles and heavy machineries, used tyres and white goods. Asbestos roofing materials are also separated by storing in shipping containers. E-waste collection is also being practiced effectively by the ICT department.

Social, cultural and behaviour

a) *Lack of information and awareness* – There is low knowledge level about waste segregation at household level, hence societal acceptance may take some time to breaking the old traditions and make changes in the ethics and attitudes of the public towards proper waste segregation needs and practices.
b) *Lack of responsibility* – There is lack of belief and inaction of the people in the need to waste separation. Behavioural change at the individual level to simply segregate waste can be a barrier.

Environmental

a) With no segregation of wastes and proper disposal of hazardous waste, chemical substances pose a risk to public health and the environment (Solid waste management in the pacific: Nauru country snapshot, 2014). However, proper segregation practices are certainly good for the environment. Hence, there are no known environmental barriers that will in any way hinder the uptake of waste segregation apart from land availability.

Human capacity

a) *Lack of capacity* – Without information, education and public awareness, and the support of clear policies in place, there is no incentives, hence the absence of segregation activities.

Public awareness and information

a) *Lack of communication* – There is very limited information available and for sharing to the public on waste segregation concepts and benefits. Without the proper communications tool, some identified barriers influencing public participation in source waste separation were found to include: lack of environmental knowledge and awareness; lack of responsibility and perceived ability to contribute to the problem; lack of knowledge on "how to separate"; lack of personal incentives and benefits; weak social norms; perceived barriers about situational factors; old habits; and insufficient feedback.

2.3.3 Identified measures for Segregation

2.3.3.1 Economic and financial measures

a) *Funding support* – Access to funding is heavily reliant on having in place an endorsed SWM roadmap to include strategies and policies. The development of the Nauru Energy Roadmap (NERM) is a good example that has enabled NUC to achieve its goals.

2.3.3.2 Non-financial measures

Technical

a) *Resources available* – For effective segregation of waste, colour-coded sorting bins should be provided at the source of generation and frequently collected for disposal and further sorting at a dedicated site. Best implemented at all schools and government buildings first before engaging districts. To be fully effective and sustainable; at community level, segregation should be driven by the private sector.

Institutional arrangement

a) *Policy establishment* – Nauru has very limited legislation relevant to waste management and governance, and no specific legislation on this topic (The University of Melbourne, Nov. 2020). Segregation and minimization of waste would need to be nested within a policy setting that supports alternative methods and creates incentives while also funding its management (SPREP, 2006).

Social, cultural and behaviour

a) *Responsible behaviour* – Changes in behaviour at all levels of society are required in order to decrease the amount of waste being generated and disposed of at landfills. Research, education and public participation are some of the useful tools for long term improvement and changes in the ethics and attitude of public towards proper waste management. Intrinsic factors, such as attitude toward recycling and environmental concern, may also affect sorting behaviour.

Environmental

a) An inefficient SWM system may create serious negative environmental impacts like infectious diseases, land and water pollution, obstruction of drains and loss of biodiversity. Waste management if done in a proper manner not only eliminates the surrounding waste but also will reduce the intensity of the greenhouse gases like methane, carbon monoxide which is emitted from the wastes accumulated.

Human capacity

a) *Personal behaviour* – The human capacity in this aspect that will most likely hinder the effective transfusion of segregation is the will and behaviour of a person to be motivated in making this technology successful. A negative behaviour or response can impact others to follow suit.

Public awareness and information

a) *Communication and public awareness* – Conducting an awareness program with the households for segregation of waste by first identifying and listing of gaps for discussion with community members on how to address these gaps. Conducting training/ orientation programs to all stakeholders that may include home composting activity training. Public communication allows people to form connections, influence decisions, and motivate change.

2.4 Semi-aerobic Landfill – Barrier analysis and possible enabling measures

2.4.1 General description of Semi-aerobic Landfill

A semi-aerobic landfill is a landfill where waste goes through a decomposition process in the presence of oxygen. This type of landfilling method has several advantages including reduction in the amount of landfill gas produced and faster stabilisation of the waste landfilled. Semi-aerobic landfills also have a leachate collection system.

In a semi-aerobic landfill, the leachate collection system consists of a central pipe (main collection pipe) with branch pipes on either side of it laid at a suitable spacing (holes with approximately one inch in diameter are cut into the pipe to allow leachate to enter).

The leachate collection pipes offer a number of advantages:

a) Leachate is drained out as quickly as possible, preventing it from fouling in the waste material and making it easier for fresh air to enter. This assists aerobic conditions in the waste layers.

b) By creating aerobic conditions, microbial activity is enhanced and the decomposition of waste is increased.

c) By laying the collection pipes in the rocks, the collection pipes are protected from clogging (blockage of the pipes from dirt) and damage during operation.

d) By quickly draining out the leachate, there is reduced pressure caused by water on the bottom ground/liner, leading to a reduced risk of leachate seepage[15].

2.4.1.1 Technology status on Nauru

NRC, through its Waste Management Division is responsible for the management and control of the municipal waste landfill. The current dump site on Nauru has been operating for an extended period of time where dumping of typical municipal solid waste at land fill is uncontrolled. The current operation is spread over approximately 5 ha with approximately 0.5 ha area for sorting and storing recoverable materials adjacent to the road. Garden waste and

[15] Amano. S., (2005). A Practical Guide to Landfill Management in Pacific Island Countries. SPREP. JICA.

cardboard is set aside (for the manufacture of compost) but there is still a large amount of both materials in the general waste stream observable on site. Where possible site staff are also separating white goods, tyres and scrap steel (Tonkin and Taylor, 2018).

Based on materials received at the dump site in the week of 26 February 2018, an estimated 26,000 m3 or 4 to 5,000 tonnes1 of material is received each year. Communities are billed $2.50 per cubic meter; businesses are charged $20 per cubic metre. There is no detailed information available on waste quantity or composition (Tonkin and Taylor, 2018).

In 2018, Tonkin and Taylor International Ltd were engaged by DCIE to provide advice on solid waste management operations and policy that resulted in a comprehensive report based on their findings with a number of options, costing and recommendations for the development of a Landfill Master Plan and Operations Plan. There has been no progress to the development of this Master Plan due to lack of funding.

Figure 7: Nauru dumpsite

2.4.1.2 Technology category and market characteristics

Semi-aerobic landfill technology has been identified by the local expert group as a capital goods when referred to as a system or facility that allows waste to go through an effective decomposition process. It can be categorised as a publicly provided goods due to its large scale and its hardware element is usually high, and the sense that it is publicly owned and operated. As a non-market goods, it is dominated by the software and orgware components of technology and are most often financed by donors and public entities.

Table 9: Semi-aerobic landfill category and characteristics

Technology	Category	Description	Market Characteristics
Semi-aerobic landfill	Capital goods [Market goods]	Machinery and equipment used in the production of goods.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make
	Publicly provided goods [Non-market goods]	Technologies in this category are often (although not always) publicly owned, and production of goods and services are available (free or paid) to the public or to a large group of persons.	• very few sites • large investment, government/donor funding • public ownership or ownership by large companies • simple market chain; technology procured through national or international tenders. • investments in large-scale technologies tend to be decided at the government level and heavily dependent on existing infrastructure and policies.
	Other non-market goods [Non-market goods]	Non-tradable technologies transferred and diffused under non-market conditions, whether by governments, public or non-profit institutions, international donors or NGOs.	• technologies are not transferred as part of a market but within a public non-commercial domain. • serves overall political objectives, such as energy saving and poverty alleviation • donor or government funding

2.4.2 Identification of barriers for Semi-aerobic landfill

Preliminary barrier identification

For this process, a list of common barrier categories provided below will be used to determine if and how they may impact the development, transfer and diffusion of semi-aerobic landfilling technology and measures identified on how to overcome each of these barriers.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;
- Human capacity barriers;
- Public awareness and information barriers.

Screening of barriers identified

2.4.2.1 Economic and financial barriers

a) *Low cost* – The semi-aerobic landfill; also known as the "Fukuoka Method" has characteristics of being a simple structure and having low cost (Kyushu International Center, 2007). Although the existing dumpsite has zero cost to construct, its impact to the environment is huge as compared to the Fukuoka method.

b) *No funding for master plan and policy* – As mentioned in section 2.4.1.1, there has been no progress in the development of an already planned and costed Master Plan due to lack of funding.

2.4.2.2 Non-financial barriers

Technical

a) *Control of solid waste flow* – Proper waste management is imperative where the flow of solid waste is well understood and controlled. In order to make the landfill function, proper maintenance of various facilities needs to be carried out on a daily basis. For a landfill employing the semi-aerobic landfill system, leachate collection and gas venting facilities are the two most important facilities to let the system work well (SPREP-JICA, 2010).

Institutional arrangement

a) *No legislation* – Nauru has no legislation specific to waste management and governance, and very little in the way of legislation that applies to issues of waste in a more general sense. The Litter Prohibition Act 1983 is the principal law regulating forms of solid waste in terms of littering offences. Some relatively recent laws governing certain places, namely derelict sites, roads and ports, and a law on disaster risk management, have incidental relevance to waste (The University of Melbourne, Nov. 2020). There is also a proposal for development of policies for waste management by Tonkin and Taylor International Ltd that is being delayed due to lack of funding.

Social, cultural and behaviour

a) *Lack of action* – It has been identified that the progress of the development of a Master Plan for a semi-aerobic landfilling system that was proposed back in 2018 has not commenced. This delay is likely to be caused by lack of funding. As a publicly provided goods, any decisions regarding its implementation is entirely dependent on government response and financial institutions.

Environmental

a) *Land topography* – The current dumpsite is located on mined land on the raised central plateau or topside where the land has been transformed into coral-limestone pinnacles as shown in Figure 8. This can become a challenge to the construction of a semi-aerobic landfill site as these pinnacle rocks need to be knocked down and the ground levelled.

b) *Land lease* – The availability of land area to set up a new semi-aerobic landfill is considered the only and main barrier due to land ownership. For government to acquire land for this purpose will require some formal land lease arrangement with land-owners.

Figure 8: Remains of phosphate mining – coral limestone pinnacles[16]

Human capacity

a) *Local capacity* – There is lack of local expertise capable of designing nor supervising the construction of a semi-aerobic landfill site, hence there is a need for engaging specialists from abroad – in particular those who have already done a site assessment

[16] Photo: https://www.amusingplanet.com/2015/06/nauru-island-country-destroyed-by.html

and situation analysis of the dumpsite, and in a position to develop (i) a concept design; (ii) detailed design and (iii) construction design, without the need to travel to Nauru.

Public awareness and information

a) *Lack of collaboration* – failure to share information and knowledge.

2.4.3 Identified measures for Semi-aerobic landfill

2.4.3.1 Economic and financial measures

a) *Funding for development of a master plan* – In order to sustain solid waste management operation including upgrading of existing landfills, an institutional approach needs to be introduced and enforced to prioritise securing of financial resources to enable implementation and development of a semi-aerobic landfill Master Plan and Policies.

2.4.3.2 Non-financial measures

Technical

a) *Operations and maintenance* – A proper O&M program should be developed to ensure sustainability of a semi-aerobic landfilling process is maintained at all times.

Institutional arrangement

a) *Institutional strengthening* – There is a need for the government to review and strengthen the waste sector by re-structuring to create a more resilient and independent waste department by introducing a new Director of SWM role with officers specialising in segregation, sorting and recycling.

Social, cultural and behaviour

a) *Action plans* – Dumpsites are truly not a site that everyone would want to go and visit, hence the lack of response and motivation for improvement despite the degradation effects to the land and GHG emissions. National mitigation efforts to reducing GHG from diesel power generation should be equally invested in improving national SWM.

Environmental

a) *Environment monitoring* – The objective of environmental monitoring is to make sure there is no hazardous effect generated from the landfill. If any possible hazard is observed, remedial measures should be taken according to the level of threat to environment and public health. Such monitoring includes leachate, groundwater, surface-water, landfill gases, temperature of waste layer (through gas venting pipe) as well as open air, precipitation, settlement of waste layer, water level of leachate retention pond, etc. (SPREP-JICA, 2010).

Human capacity

a) *Capacity building* – Local group short training courses in concept, design and maintenance of semi-aerobic landfill should be considered to obtain employee self-confidence and sustainability of systems.

Public awareness and information

a) *Policy initiatives* – Stakeholder consultations on initiatives and during development of policies to include educating the community and businesses about the importance of waste sorting and waste minimisation.

2.5 Baling – Barrier analysis and possible enabling measures

2.5.1 General description of Baling

Baling is a process of compressing and binding mainly waste materials into compact bales for easier handling and transportation. Baling simply reduces the volume of waste product and has a number of benefits. The process of baling can be carried out either at the source or at the dumpsite. Baling machines are used in industries like agriculture, retail, automotive and plastic products manufacturing, as well as schools, recycling centres and junk yards. and commercial use. Garbage that cannot be recycled or reused is compacted to reduce the volume of trash in landfills, but balers also increase the convenience of handling and transportation for recyclable materials like plastic bottles, metal cans, cardboard boxes and paper products.

Baling is a process that require an integrated and effective segregation process to function effectively. Baling machines although are straight forward to operate and do not require any special training, operators must understand the fundamental machine safety rules.

Balers are important to any business's or country's recycling program. These machines are extremely helpful when it comes to compressing large amounts of recyclable material for easier shipment and storage. With balers, smaller companies don't have to invest as much in other areas of waste management e.g. collection bins. Larger companies on the other hand, can easily store large quantities of recyclables and sell them to recycling companies to make some money.

2.5.1.1 Technology status in Nauru

NRC, through its Waste Management Division is also responsible for the baling of recyclable wastes such as plastic bottles and aluminium cans, as well as crushing of bottles. A waste baling facility has been set-up in a resource recovery area adjacent to the dumpsite area where a waste compacting and bottle crushing machines are installed. These are shown in Figure 9. These two machines were funded by the Government of Japan under the GGP program.

Figure 9: Waste baler/ compactor and bottle crushing machines

Recyclable wastes segregated from the source are usually stockpiled within the resource recovery area for further sorting before they are compacted and crushed. The baling process is dependent on segregated waste arriving at the dumpsite which is very minimal compared to those that end up in the landfill. Hence, there is not much waste compacting activity happening due to the lack of waste segregation from the sources which makes manual sorting at the dumpsite impractical due to health issues.

2.5.1.2 Technology category and market characteristics

Baling technology is categorised by the waste expert working group as a consumer and capital goods. As a consumer goods, it can be intended for the mass market more so in businesses and institutions with a characteristic as requiring large and complicated supply chains with many actors. As a capital good, it is referred to as a machinery or equipment that produces compacted end products for ease of handling and recycling. Although it may not require relatively large capital investments, its demand may be profit-driven if the end products can be further processed or recycled.

Table 10: Baling category and characteristics

Technology	Category	Description	Market Characteristics
Baling	Consumer goods [Market goods]	Specifically intended for the mass market; households, businesses & institutions.	• a high number of potential consumers • interaction with existing markets and requiring distribution, maintenance and installer networks in the supply chain • large and complicated supply chains with many actors, including producers, assemblers, importers, wholesalers, retailers and end consumers • barriers may exist in all steps in the supply chain • demand depends on consumer awareness and preferences and on commercial marketing and promotional efforts
	Capital goods [Market goods]	Machinery and equipment used in the production of goods, e.g. consumer goods or electricity.	• a limited number of potential sites/consumers • relatively large capital investment • simpler market chain, i.e. few or no existing technology providers • demand is profit-driven and depends on demand for the products the capital goods are used to make

2.5.2 Identification of barriers for Baling machines

Preliminary barrier identification

This section of the report looks at common barriers that may or may not impact the development, transfer and diffusion of baling technology in Nauru.

- Economic & financial barriers.
- Technical barriers;
- Institutional arrangement barriers;
- Social, Cultural and Behavior barriers;
- Environmental barriers;

- Human capacity barriers;
- Public awareness and information barriers.

Screening of barriers identified

2.5.2.1 Economic and financial barriers

a) *No financial barrier* – Baling equipment do not require relatively large capital investments. Two vertical baling equipment are readily available on Nauru where they have been set up at a resource recovery area at the dumpsite. However, there is rarely any baling activities going on as there is no evidence on production of compacted wastes such as plastic bottles. This is due to lack of waste segregation from the source and sorting being carried out at the dumpsite.

2.5.2.2 Non-financial barriers

Technical

a) *No technical barrier* – Baling equipment are basic to operate. These are simply fed with recyclable waste products such plastic bottles, cans, cardboards, etc. and by the press of a button, it compresses the waste products. However, safety in operating baling machines is important and workers must obtain some form of operator's certification both for their own safety and proper handling and operating of machine.

Institutional arrangement

a) *Lack of Institutional arrangement* – There is lack of institutional arrangement to develop and enforce waste segregation policies. The outcome is uncontrolled dumping with contaminated recyclable waste that cannot be sorted.

Social, cultural and behaviour

a) *Lack of interest* – Baling is not a new technology to Nauru. In the past, manual compacting machines have been used by individuals to crush aluminium cans intended for export to recycling plants which due to their contamination level was not possible. A number of these compacting machines are no longer in use.

Environmental

a) *Land acces*s – Baling equipment do not require a big land area for installation but will require large land area for the purpose of stock-piling of sorted waste and storage area for the crushed and compacted recyclable wastes.

Human capacity

a) *Safety* – Baling machines although are simple to operate can cause injury if not operated properly.

Public awareness and information

a) *Lack of public awareness and collaboration* – failure to share information and knowledge on basic SWM concepts in a participatory communication approach will hinder diffusion of segregation and baling technologies.

2.5.3 Identified measures for Baling machines

2.5.3.1 Economic and financial measures

a) *Financial support to segregation process* – An effective segregation process will in turn result in an effective and productive baling process at the dumpsite. Waste segregation at the source require two distinct collection bins to be placed at selected sites for collection of dry and wet wastes. These are collected and transported to the resource recovery area at the dumpsite where further sorting of recyclable waste can be carried out. If all wastes can be segregated from the source, then there will be no need for sorting at the dumpsite.

2.5.3.2 Non-financial measures

Technical

a) *Productivity* – Effective segregation and sorting practices are key to a productive baling process.

Institutional arrangement

a) *Institutional strengthening* – DCIE should develop a waste segregation and baling strategy that are integrated into an SWM policy.

strategy Several operational baling machines are readily available and properly set up in an area at the dumpsite specifically for baling recyclable wastes that include cans, plastic bottles and bottles. However, there is an absence and therefore a need for the development and enforcement of an institutional arrangement. A strategy should aim to encourage baling activities at the source like the government offices, hotels, supermarkets, etc. to reduce exposure to workers of airborne microorganisms and toxic products at dumpsites.

Social, cultural and behaviour

a) *Aluminium can-crushing initiative* – NRC should engage a consulting firm that specialises in recycling plants to carry out a feasibility study for provision of a small sized furnace for melting aluminium cans that would encourage the public to continue the practice of crushing cans and selling to NRC.

Environmental

a) *Resource recovery facility* – A dedicated area for dumping of segregated dry waste should be established that is easily accessible to the public. This will provide a new look to the public as a change for improvement.

Human capacity

a) *Capacity building* – A number of operators should be trained to be able to safely operate a baling machine.

Public awareness and information

a) *Incentives* – Information policies focusing on the promotion of home baling could also positively contribute to the dissemination of the technology.

2.6 Linkages of the barriers identified

Weak and fragmented SWM is considered an environmental problem in Nauru and one of the leading causes of degradation of its natural resources. Linkages of barriers have been assessed from two perspectives. First, there are barriers that are common to all technologies, and hence common measures which can benefit all technologies. Therefore, implementing measures to overcome the common barriers can lead to more effective scaling up of mitigation actions, and hence increases the ambition of GHG emission reductions. Second, there are linkages between barriers for each technology. These linkages imply that a holistic or integrated approach has to be adopted when developing the technology action plans (TAPs) in order to avoid partial implementation of measures proposed for the mitigation technologies.

Common barriers allow for focusing on policy measures that would contribute to the mitigation of most important obstacles and trigger further diffusion of different technologies.

2.7 Enabling framework for overcoming the barriers in the Waste Sector

The governance institutions of Nauru are key building blocks for progressing the implementation and achievement of the NSDS priorities. Although progress has occurred in strengthening in most governance institutions, more work is required in strengthening policies on SWM. The existing regulations are not strictly enforced, and the lack of an environmental levy promotes inexpensive products which lack biodegradable packaging. The NRC Waste Management Division that is responsible for the dumpsite operations lack sufficient human capacity for properly collecting and disposing of wastes (Republic of Nauru, 2019).

Without adequate measures to combat the growing sources and extent of pollution, Nauru's efforts to maintain healthy societies, to stimulate sustainable development and new investment and to build a sustainable future for its people may be permanently undermined. In addition, there is need to shift long held attitudes and behaviours pertaining to waste generation and management at all levels.

SWM institutional arrangements work well when the following conditions are met: (i) roles and responsibilities of each agency involved in SWM are well defined, (ii) adequate financial and human resources exist within responsible agencies to effectively carry out their respective mandates, and (iii) there is sufficient public participation and cooperation in the management of solid wastes.

Integrated Communications

An integrated communications approach within a national strategy and regional initiatives can highlight the appropriate communication tools to be used to reach the various stakeholders/audiences. Around the region a number of countries have shown that communications can be an effective way to help individuals, communities and businesses to reduce their waste. However, these communications programmes are only successful when part of a broader strategy that incorporates other elements of waste management such as new public services, new policies, and economic incentives. (SPREP, 2006).

Integrated SWM Approach

The four waste technologies being assessed here; if all managed properly will contribute to an effective SWM system taking into account that *the most preferred option in a waste management system is to minimise the amount of waste generated while the least option is landfilling* (Rousta, 2018). Effective waste segregation at the source of waste generation is key to effective composting and baling, thus reducing waste ending up at the landfill. Having a controlled semi-aerobic landfill further reduces GHG emissions and contamination to ground water. As illustrated in Figure 10, The absence of a waste segregation process will impact production of composts and recycling process, with an increase in waste ending up at the landfill.

There is a need to establish the appropriate framework and standards for proper waste management through the development of appropriate legislation and policies that addresses all the four waste technologies. As the supporting regulatory framework and human capacity increases for the integrated SWM system then should the recycling process be integrated also with a marketing approach that focuses on recycling the already sorted and compacted wastes such as plastic, aluminium and E-wastes into usable materials. Producing goods from recycled sources is often less energy intensive than manufacturing from raw material and can thereby reduce production costs and carbon emissions.

Government at all levels should consult and work with people and organizations throughout the development and implementation of an integrated waste management strategy and action plan.

Figure 10: An integrated SWM approach

Institutional Capacity Strengthening

Waste management programmes require input from a wide range of skilled personnel, including environmental educators, managers, engineers, landfill operators, environmental management and public health specialists, planners and policymakers (SPREP, 2006).

There is a need to create a position within the DCIE for a Director of SWM role with fully-trained officer-level staff specialising in waste segregation, composting and recycling. The development of an SWM Roadmap should also be considered. More coordination is required between DCIE, NRC and the private sector for an effective and integrated SWM system that will result in a great reduction in GHG.

References

ADB. (2014). *Solid waste management in the Pacific - Nauru country snapshot.*

ADB. (2017). *Final Report (Feasibility Report).*

Bimenyimana, S., Ihirwe, J. P., & Asemota, G. N. (2018). Optimization Comparison of Stand-Alone and Grid-Tied Solar PV Systems in Rwanda. *Open Access Library Journal*, Volume 5.

Blakers, A., Mathews, S., Bin, L., Kirsten, A., & Anna , N. (2017). *An atlas of pumped hydro energy storage.* Australian National University.

CTCN. (2020, June 3). *ctc-n.org*. Retrieved from OTEC: Ocean Energy Technical Pre-feasibility Study: https://www.ctc-n.org/technical-assistance/projects/otec-ocean-energy-technical-pre-feasibility-study

CTCN. (n.d.). *Ocean thermal energy conversion*. Retrieved from CTCN: https://www.ctc-n.org/technologies/ocean-thermal-energy-conversion

CTC-N. (n.d.). *Ocean thermal energy conversion*. Retrieved from https://www.ctc-n.org/technologies/ocean-thermal-energy-conversion.

Dieter, D., & Steinhauser, A. (2008). *Biogas from Waste and Renewable Resources: An Introduction.* Weinhem, Germany: Wiley.

EnergyAustralia & Aru. (2020). *Cultana Pumped Hydro Energy Storage Project.* Victoria: ARENA Knowledge Sharing Report (Public).

GHD. (July 2020). *Proposal for Nauru Pumped Hydro Power Energy Storage - Feasibility Study (NZ MFAT).*

Hydrowires. (2020). *Pumped storage hydropower FAST commissioning technical analysis.*

IRENA. (2016). *Measuring small-scale biogas capacity and production.* Abu Dhabi: International Renewable Energy Agency (IRENA).

Ivan Nygaard, U. E. (2015). *Overcoming Barriers to the Transfer and Diffusion of Climate Technologies: Second Edition.* Copenhagen: UNEP DTU Partnership.

Kyushu International Center. (2007). *Caution for application of "Fukuoka Method".* JICA.

Muralidharan, S. (2012). *Assessment of Ocean Thermal Energy Conversion.* Massachusetts: Massachusetts Institute of Technology.

(2017-2026). *National solid waste management strategy.*

(2018). *Nauru Energy Road Map 2018 to 2020.* UNDP.

Nugent, D., & Sovacool, B. (2014). Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey. *Energy Policy*, 65:229–244.

Okinawa Yanbaru seawater pumped storage power station. (2020, September 08). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Okinawa_Yanbaru_Seawater_Pumped_Storage_Power_Station

PACCSAP. (2015). *Current and future climate of Nauru.*

Periathamby, A., & Herat, S. (2014). Sustainable waste management in Small Island Development State. *Waste management and Research*.

Piantedosi, C. (August 2021). *Decision Paper - Electricity Solar Feed-in Scheme.* Nauru.

Rajendran, K., Aslanzadeh, S., & Taherzadeh, M. J. (2012). Household Biogas Digesters - A Review. *Energies*.

Republic of Nauru. (2014). *Second National Commission.* Yaren.

Republic of Nauru. (2019). *Nauru's National Sustainable Development Strategy 2019-2030.*

Rouse, J., Rothenberger, S., & Zurbrugg, C. (2008). *Marketing compost.* Dubendorf, Switzerland: Eawag.

Rousta, K. (2018). *Thesis: Household waste sorting at source - A procedure for improvement.* Boras, Sweden.

(2014). *Solid waste management in the pacific: Nauru country snapshot.* ADB.

SPREP. (2006). *Solid Waste Management Strategy for the Pacific region.* Apia: SPREP.

SPREP-JICA. (2010). *A pracitical guide to landfill management in Pacific Island Countries an Territories.* Apia, Samoa: SPREP.

The University of Melbourne. (Nov. 2020). *Assessment of Legislative Frameworks Governing Waste Management in Nauru.* Apia, Samoa: SPREP.

Tonkin and Taylor. (2018). *Waste Management System Operations and Policy - Preliminary Advice.* Wellington, NZ.

Tsiode, B. (2018, December 18). *Nauru: Stuck between a rock… and the unforgiving ocean.* Retrieved from Asian Development Blog: https://blogs.adb.org/blog/nauru-stuck-between-rock-and-unforgiving-ocean

U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy. (2014). *Biogas Opportunities Roadmap - Voluntary Actions to Reduce Methane Emissions.*

Annex A.1: Energy Sector - Market mapping, problem/ solution trees

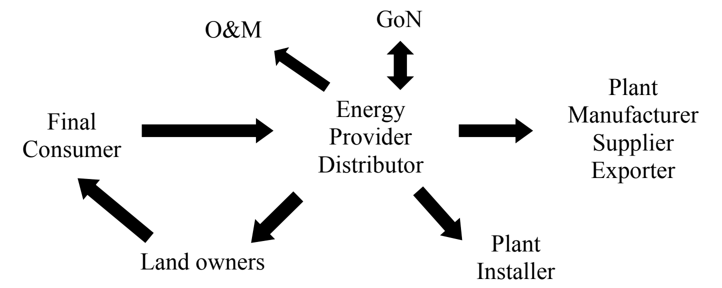
A.1.1 OTEC Technology

1.1.1 Market Mapping – *OTEC Technology*

BUSINESS ENVIRONMENT

- Ministry of CIE & CCNR – Energy, Environment, Policies & Regulations
- Ministry of Utilities – Technical
- Ministry of Finance – Fund, Tax exemption
- Ministry of Justice – Customs

MARKET ACTORS



SERVICE PROVIDERS

- Ministry of Education – USP, TVET
- Ministry of Utilities – NUC
- Ministry of Finance – Banks
- Members of Parliament
- Community Leaders & Groups
- Private Sector
- Public

1.1.2 Problem Tree – *OTEC Technology*

	No skilled workers				EFFECTS
No infrastructure development opportunities in energy sector	Reliant on fossil fuel. High cost of power to consumer		Opportunity for technology uptake not possible	No support from community	
Rely on diesel generation. High dependence on fuel import	Technology uptake not possible	Reliant on diesel generation	No supporting EIA report	Negative impact on feasibility	
The uptake of OTEC technology for power generation					PROBLEM (Cause/ Effect)
High capital cost	Lack of institutional capacity	Early stages of development Technology not fully proven	No EIA done	Issues on community values/ amenities (Land lease)	CAUSES
Lack of funding for initial feasibility	Technology not available or developed		No feasibility carried out	No community consultation & awareness	
	Lack in trained/ skilled workers		Technology not available		

1.1.3 Solution Tree – *OTEC Technology*

RESULTS

	Increased work opportunity			
	Reduce reliance on fossil fuel. .Lower energy bill to consumers		Technology development increased	Full support from community
Reduced reliance on fossil fuel import	Technology development	Reduction on fossil fuel use. Reduction in GHG emission	Supporting EIA available	Positive impact on feasibility

The uptake of OTEC technology for power generation

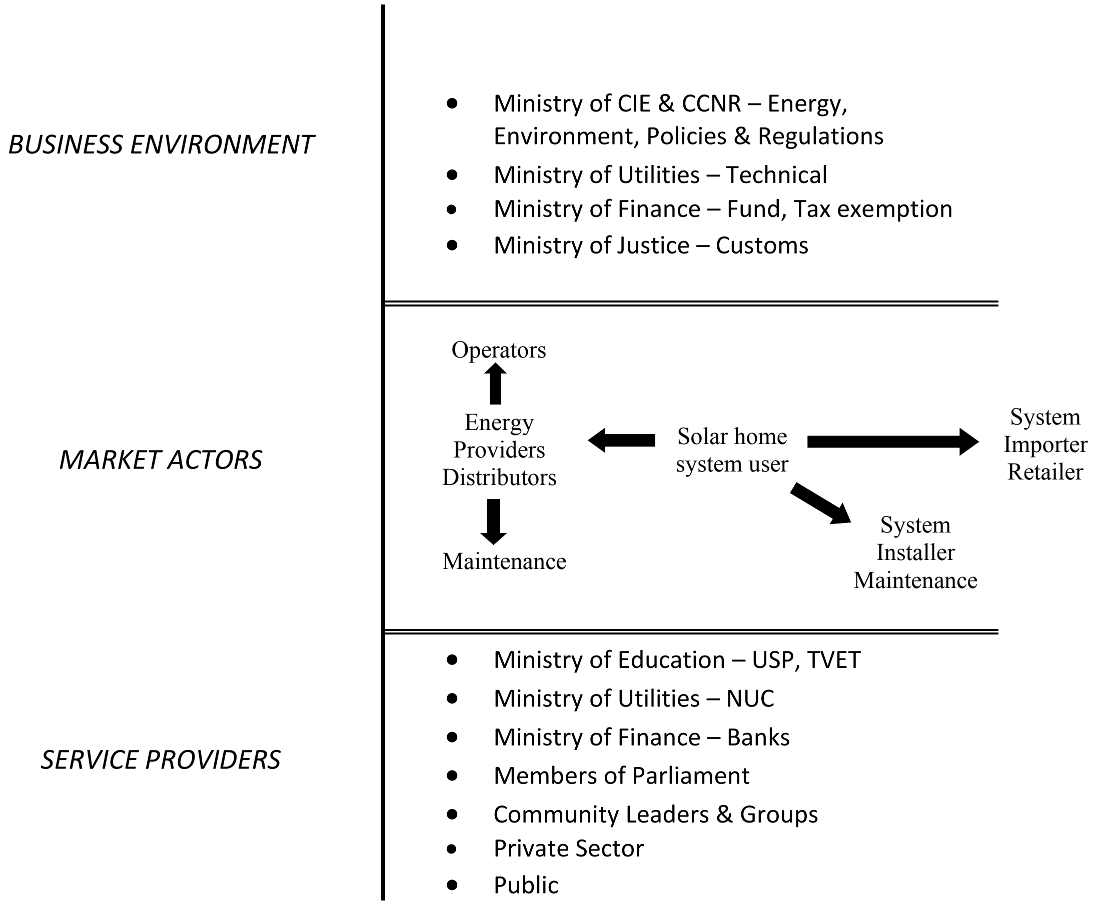
PROBLEM (Effect)

MEASURES

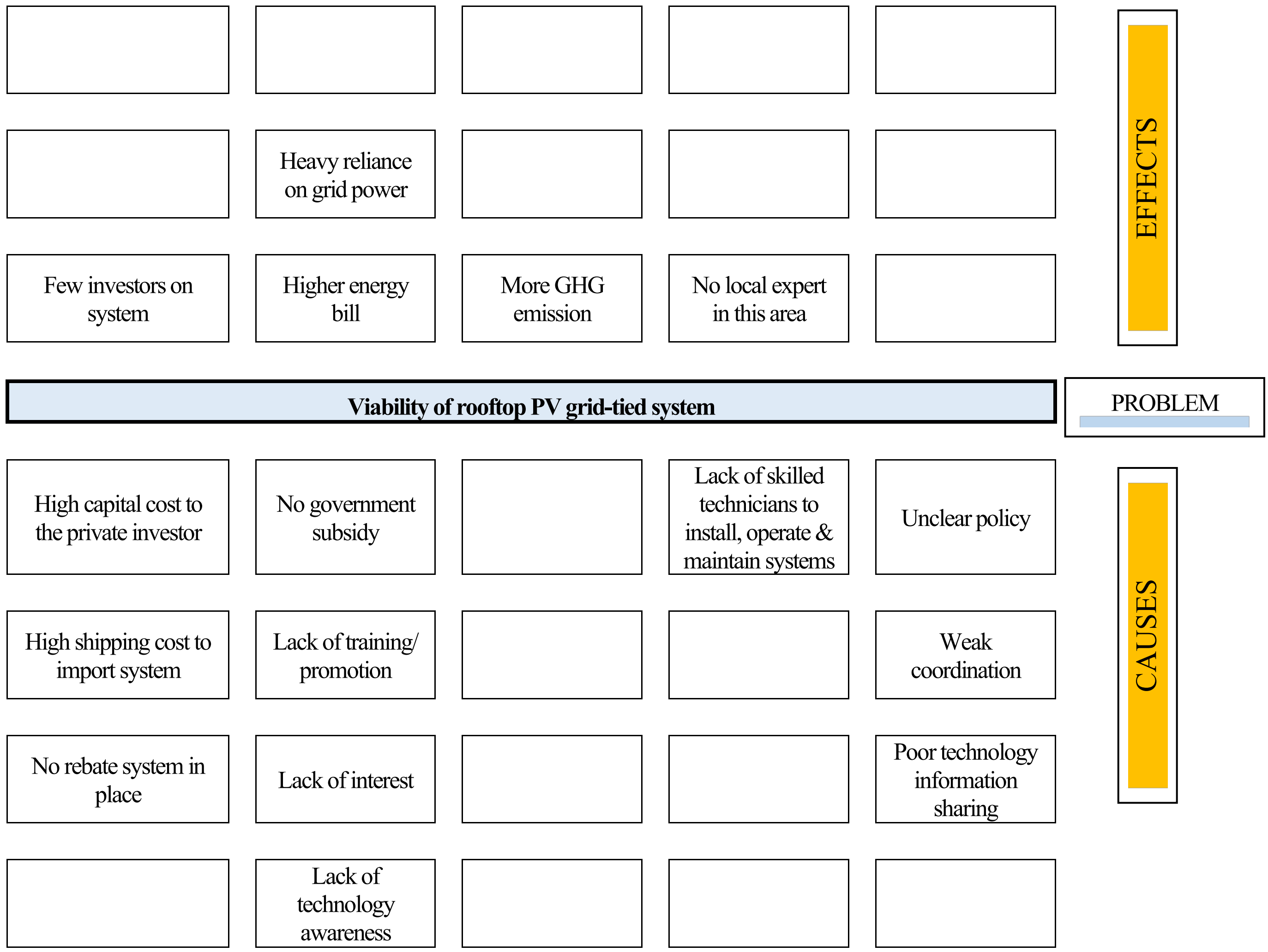
Low capital cost	Developed institutional capacity	Technology fully developed and proven	EIA done	No issues on community values/ amenities
Funding available for feasibility	Technology fully developed		Feasibility done	Community consultation & awareness
	Capacity building in place		No impact on community values / amenities	

A.1.2 Grid-tied Solar PV Technology

<u>1.2.1 Market Mapping</u> – *Grid-connected Roof Top Solar PV Technology*



1.2.2 Problem Tree – *Grid-connected Roof Top Solar PV Technology*



1.2.3 Solution Tree – *Grid-connected Roof Top Solar PV Technology*

RESULTS

	Increased ownership			
Lower energy bill	Heavily reliance on solar power capacity generated back to the grid			
Increased number of investors on system	Low energy bill	Low GHG emission	Increased local expertise	

Low initial system cost/ Rooftop solar PV grid-tied system is taken up

PROBLEM (Effect)

MEASURES

Low capital cost to the private investor	Government subsidy available		Skilled installers	Clear policy
Low shipping cost of imports	System promoted and training available			Strong coordination
Rebate system in place	Community interest			Information sharing
	System awareness in place			

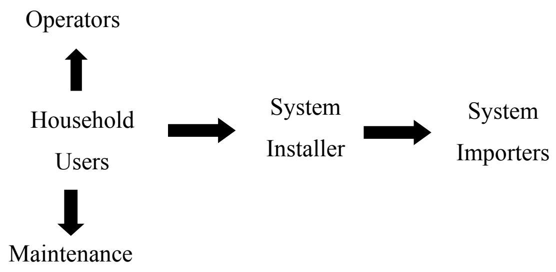
A.1.3 Biogas Technology

<u>A.1.3.1 Market Mapping</u> – *Biogas Technology*

BUSINESS ENVIRONMENT

- Ministry of CIE & CCNR – Energy, Environment, Policies & Regulations
- Ministry of Finance – Fund, Tax exemption
- Ministry of Justice – Customs

MARKET ACTORS



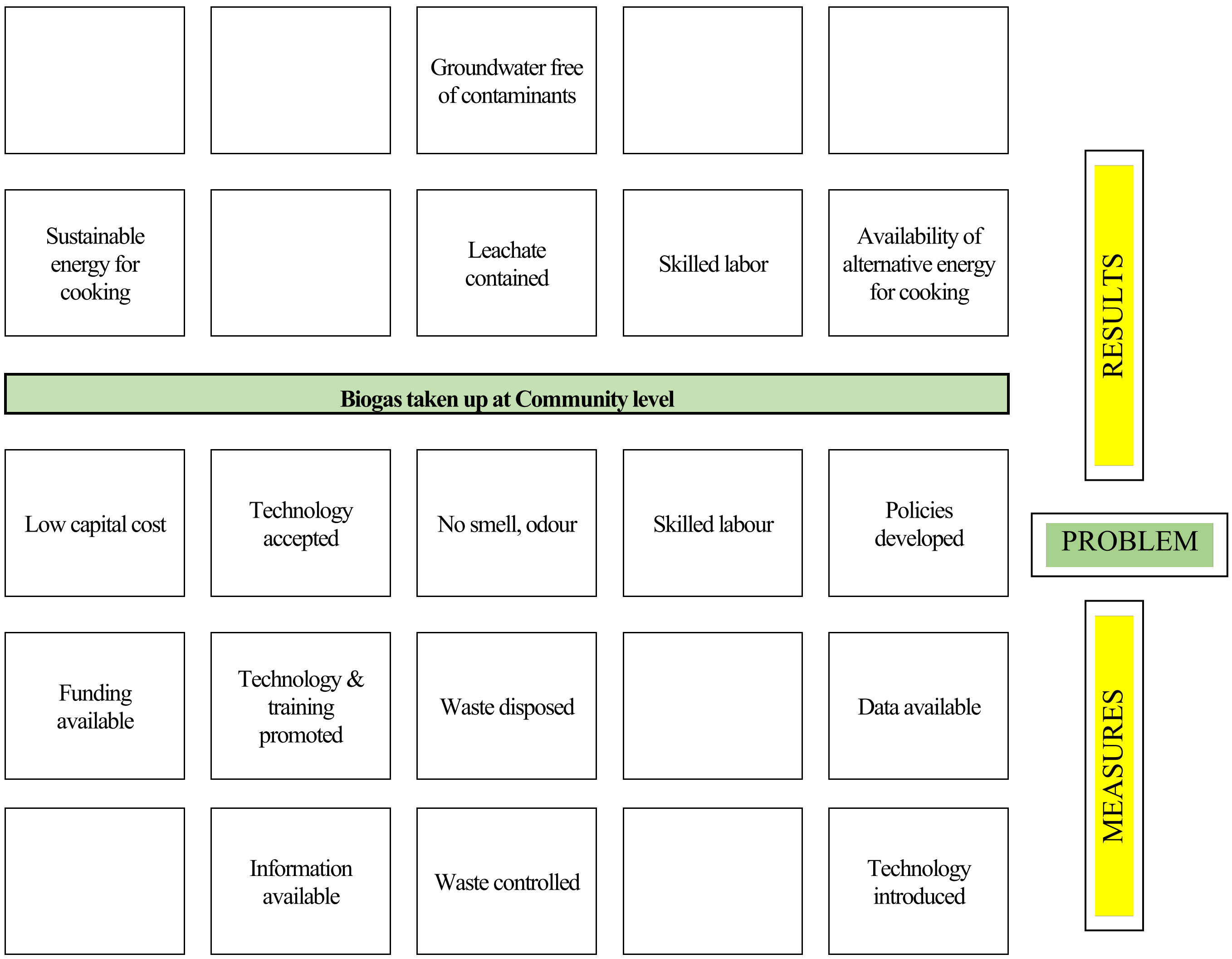
SERVICE PROVIDERS

- Ministry of Education – USP, TVET
- Ministry of Finance – Banks
- Members of Parliament
- Community Leaders & Groups
- Private Sector
- Public

A.1.3.2 Problem Tree – *Biogas Technology*

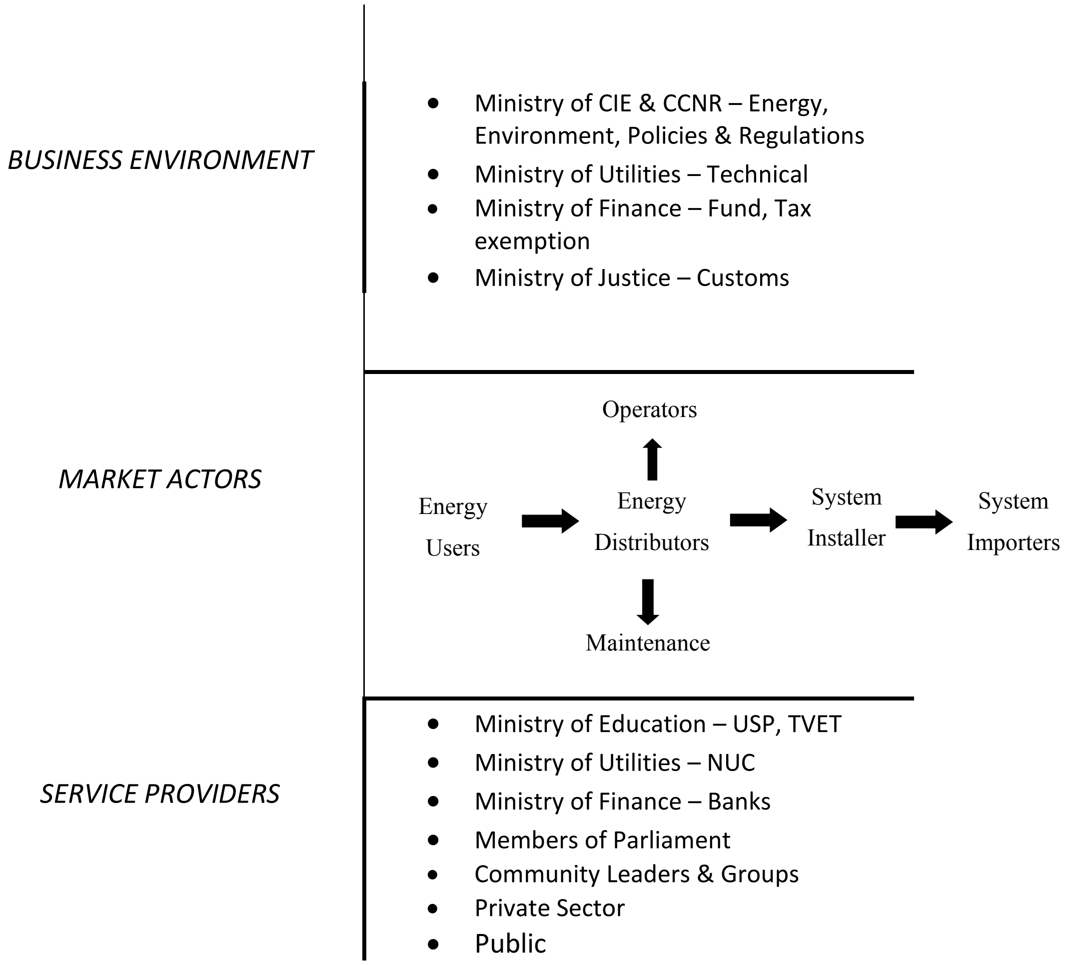
		Groundwater contamination			EFFECTS
Reliance on costly gas and electricity for cooking		Leachate soak through	No skilled labor	Loss of new technology opportunity	
Biogas uptake at Community level					
High capital cost – pig farming & biogas equipment	Technology acceptance	Smell/ odour	No skilled labour	No policies	PROBLEM
Lack of funding availability	Lack of training/ promotion	Disposal of waste		Lack of data	CAUSES
	Lack of interest	No waste control		Lack of technology awareness	
	Lack of information				

A.1.3.3 Solution Tree – *Biogas Technology*



A.1.4 PHES Technology

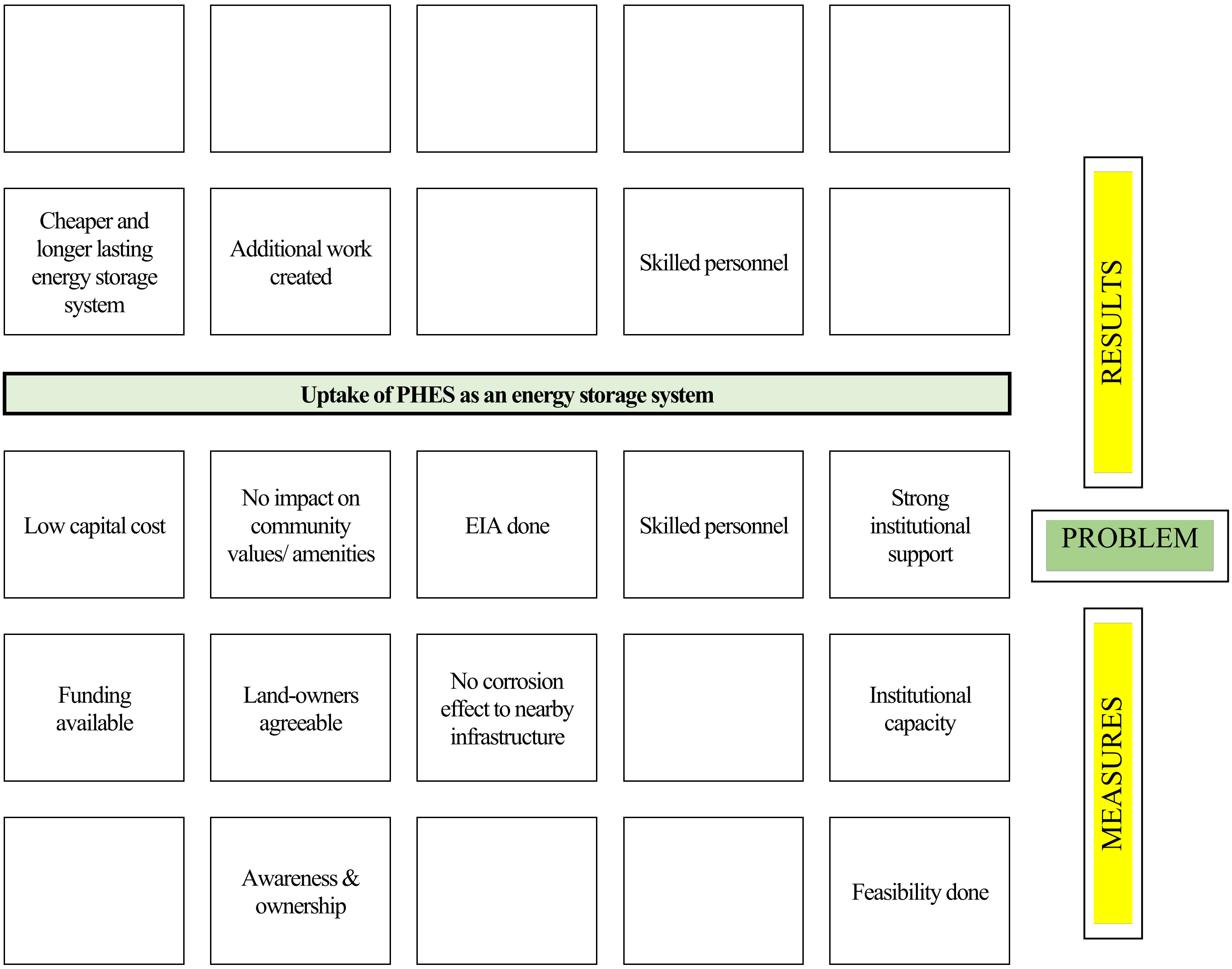
<u>A.1.4.1 Market Mapping</u> – *PHES Technology*



A.1.4.2 Problem Tree – *PHES Technology*

EFFECTS	High dependence on expensive battery energy storage system	No additional work opportunity		No development in skilled personnel	
PROBLEM	**Uptake of PHES as an energy storage system**				
CAUSES	High capital cost	Impact on community values/ amenities	No EIA done	No skilled personnel	Lack or weak institutional support
	Lack of funding	Land-owner issues	Corrosion caused by seawater breeze		Lack of institutional capacity
		Lack of awareness			No feasibility done – only pre-feasibility

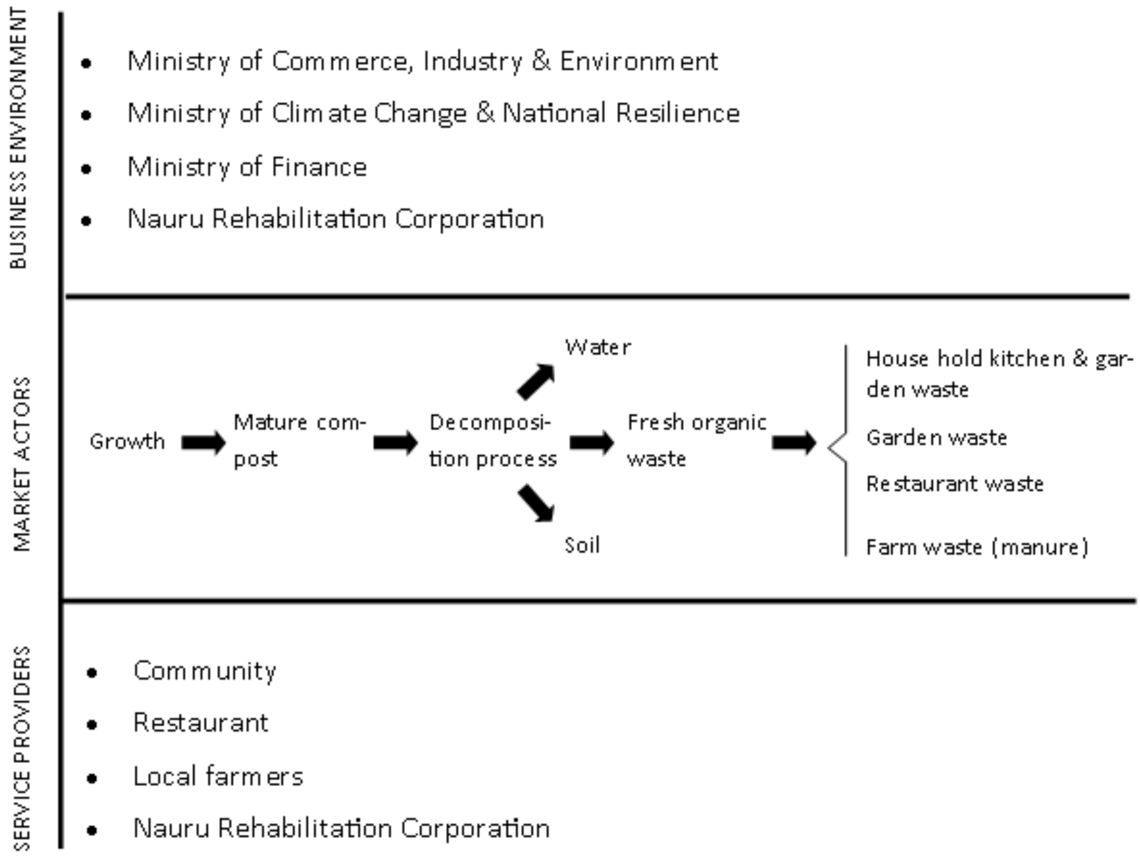
A.4.3 Solution Tree – *PHES Technology*



Annex A.2: Market mapping, problem/ solution trees for Waste Sector Technologies

A.2.1 Composting Technology

<u>2.1.1 Market Mapping</u> – *Composting Technology*



A.2.1.2 Problem Tree – *Composting Technology*

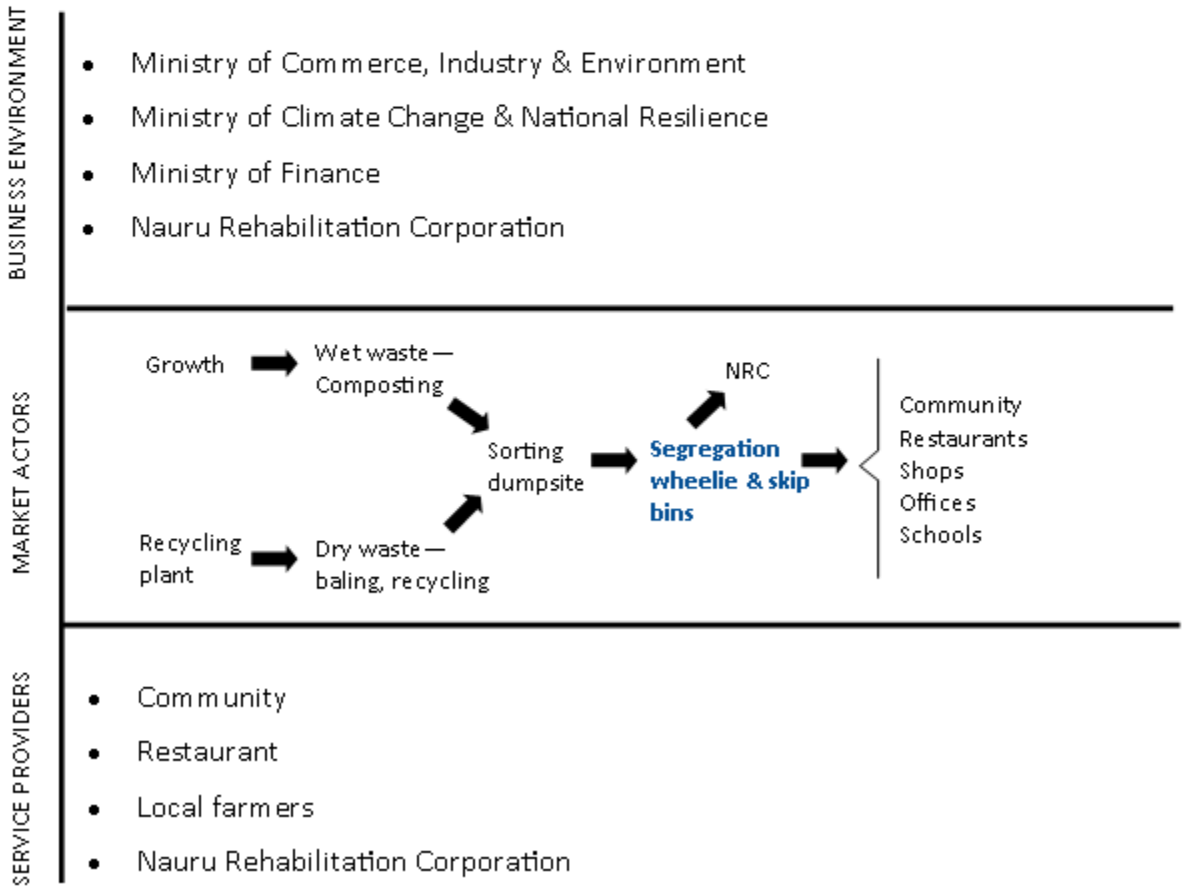
					EFFECTS
Rely on purchasing fertilisers					
No compost = No crops	Inability to grow crops	No interest in composting		Increase risk of soil erosion	
Uptake of MSW composting process					PROBLEM
Limited resource availability	Lack social support	Lack of skilled personnel	No structured institutional arrangements	Poor agriculture production	CAUSES
No access to composting materials	Lack of awareness at community level	No programs available	No policy on disposing of wet wastes	Poor soil condition. No nutrients	
	Lack of educational awareness		No segregation process	Inadequate soil moisture and temperature	
				Lack of organic matter	

A.2.1.3 Solution Tree – *Composting Technology*

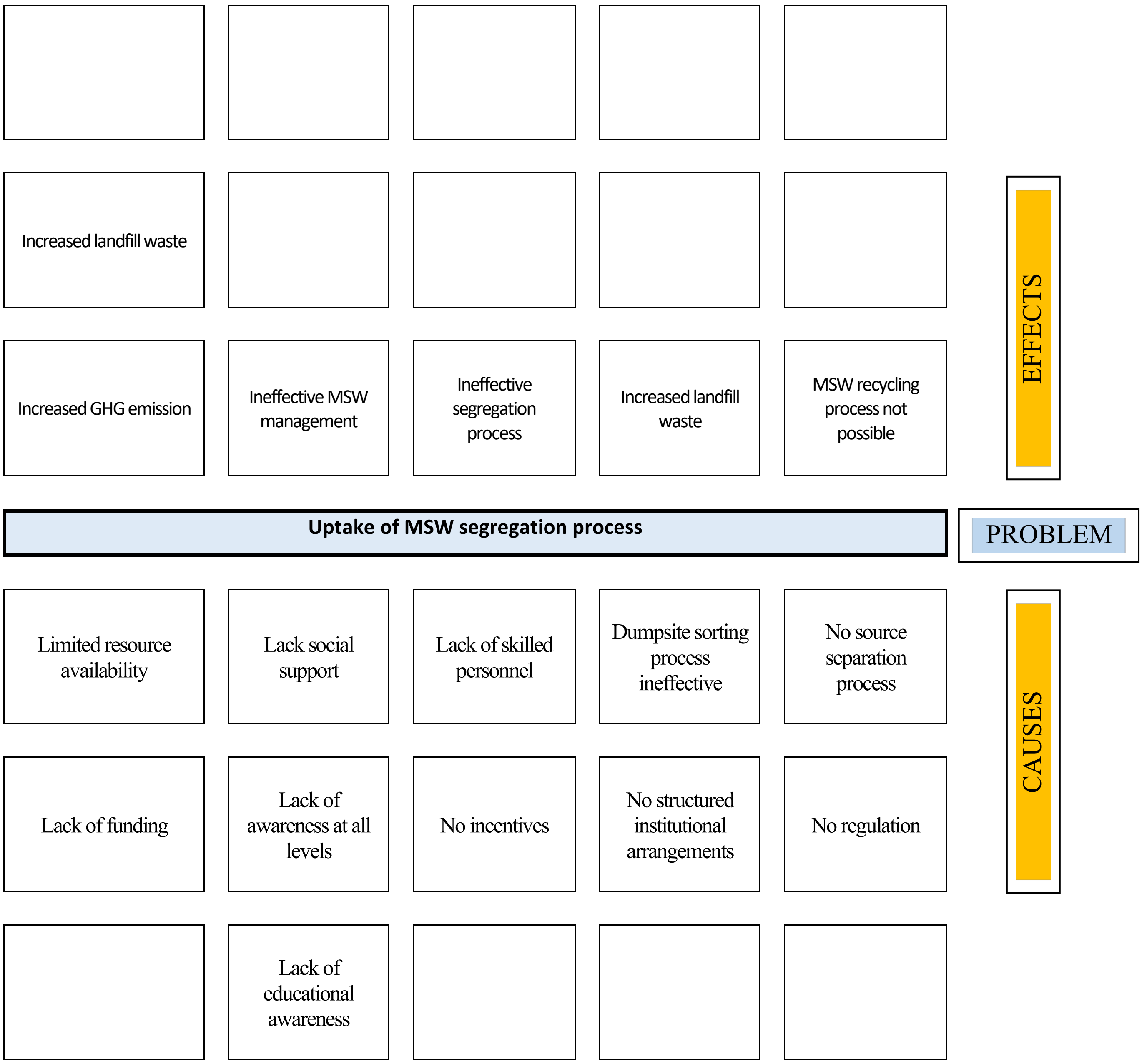
Reduce risk of soil erosion					RESULTS
Compost readily available	Capacity to make compost	Great interest in composting		Fertile and healthy soil	
Uptake of MSW composting process					STARTER PROBLEM
Resource available	Social support	Skilled personnel available	Institutional arrangement in place	Good agriculture production with	MEASURES
Composting material accessible	Arrange community workshops	Programs available	Policy on collecting and disposal of wet wastes	Improved soil condition reach in nutrients	
	Include in school curriculum			Adequate soil moisture and temperature	
				Sufficient organic matter	

A.2.2 Segregation Technology

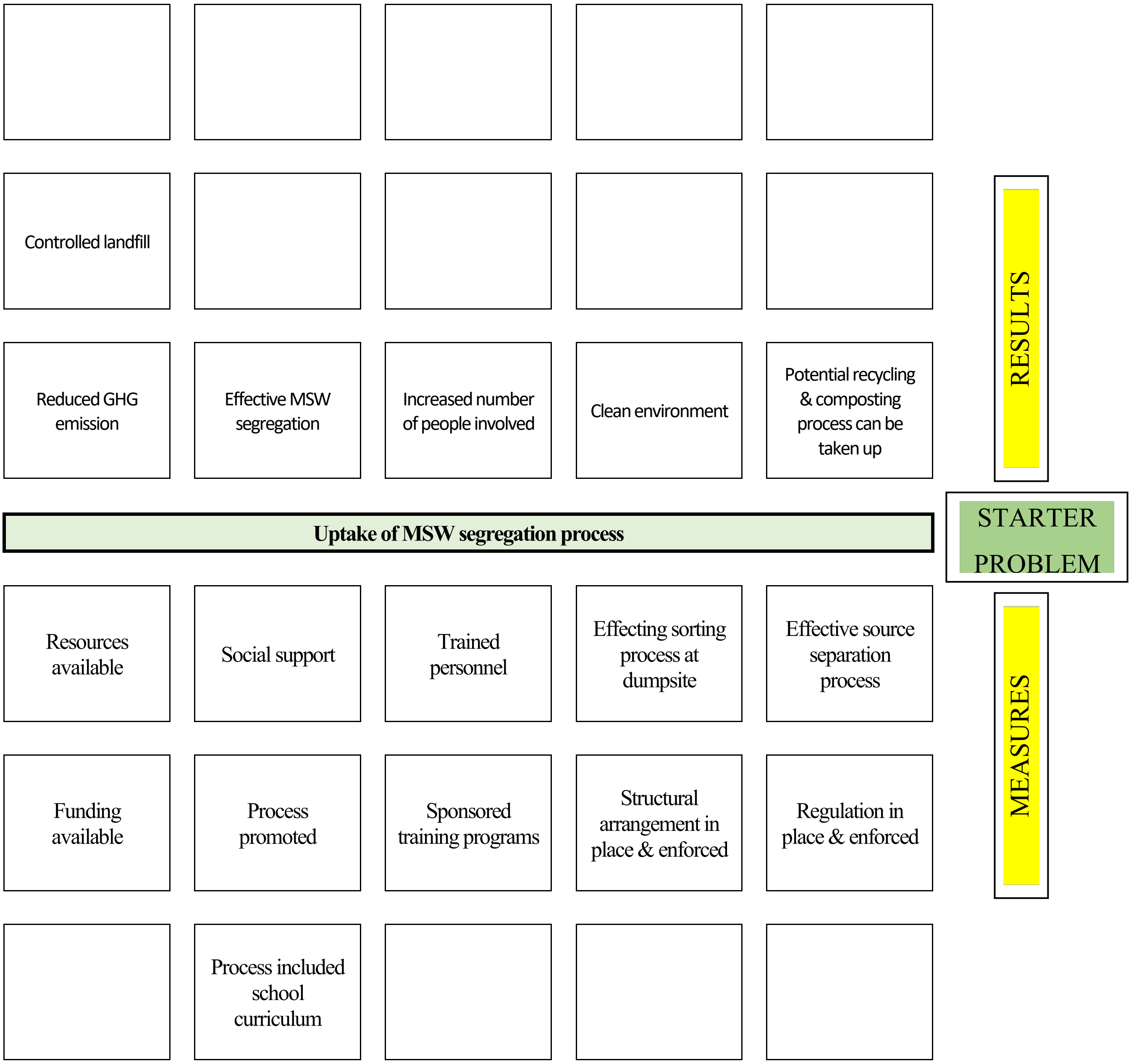
2.2.1 Market Mapping – *Segregation Technology*



A.2.2.2 Problem Tree – *Segregation Technology*

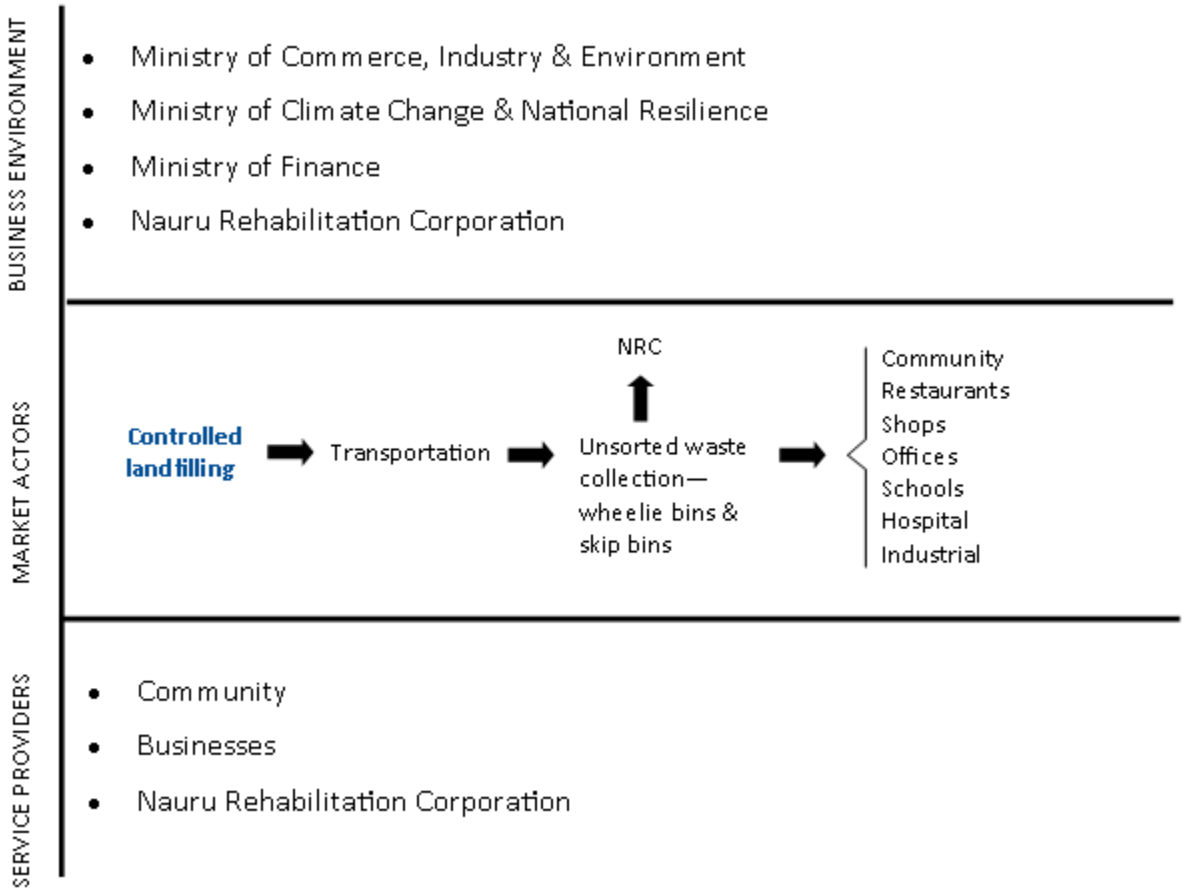


A.2.2.3 Solution Tree – *Segregation Technology*



A.2.3 Semi-aerobic Landfill Technology

A.2.3.1 Market Mapping – *Semi-aerobic Landfill Technology*



A.2.3.2 Problem Tree – *Semi-aerobic Landfill Technology*

EFFECTS

		Increased GHG emissions		Institutional arrangement not possible
	No skilled worker in SWM	Pollution		Unhealthy environment
Uncontrolled landfilling	Implementation of SWM strategy not possible	Increase in hazards - fires	Recycling and composting not possible	Disaster

PROBLEM

Uptake of semi-aerobic landfilling

CAUSES

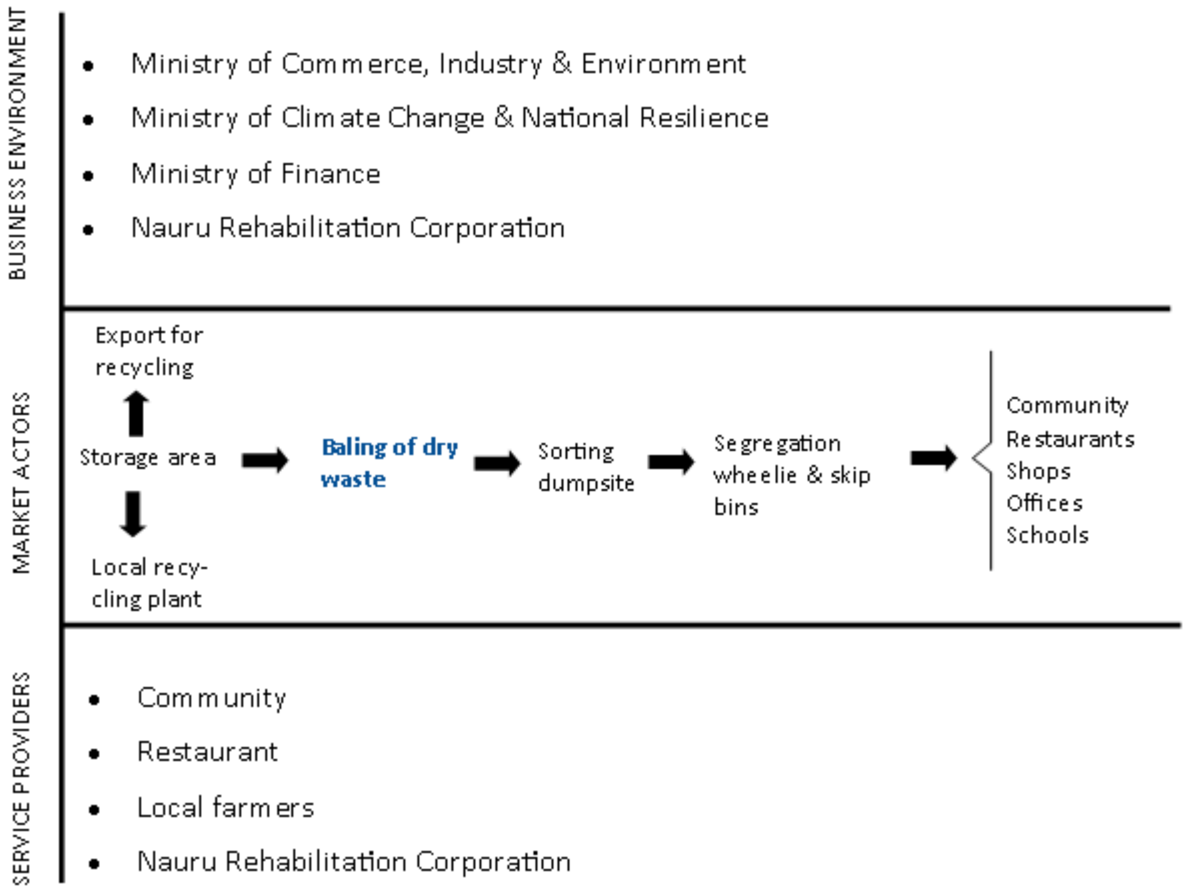
Lack of resources	Lack of skilled & trained personnel	Improper landfilling practices	Ineffective segregation process	Lack of institutional arrangement enforcement
	No SWM training opportunities	Lack of policy	Lack in management skills	Lack of awareness on benefits of process
				Lack of monitoring and data collection

<u>A.2.3.3 Solution Tree</u> – *Semi-aerobic Landfill Technology*

		Reduction in GHG		Effective monitoring & evaluation of process	
	More skilled workers SWM	Controlled pollution		Safer and cleaner environment for all	RESULTS
Better control and management of landfilling	Effective implementation of SWM strategy	Less hazards	Increased potential for recycling and composting	Blessing	RESULTS
Uptake of semi-aerobic landfilling					STARTER PROBLEM
Availability of resources	Qualified and skilled personnel	Proper landfilling techniques in place	Effective segregation process	Institutional arrangement enforced	MEASURES
Funding available	SWM training opportunities available	Policy in place	Skilled management & staff	Effective awareness raising programs in place	MEASURES
				Effect monitoring and data collection system in place	

A.2.4 Baling Technology

<u>A.2.4.1 Market Mapping</u> – *Baling Technology*



<u>A.2.4.2 Problem Tree</u> – *Baling Technology*

					EFFECTS
	Lack of interest	Uncontrolled dumping	Unskilled workers	Process not feasible	EFFECTS
Process not possible	Process cannot be managed	Landfilling becomes a hazard. Increased GHG.	Wasted investment	Disaster	EFFECTS
Non-effective baling process					PROBLEM
Limited resources	Lack of skilled & trained personnel	Absence of an effective baling process	Ineffective baling process	Lack of institutional arrangement enforcement	CAUSES
	No training opportunities	Process not practiced nor enforced	Lack in management skills	Lack of awareness on benefits of process	CAUSES
				Lack of monitoring and data collection	CAUSES

A.2.4.3 Solution Tree – *Baling Technology*

				Effective monitoring & evaluation of process	
	Increased interest & number of workers	End results. Motivation increased	Capable working team	Safer & cleaner environment for all	RESULTS
Process feasible	Process feasible and manageable	Controlled solid waste ending up in landfills. Reduced GHG.	Increased production of baled recyclable waste.	Blessing	
Non-effective baling process					STARTER PROBLEM
Resources available	Skilled and trained personnel available	Effective baling process	Effective baling process	Institutional arrangement in place	
	Training available	Process practiced effectively	Good management skills	Awareness raising on environmental impacts	MEASURES
				Effect monitoring and data collection system in place	

Annex A.3: Technology Expert Working Groups

A.3.1 Energy Sector Working Group

i) Reagan Moses — *Secretary for Climate Change & National Resilience, GoN*
ii) Midhun Ajaykumar — *Director of Energy, DCCNR, GoN*
iii) Carmine Piantedosi — *CEO, NUC*
iv) Ali Mohammed — *General Manager operations, NUC*
v) Apenisa Manuduitagi — *Renewable Energy, Metering & Regulatory Affairs, NUC*
vi) Tyron Deiye — *Consultant – CC & Migration Specialist, GoN*
vii) Abraham Aremwa — *TNA Mitigation Consultant*

A.3.2 Waste Sector Working Group

i) Reagan Moses — *Secretary for Climate Change & National Resilience, GoN*
ii) Bryan Star — *Director of Environment, DCIE, GoN*
iii) Grace Garabwan — *SWM Officer, DCIE, GoN*
iv) Jallah Jeremiah — *Director of Water Unit, DCCNR*
v) Creiden Fritz — *Director of Commerce, DCIE, GoN*
vi) Abraham Aremwa — *TNA Mitigation Consultant*