REPUBLIC OF VANUATU

TECHNOLOGY NEEDS ASSESSMENT MITIGATION REPORT

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TECHNOLOGY NEEDS ASSESSMENT REPORT:

CLIMATE CHANGE ADAPTATION TECHNOLOGIES IN AGRICULTURE AND WATER SECTOR REPORT

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Disclaimer

Foreword

Vanuatu is one of the most vulnerable countries in the world to climate change and disaster risks. The island nation experiences cyclones, storm surges, landslides, flooding and droughts, which become more intense as a result of climate change. Vanuatu is also highly exposed to geophysical threats such as volcanic eruptions, earthquakes and tsunamis, as well as human, animal and plant diseases, and human cause disasters. Categorize as a least developed country, the impacts of climate change have already undermined the country's development. These impacts will continue to worsen in the future if the drivers of climate change are not addressed and if the most vulnerable sectors are not supported.

Recognizing these circumstances, the Vanuatu government ratified the Paris Climate Change Agreement on the 18th of June 2016 and submitted the National Determined Contributions (NDC) and emission reduction targets to the United Nations Framework Convention on Climate Change (UNFCCC). Vanuatu's NDC mitigation target is transitioning close to 100 percent renewable energy in the electricity (energy) sector by 2030. The NDC Implementation Roadmap aims at providing a pathway for the implementation of specific climate change mitigation actions in Vanuatu, which can assist in achieving the target defined in Vanuatu's NDC. To support the implementation of the country's INDC, Vanuatu has participated in the third phase of the "Technology Needs Assessment (TNA)" aimed specifically at identifying priority technology transfer investments and to asses which environmentally sound technology (EST) are most relevant for meeting the country's climate change adaptation and mitigations targets.

The Ministry of Climate Change Adaptation (MCCA) recognizes that the TNA Project, implemented in collaboration with the United Nations Environment Programme (UNEP) and UNEP DTU Partnership (UDP), and with the Asian Institute of Technology (AIT) funded by GEF, as the first comprehensive national exercise undertaken towards assessing our climate change technology needs. The TNA process was coordinated by the MCCA through the Climate Change Department, with consultations of relevant technical working group (TWG), relevant stakeholders, local experts and national consultants.

The First Part of the Technology Needs Assessments (TNA) Report aims to present and short-list prioritized sectors that have maximum potential for mitigation in the light of the country's long-term development policies. The National Advisory Board (NAB) for the Vanuatu Climate Change Ministry decided the TNA priority sectors. Through the NAB consultation process and judgment, two major economic sectors were identified and prioritized for TNA Mitigations: Energy and Waste-to-Energy sectors.

Vanuatu is proud to have completed the first step of TNA through the collaborative engagements of other government agencies, private sector and the social community. This collaborative approach has enable the identification of various technologies for our energy and waste-to-energy sector in accordance to our Vanuatu's National Policy on Climate Change which is to promote durability solutions to safeguard our environment and incorporate elements of conservation and protection of biodiversity for our surrounding ecosystems.

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The Government of the Republic of Vanuatu

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This report compilation was successful because of the anointed understanding from God the everlasting Father and the individuals that were involved in the process leading up to the completion of this report. Their assistance, support and guidance has allowed me to complete and submit the TNA report. I therefore would like to take this opportunity to express my sincere heart-felt appreciation in thanking all these people.

I wish to thank the former Director General to the Ministry of Climate Change, Mr. Jesse Benjamin for allowing me to participate in this Vanuatu TNA process. In addition, the Country Coordinator and the technical working group for mitigation that were nominated from the relevant line departments and the civil society. Your time, guidance, encouragement and involvement has enable me to complete this step 1 of the TNA process.

Finally, I would like to express my sincere gratitude to the Global Environment Facility for funding this climate technology pathway for implementing the Paris Agreement, and implemented by the UN Environment through the UNEP DTU Partnership.

Executive Summary

The First Part of the Technology Needs Assessments (TNA) Report aims to present and short-list prioritized sectors that have maximum potential for mitigation in the light of the country's long-term development policies. The National Advisory Board (NAB) for the Vanuatu Climate Change Ministry decided the TNA priority sectors. Through the NAB consultation process and judgment, two major economic sectors were identified and prioritized for TNA Mitigations: Energy and Waste-to-Energy sectors.

This report has been prepared through a consultative process with the involvement of stakeholders from government, non-government organizations, private entrepreneurs and the Vanuatu Woman's agencies of the relevant sectors and sub-sectors prioritized for TNA. In the TNA consultation process, stakeholders from a wider sector and also from the civil societies have been involved to identify new knowledge, especially local knowledge, and insights on specific technology challenges and opportunities. Apart from the stakeholder consultation, a number of policy documents, for example the Vanuatu's National Determine Contributions Implementation Roadmap (NDC-IR), prepared in March 2019 and Vanuatu National Sustainable Development Plan (NSDP), (2016 - 2030) prepared in 2015, National Planning Framework were further analyzed in identifying and prioritizing the sectors potential for mitigation benefits and necessities.

Thus, in view of the country's efforts to undertake and follow low carbon development path as stated in the NDC-IR and to realize the targets set for vision 2030, the sectors/subsectors of the Energy Sector, especially power generation, has been prioritized for mitigation to meet the rising energy demand (NDC-IR, 2019) .

There exists a participatory problem solving approach facilitated by the Mitigation Consultant to get the TWG actively involved in the analysis process. In identifying of generic mitigation and technological options in the organized open meetings and working group sessions, and capacitated the TWG to carry out prioritization of technology options and alternatives through the multi-criteria analysis (MCA). Criteria used in all technology prioritization exercises invariably reflect costs, environmental, social and economic pre-requisites for and/or corresponding impacts of technology deployment, as well as technical attributes, mirroring performance of proposed technologies.

The criteria for selecting mitigation measures priorities have been established by exploring what extent of investments in technologies for mitigation would contribute to emission reduction in the context of country's aspiration of achieving the sustainable development goals. Thus, the basic criteria for technology prioritization for mitigation measures are: development benefits, implementation potentials and contribution to climate change response goals.

Development benefits define climate change mitigation technologies that offers the greatest value to the country in meeting its current national development priorities. Implementation potential defines scale of implementation and diffusion of the technology, which can be realistically achieved if key barriers are overcome. Contribution to climate change response goals defines technologies that will make the biggest contributions to the country's efforts to undertake a clean development path that will contribute to the global mitigation effort.

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List of abbreviations and Acronyms

ADB	Asian Development Bank
BEV	Battery Electric Vehicle
BMW	Biodegradable Municipal Waste
BUR	Biannual Update Report
CCDRRP	Climate Change and Disaster Risk Reduction Policy
CDS	Country Development Strategies
CH_4	Methane
CO_2	Carbon Dioxide
COP	Conference of Parties
CTCN	Climate Technology Centre and Network
DEPC	Department of Protection and Conservation
DoE	Department of Energy
DLA	Department of Local Authority
EIA	Environmental Impact Assessment
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIZ	German Agency for International Cooperation
GoV	Government of Vanuatu
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engines
ISIC	International Standard Industrial Classification
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JICA	Japan International Corporation Agency
LECRDS	Low Emissions Climate Resilient Development Strategies
LPG	Liquefied Petroleum Gas
MBT	Mechanical Biological Treatment
MCA	Multi criteria analysis
MCCA	Ministry of Climate Change Adaptation
MoH	Ministry of Health
MoL	Ministry of Lands
MRV	Measuring, Reporting and Verification
MSW	Municipal Solid Waste
NAB	National Advisory Board
NC	National Communication
NCCC	National Climate Change Committee
NDC	National Determine Contribution
NEDC	New European Driving Cycle
NERM	National Energy Road Map
NGEF	National Green Energy Fund
N_2O	Nitrous Oxide
NSDP	National Sustainable Development Plan
NSDS	National Strategy for the Development of Statistics
O&M	Operation and Maintenance
RDF	Refuse Derive Fuel

RE	Renewable Energy
RPZs	Rural Production Zones
SNC	Second National Communication
SPC	South Pacific Community
SRF	Solid Recovered Fuel
TNA	Technical Needs Assessment
UN	United Nation
UNDP	United Nations Development Programme
UNELCO	Union Electrique du Vanuatu Limited
UNFCC	United Nations Framework Convention on Climate Change
URA	Utilities Regulatory Authority
VAT	Value Added Tax
VIPA	Vanuatu Investment and Promotion Authority
VNSO	Vanuatu National Statistic Office
VREP II	Vanuatu Rural Electrification Program (Phase 2)
VUI	Vanuatu Utility Infrastructure

Physical Units

1 Gg = 1,000,000 g
1 Gg = 1,000 metric tonnes (mt)
I ha = 10,000 m^2
1 ha = 0.01 km^2
1 kV = 1,000 V
1 kW = 1,000 W
1 MW = 1,000 Kw
1 GW = 1,000 MW

1 US gallon = 3785.41 cc
1 Imperial gallon = 4546.09 cc
1 liter = 1,000 cc
1 mile = 1.6093 km
1 $rad.s^{-1}$ = 0.5493 rpm
1 hp = 754.7 W
1 BTU = 1055.06 J
1 bar = 14.5038 psi
1 bar = 100 kPa
1 atm = 101.3 kPa
1 atm = 1013 mb

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Chapter 1: Introduction

1.1 About the TNA Project

Since 2009, a global Technology Needs Assessment (TNA) Project, under the Poznan Strategic Programme on Technology Transfer was established at the Fourteenth Conference of the Parties (COP 14). These programme are financially supported by the Global Environment Facility (GEF) that has availed developing country parties to the United Nations Framework Convention on Climate Change (UNFCCC) with financial and technical support to determine their technology priorities for the mitigation of greenhouse gas emissions and adaptation to climate change. The United Nations Environment Programme (UNEP) is implementing the project through the UNEP DTU Partnership (UDP). Also, the University of South Pacific (USP) is providing technical support for the Pacific Countries. Under the current phase of the TNA Project (i.e., Phase III), Vanuatu is one of the countries to implement the TNA Project built upon country driven activities leading to identification, prioritization and diffusion of climate friendly and climate smart technologies, with the capacity building and guidance from the accredited experts.

The overall goal of the TNA process is to come up with select technologies that will enable Vanuatu "to achieve development equity and environmental sustainability, and to follow a low emissions and low vulnerability development path" (UNDP, 2015). The GEF driven project aims to meet the following objectives;

- To identify and prioritize technologies through country-driven participatory processes that can contribute to mitigation goals of the country, while meeting the national sustainable development goals and priorities and;
- To identify barriers hindering the acquisition, deployment, and diffusion of the prioritized technologies.

The Climate Technology Centre and Network (CTCN) is the operational arm of the UNFCCC Technology Mechanism. The CTCN mission is "to stimulate technology cooperation and enhance the development and transfer of technologies to developing country Parties at their requests". The UNFCC Modalities and Procedures (2013) defines the CTCN's support to developing countries, which include the following;

- Development and conduct of TNAs, road maps and action plans to support identification of technologies and adequate planning;
- Implementation of TNA/Technical Action Plans (TAPs) outputs in the form of technology projects, programs or strategies to enable concrete actions in country.

The first step to this TNA process is Sector prioritization and includes:

- Identification of the sectors with high GHG relevance;
- Review national GHG inventory to identify the GHG emitting (sub)sectors, and analyze their interrelationships. Also, identify data gaps, and collect information on new technologies;
- Asses sectorial and development plans so there is certainty of the future trends;
- Get the short list of prioritized (sub)sectors according to their maximum mitigation benefits and;
- Stakeholder consultation and use of multiple criteria analysis (MCA) (GHG mitigation and development priorities) for prioritizing sectors.

1.2 Existing national policies on climate change mitigation and development priorities

As a signatory to the UNFCCC and its related protocols, the Vanuatu government has been actively involved in international negotiations to chart a sustainable greenhouse emissions reduction pathway that keeps humanity safe. Until recently however, policies and response measures to mitigate and adapt to climate invariability have not been translated into an overarching policy that promotes a holistic view of diverse climatic activities and integrated solutions to overt risks and challenges. The Vanuatu Climate Change and Disaster Risk Reduction Policy (VCCDRRP) prepared under the aegis of the United Nations Development Programme (UNDP), the Secretariat of the Pacific Community-German Agency for International Cooperation (SPC/GIZ), and the Australian Government. The Policy represents the country's determined and systematic response to individual climate threats and their positive feedbacks to sustainable development, wellbeing and ecological integrity (VCCDRRP, 2015).

The strategic goal for the VCCDRRP is to achieve the mainstream of climate change into national planning, budgeting, decision-making, and programme implementations, through effective institutional mechanisms, coordinate financial resources, and enhanced human resources capacity, by 2030. One of the focal issues addressed in the VCCDRRP is rapid transformation of the current economic structure and operations sync with low carbon and resilient economic development. In this regard, specific objectives that give added impetus to the TNA included purposeful plans for deployment of sound and equitable adaptation and mitigation measures to reduce vulnerability to climate change and enable transition to a low-carbon economy. Activities identified and assigned emission reduction targets specified in the NDC fall within the agriculture, energy, manufacturing, transport, waste, and household sectors. The NDC-IR 2019 buttresses the point that technology transfer has a critical role in the global community's successful response to climate change challenges, and articulated in detail specific technology transfer requirements in the afore-mentioned sectors (NDC-IR, 2019) (VCCDRRP, 2015) (SNC, 2014).

Vanuatu has also developed the National Determined Contribution (NDC) implementation roadmap for the energy sector, Vanuatu's only sector with a NDC target and an integrated Monitoring, Reporting and Verification (MRV) framework and tool. The NDC implementation roadmap will be used to access international climate finance with the aim of structuring finance for implementation, including leveraging international public and private sector contributions for NDC implementation. In addition, the integrated MRV tool will enable routine compilation of data and information on progress towards the realisation of the NDC targets including sustainable development pursuits. The integrated MRV framework is also well aligned with reporting requirements under the National Communications (NC) and Biannual Update Reports (BUR). Stakeholder capacity building for implementation of the mitigation contributions will also be supported to strengthen the NDC implementation process.

Under the NDC Implementation Roadmap First of all, there are basic interventions, which are recommended to be implemented:

- Interventions under implementation or preparation: project under implementation such as VREP II or the Talise Hydro Power Project bring good contributions towards the target and should be finalised as planned. Focus should be on implementations under preparation to secure funding and push for implementation.
- Coconut for Fuel Strategy: this is the key element in providing a sizeable contribution to achieving the NDC target and is the first implementation step to be carried out.

- Revision of the Vanuatu Electricity Supply Act: this is a key step for stronger involvement of the private sector and should allow attracting private capital for the investment into renewable energy projects. Batteries: a total of 37 MWh of battery storage capacity are necessary to secure a well-functioning grid, where overproduction can be stored for later consumption.

In addition to these basic interventions, 2 options are suggested for achieving the NDC target.

Option 1 includes the installation of 7.6 MW solar PV and 5.1 MW wind, which together can contribute around 30% to the target. The majority of the contribution towards the target (57%) will come from the use of coconut oil. Total costs of Option 1 are USD 73.3 m (excluding costs for the Sarakata hydro power project as they haven't been determined yet). It is assumed that a pricing arrangement for coconut oil can be found, which is not leading to ongoing operation costs, the costs for carrying out the Coconut for Fuel Strategy are included.

Option 2 includes the installation of 7.6 MW solar PV, which is seen as the renewable energy source with lowest generation costs. The main contribution in Option 2 will come from geothermal (36%), which requires successful drilling and considerable investment for the implementation. The availability of geothermal allows reducing the input of wind energy and it suggested that only half of the additional capacity (2.6 MW) is installed. The remaining gap will be covered by coconut oil and a total of around 6 million litres will be required to achieve the target. Total costs of Option 2 are USD 66.5 m (excluding costs for the Sarakata hydro power and the geothermal project as they haven't been determined yet). It is assumed that a pricing arrangement for coconut oil can be found, which is not leading to ongoing operation costs, the costs for carrying out the Coconut for Fuel Strategy are included (NDC IR, 2019).

In the past, no consistent energy policy or strategy existed in Vanuatu. Those Renewable energy policies and projects that were implemented were fragmented and often driven by proposals from development partners. This approach was not successful, and in response, the government developed a comprehensive National Energy Road Map (NERM) in 2013.The NERM identified five priorities for the energy sector: access, petroleum supply, affordability, energy security, and climate change. It set out objectives, targets and actions to achieve these priorities and contribute to the NERM's overall vision.

The NERM clearly identifies the issues in the energy sector as a challenge to the country's economy, and as restricting economic and social development. In the NERM, access to electricity is identified as one of the country's five development priorities, from remote rural areas to those who are already serviced by a utility under an existing concession. The goal of NERM is to increase electricity access for the rural population and extend the existing grid to reach an increasing number of people. The updated NERM (2016-2030) which was endorsed by the Government in June 2016 has the same vision as the earlier NERM, and its objectives, targets, and actions are intended to be consistent. The update was meant to provide more detail on particular areas (especially energy efficiency and green growth), and improve consistency of the priorities and objectives. The updated NERM focuses on five priorities: accessible energy, affordable energy, secure and reliable energy, sustainable energy, and green growth.

The updated NERM of 2016 included in Appendix B: Implementation Plan a long list of investments and actions that could help meeting the NERM targets. The planned activities were grouped into the following categories:

- Investments and Donor Programmes
- Policies, laws and regulations
- Analysis and studies
- Capacity building and institutional development
- Other

This category basically covers the following types of investments:

- Renewable energy
- Rural electrification
- Energy efficiency
- Grid extension

During 2019, the NERM Implementation Plan (NERM-IP) was reviewed and updated. The NERM progress towards targets was also investigated. The NERM-IP includes a total of 12 indicators to measure progress and has targets defined both for 2020 and 2030. In the priority Accessible Energy, there is excellent progress with the electrification of households and the 2020 targets have been or will be achieved. Electrification of public institutions is behind schedule.

In sustainable energy, the share of electricity generated from renewables has seen a sharp decline and was 0% in 2017 due to coconut oil prices. For the other indicators under this priority, further work on defining monitoring procedures is required. In the priority Green Growth, the share of coconut oil has been at 0% in 2017, but electricity use by rural tourism bungalows is above target. Based on the progress up to now and the targets defined for 2020 and 2030, measures required for achieving the targets have been identified.

In line with Government of Vanuatu's (GoV's) decentralization policy supporting development of all the six (6) provinces and town municipalities it is essential to decentralise the efforts of the NERM and to better integrate provincial governments and municipalities in the NERM-IP.

Mainstreaming of the NERM IP into Provincial Governments and Municipalities Development Strategies were also carried out as part of the NERM-IP review and updating. A sustainable energy strategy and action plan for the local administrative bodies (Provincial Governments and Municipalities) has been developed. Recommendations on the follow-up strategy by DoE to support the municipal & provincial stakeholders to implement the action plan is also included in the action plan.

The updated Vanuatu National Energy Road Map 2016-2030 defines a robust Monitoring, Verification, and Evaluation Plan (MRV) to monitor the status and progress for the NERM actions. The objectives, quantitative targets, and implementation plan under the NERM sets the framework for DoE to monitor and evaluate NERM implementation (NERM 2016 -2030, 2016).

The rural electrification National Appropriate Mitigation Action (NAMA) design document has as its main concern rural electrification and micro grids to improve access to electricity in the predominantly rural sector.

NAMAs are voluntary, non-binding policy instruments that provide a framework for pursuing a country's socio-economic and development goals, while contributing towards global greenhouse gas mitigation efforts. Thus, they have the dual objective of mitigating climate change while allowing economic objectives to be reached. The Intended National Determined Contributions under the UNFCC on the other had have the prime objective to reduce emissions of greenhouse gasses, although it is realised that developing countries have the opportunity to improve their well-being, at least until their per capita emissions draw level with world average levels; after which the pressure to reduce emissions will intensify.

The NAMA covers two interventions. Under Intervention 1, micro grids will be established. Rural communities/tourism and agricultural facilities/health centres/schools are the focus of these micro grids due to their demand for electricity for lighting, cooling and appliances. The micro grids will use renewable

energy sources (solar, wind, hydro) and will provide electricity for lighting, radio and phone charging for households, and for service and production activities in Rural Productivity Zones (RPZs).

Intervention 2 will support extension of existing electricity grids on different islands. Households, public institutions and tourism/commercial consumers in the proximity of lines will be connected.

Electricity will be provided for lighting, audio/TV, mobile phone charging, coastal fishing (refrigeration of the fish catch), tourism facilities (lodges), agricultural facilities (preparing, processing and packaging produces) or the production of handicrafts.

The total cost of the NAMA is estimated at around US$5.5 million. This includes support to cover the investment costs of the two interventions as well as extensive capacity-building efforts. According to the NAMA report over the 15-year lifetime of the NAMA, emission reductions will reach around 13,500 tons of CO2 which amounts to around 900 tonnes per annum or 0.9Gg per annum.

Under the UNDP NDC Support Programme, the Department of Energy (DoE), Government of Vanuatu has carried-out a detailed techno-economic feasibility study for a solar micro-grid for Wintua and Lorlow village communities. Under the NAMA programme, The Vanuatu Ministry of Climate Change (MoCC) has now secured funding from Government of Austria for implementation of a solar micro-grid for the two village communities, Wintua and Lorlow located in South West Bay on Malekula Island, Vanuatu.

International Renewable Energy Agency (IRENA) Renewables Readiness Assessment has recently been carried out for Vanuatu. This detailed report reiterates that like all Pacific Island nations Vanuatu has an excellent solar resource and that this resource is available throughout the populated areas of the country and could be used to generate electricity to offset the cost of imported fuels (IRENA, 2015).

The report notes that several solar photovoltaic (PV) projects with a total capacity of more than 2.6 megawatt (MW) are under consideration. Interest from independent power producers (IPPs) in solar PV electricity generation has been increasing. Moreover, the first stage 4 MW geothermal plant is expected to go on steam before 2020, and some hydropower may also be added. The Port Vila grid currently has 3 MW of wind and the 26.5 MW diesel generator sets use between 5% and 20% coconut oil the quantity depending on availability and the economics of using the bio fuel instead of diesel. The Luganville Grid on Espiritu Santo in Vanuatu has a 1.2MW hydro plant and 2.9 MW diesel generations. In addition, there is a small amount of grid connected solar PV.

The report also suggests that to fulfil the aims in National Energy Road Map, it would be necessary to establish and enforce technical standards for grid-connected systems and regulatory capacity for small scale distributed generation systems. In addition, detailed models of the grid need to be pursued as the addition of intermittent sources such as solar PV could stretch the stability of the (30MW) grid system on Efate, Vanuatu in particular.

In terms of major mitigation options this report identifies a mix of geothermal, wind, biofuels and solar PV as the key technologies suitable for Vanuatu. The report is not, however, particularly ambitious in terms of projected installed capacity of PV citing grid stability concerns that would limit PV penetration to a few MW. In addition, the geothermal sources are still at the exploratory stage and with estimated upper temperatures of around 50 – 60 degrees C the plant efficiency is likely to be relatively low.

One of the problems identified by the report was how to handle the large night time load on the Efate grid from solar PV in particular. Most of this load is likely to be air conditioning and so one option would be to generate cooled water during the day and circulate the water from storage tanks at night. The other more conventional option for load shifting would be to use storage batteries.

To contribute to achieving its energy access and sustainability targets, the Government of Vanuatu (GoV) approved the establishment of a National Green Energy Fund (NGEF) in April 2016. The NGEF is intended to mobilize a pool of financial resources sufficient to provide all households with access to electricity and meet the sustainable energy target by 2030.

The general characteristics of NGEF include:

It will operate as a revolving fund, with an anticipated initial start-up capital of USD 10 million, to be sourced mainly from international sources, and from yearly contributions from domestically consolidated energy funds, totalling USD 300k.

It will offer four types of funding:

- Debt via intermediaries, including financial institutions and non-financial institutions in Vanuatu
- Project equity for project developers and technology providers
- Risk sharing, in the form of a first loss facility for local banks
- Small grants for public institutions (no more than 5% of total fund investments)

Energy efficiency investments should be included as well as renewable energy development, with a primary focus on increasing energy access in off-grid areas.

Renewable Energy Electrification Master Plan for Vanuatu - a renewable energy-based off-grid electrification master plan for remote islands of Vanuatu was developed during 2016 which would both: i) fit the specific cases of pilot islands (Mataso, Makira, Emae and Aneityum) pre-selected by the government of Vanuatu), and ii) subsequently allow a broader replication to further remote islands in Vanuatu. The master plan has two main components: i) preliminary technical designs for renewable-energy based electrification for the four islands; and ii) based on this sample of islands, development of a masterplan for electrifying Vanuatu's outer islands through affordable renewable energy.

National Sustainable Development Plan 2016-2030 (also called as "Vanuatu 2030 - The People's Plan") charts the country's vision and overarching policy framework for achieving a Stable, Sustainable and Prosperous Vanuatu within the next fifteen years, and in doing so sets out the national priorities and context for the implementation of the new global Sustainable Development Goals over the same period.

The key goals and policy objectives under the Vanuatu 2030 also include enhanced resilience and adaptive capacity to climate change and natural disasters (adaptation) and Prioritising renewable sources of energy and promote efficient energy use (mitigation).

The Ministry of Climate Change through its departments and the National Advisory Board (NAB) ensures that climate change priorities are streamlined and linkages made under the broader national development priorities and policies.

Vanuatu National Forest Policy (2013-2023) Vanuatu acknowledges the need to adapt to climate change and targets to "integrate climate change adaptation issues into forestry sector planning and activities". However, the enforcement of regulations is hindered by the fact that all forests are privately owned, whereas the constitution demands from landowners to manage their land in a way that "safeguards the national wealth, resources and environment in the interests of the present generation and of future generations".

The policy identifies the integration of climate change mitigation issues into forestry sector planning and activities as a specific objective. In particular, this includes the development of a national REDD+ initiative by the Department of Forests, the National Advisory Board on Climate Change and Disaster Risk Reduction (NAB) and non-governmental organisations.

1.3 Sector selection

Selection of TNA mitigation sectors which are: Energy and Waste-to-Energy sectors was an administrative decision by the National Advisory Board (NAB) to the Vanuatu Ministry of Climate Change and Adaptation and consistent with national efforts to chart a trajectory for green development and strengthen Vanuatu's image of a responsible global citizen. In fact, the energy sector especially the electricity generation sub-sector, transport, livestock, Nitrous Oxide (N_2O) from agriculture soils and waste sectors feature consistently among the top five sources of carbon dioxide (CO_2) and methane (CH_4) emissions in the Vanuatu Second National Communication to the UNFCC (SNC, 2014).

The Technical Working Group (TWG) close work collaboration during the identification and prioritsation of the mitigation technology is paramount in the TNA processes leading to technical action plan. The principal function of the TWG is to guide and assist the TNA processes. That is during its technologies selection process and its support of national and climate change mitigation actions. In consistent with key national policies including the National Climate Change & Disaster Risk Reduction Policy (CCDRR) and the National Energy Road Map (NERM) and the National Determine Contributions (NDC), while contributing to the Global mitigation response consistent with the goals of the Paris Agreement.

The TWG has guided the consultant in its contribution to ensure Vanuatu tracks along the sustainable development pathway as prescribed by the National Sustainable Development Plan and to ensure Vanuatu meets its mitigation reporting obligations to the UNFCCC.

The TWG's also supports functions to the Vanuatu Department of Climate Change and entail very close collaboration with Government, Non-Government agencies, Private sectors, Academic institutions, civil societies and Faith base organizations.

The roles and responsibilities of the TWG includes;

- Conduct a stocktake of mitigation relevant policies and legislative frameworks biannually or at intervals to be decided by the TWG
- Engage in and or facilitate contribution to the development or review of mitigation relevant policies and legislative frameworks as appropriate
- Conduct a stocktake of mitigation relevant projects or programmes under implementation in Vanuatu biannually or at intervals to be decided by the TWG
- Contribute, where necessary, to the development and implementation of mitigation relevant projects or programmes in Vanuatu
- Contribute, where necessary, to the National Communications and Biannual Update reporting processes
- Contribute, where necessary, to National GHG inventory processes and or activities
- Provide guidance and advice on mitigation Information, Education and Communications processes, standard messaging etc.
- Oversee the works of climate change mitigation matters in Vanuatu in close collaboration with the department of climate change
- Facilitate information disseminations and sharing and review of final reports
- Engaging and facilitating mitigation research

1.3.1 An overview of sectors, projected climate change, and GHG emissions status and trends of the different sectors

The GHG emissions in the energy sector are primarily associated with fuel combustion and fugitive emissions from fuels. Since Vanuatu is 100% dependent on imported fossil fuels to meet its energy demand and has no mining and exploration activities, fugitive emissions from fuels are not considered in GHG estimation. Emissions from the energy sector from fuel combustion includes the following categories:

- Energy Industries
- Manufacturing Industries and Construction
- Domestic Aviation
- Road Transport
- National Navigation
- Commercial/Institutional Sector
- Residential
- Fishing

In the year 2000, the energy sector was the second dominant source of GHG emissions in Vanuatu accounting for 12% of total GHG emissions in country. GHG estimation from the energy sector is based on data from Vanuatu National Statistics Office (VNSO), Customs Department on fuel imports, Department of Energy and UNELCO. GHG emissions from fuel combustion in Vanuatu are associated with the use of petroleum products mainly for electricity generation and road transport. Kerosene and LPG are mainly used for cooking. The total GHG emissions from the energy sector are estimated to be 70.34Gg CO_2e. Table 1.1 below presents CO_2e emissions from different sub sectors under the energy sector (NSDS, 2014).

Source	2000
Energy Industries	30.21
Manufacturing & Construction	1.08
Transport	34.69
Other Sectors (Commercial, residential, fishing)	4.37
Total CO_2e Emissions	**70.34**
International Bunkers (not included in national total)	**5.90**

Table 1.1 Emission from Energy Sector in Vanuatu (Gg CO_2e)

Table 1.2 presents emission of different gases from energy sector in Vanuatu. From the table it can be inferred that the most prominent GHG emitted from the energy sector is CO_2 amounting to 69.61Gg followed by CH_4 emissions of 0.02Gg. Some minor NOx and CO emissions associated with the energy sector exist and are estimated to be 0.45 and 1.41Gg respectively (SNC, 2014).

Source	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	Total CO_2e
Energy Industries	30.10	0.00	0.00	0.08	0.01	0.00	0.001	**30.21**
Manufacturing Industries and Construction	1.07	0.00	0.00	0.00	0.00	0.00	0.00	**1.08**
Domestic Aviation	2.84	0.00	0.00	0.01	0.00	0.00	-	**2.87**
Road	30.44	0.00	0.00	0.31	1.09	0.21	-	**30.60**
National Navigation	1.22	0.00	0.00	0.03	0.02	0.00	-	**1.22**
Commercial/institutional	0.31	0.00	0.00	0.00	0.00	0.00	-	**0.31**
Residential	3.53	0.02	0.00	0.01	0.28	0.03	-	**3.98**

Fishing	0.09	0.00	0.00	0.00	0.00	0.00	-	**0.09**
Total GHG Emissions	**69.61**	**0.02**	**0.00**	**0.45**	**1.41**	**0.25**	**0.00**	**70.34**
International Bunkers (not included in National total)	**5.90**	**-**	**-**	**-**	**-**	**-**	**-**	**5.90**

Table 1.2 GHG Emissions from Energy Sector in Vanuatu (Gg CO_2e, 2000)

1.3.2 Process and results of sector selection

The National Advisory Board to the Vanuatu Ministry of Climate Change decides on the sector selection process during the consultation meeting that was organized by the TNA coordinator. The sectors were selected taking into consideration the Vanuatu energy policies such as the Vanuatu National Energy Framework Policy (2015) and the Vanuatu Climate Change and Disaster Risk Reduction Policy (2015) and the trends of the sectors as shown on the above tables. The agreed sectors to be included in this TNA process after the inception workshop and several of the consultation meetings with the NAB, the TWG and relevant stakeholders are;

(a). Energy Sector and technology options includes;

- Biodiesel/internal combustion technology
- Blending Fossil with Biodiesel
- Efficiency Wood Stove
- Battery Electric Vehicle
- Solar Electric Boat

and (b). Waste –to-Energy Sector and the technology options includes;

- Mechanical Biological Treatment
- Manure Based Biogas Digesters
- Compact Biogas Digester for Urban Households
- Anaerobic Digestion-Biogas Plant

A more detailed description of technologies are in the Annex I of this TNA report.

Chapter 2: Institutional arrangements for the TNA and stakeholder involvement

The relevant institutional structure for implementing the TNA in Vanuatu is shown in Figure 2.1 below;

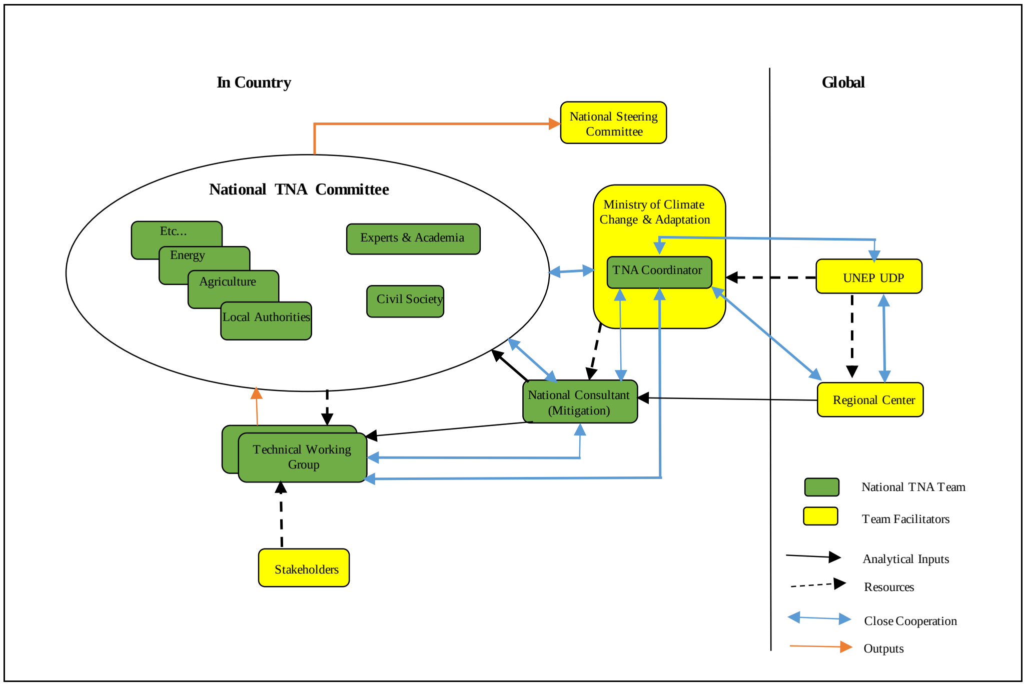

Figure 2.1 Vanuatu TNA Institutional Structure

The project governance is centered in the National Advisory Board (NAB), constituted by gender, development, environment, business and management, energy, finance, and climate specialists and policy analyst and specialists. The NAB whose remit is to manage the strategic direction of the TNA project is headed by the Director General to the Ministry of Climate Change and Adaptation (MCCA).

At the operation level, the Department of Energy and Department of Climate Change, constituted by Project Coordinator, Project Consultants handles project accounts and provides administrative and logistic support to the technical working groups. It is worth noting that the focal point for technology transfer in Vanuatu is headed by the in country Project Coordinator.

2.1 National TNA Team

The Ministry of Climate Change and Adaptation, illustrated as an integral part of the TNA project structure in Figure 2.1, is the institutional equivalent of the National TNA Team. The National TNA Team comprises of a steering committee, national TNA coordinator, sectorial working groups and two consultants for mitigation and adaptation respectively. The MCCA assembles technical members from within the relevant stakeholders of the TNA project. The TNA sectorial working group members and the consultant are entrusted to carry out scheduled TNA activities. The TNA Consultant undertakes tasks independently initially to plan out the consultation process and collating all relevant background information. The technical working group members are advised by the National Coordinator to converge into a consultation process to work on specific tasks that may require joint decision-making. There may be in between meetings

in which members communicate on relevant topics/issues by voice, SMS text and email. The TNA National Project Consultants reports on the implementation progress of the TNA to the NAB. In principle, the technical working group members are drawn from the National Climate Change Committee.

2.2 Stakeholder engagement process followed in the TNA

In addition to representatives of institutions involved in the governance of the TNA project, proactive stakeholders are drawn from the public, private and voluntary sectors, represented in the National Climate Change (NCC) Committee, such as the Department of Agriculture that can supply data on the agriculture waste that can be utilized in the Waste-to-Energy sector of the TNA process. At the outset, all major stakeholder institutions/organizations were invited to an inception workshop that provided background information on the project; its history, objectives and institutional arrangements. Stakeholder engagement in general had two broad objectives: 1) to seek views and opinions of stakeholders on matters; and 2) to make transparent decisions of national interest jointly. The first was pursued through consultative workshops, and the second through working sessions held between the mitigation consultant and working group members. There were also some be bi-lateral meetings for a more focused discussion with more relevant stakeholders. Considering that thematic working groups on energy and waste management do not currently exist under the NCC's Mitigation Cluster, and further considering the inter sectorial dimensions of both sectors, a mixed group of stakeholders including lead department agencies were established to work closely with the consultant and to take collective ownership of the decision-making process. In all cases, prior distributed meeting agendas served as the basis for stakeholder engagement. Unfortunately, the Department of Environment, the Department of Local Authorities and Pacific Energy representatives were unable to participate in the process although they are key stakeholders and will be consulted in the remaining phase of the project (see Annex II). Consultative workshops were organized to enable discovery of restricted sets of mitigation technology options. The committed stakeholders, identified, reviewed and validated structured and refined technologies put forward or emerging from the discussions, considered recommendations by the consultant, and carried out guided prioritization of technologies, pursuant to an introduction to multi criteria analysis (MCA) methodology. The TNA factsheets were developed by the mitigation consultant to present on the list of prioritized technologies (see Annex I).
Although this may be of high importance to achieving our results, engaging all stakeholders was unachievable due to unavoidable circumstances such as limited time and resources.

2.2.1 Gender aspects in the TNA process

To ensure that all genders can benefit equally from actions set out in TNAs and that gender inequalities in activities and outcomes are reduced or be eliminated, gender differences need to be taken into account throughout the entire TNA process and its outcomes. By systematically mainstreaming gender issues into the TNA, it will be possible to ensure that women and men have equal opportunities in relation to the Technology Action Plans (TAPs) that are planned to come out of the TNAs, as well as contributing to achieving their countries' Nationally Determined Contributions (NDCs) and the Sustainable Development Goals (SDGs). It is important that the TNA national coordinators and consultants with the necessary knowledge of gender-sensitive approaches to enable us to integrate gender issues into the adaptation and mitigation technology assessments.

2.3 Process for technology prioritization

Technology prioritization is part of the broader problem of technology deployment that is strongly correlated with private/public investment choices and technology transfer mechanisms anchored in global policies on sustainable development. The process begins with building an understanding of relationship between key issues in each sector and existing technologies. To this end, a situation analysis covering the policy, organizational and technological landscapes in each of the selected sectors, and change drivers paved the way for identification of the most pressing challenges, some of which are solvable through strategic deployment of technologies that have a primary focus on stabilizing and reversing current GHG emission trajectories, but are also capable of spurring economic growth and enhancing citizens' quality of life. Second, climate-friendly technologies with significant mitigation potential are identified through information canvassing by means of literature reviews and stakeholder consultations. For the type of quantitative analysis envisaged, a minimum of four alternative technologies per sector is emphasized for credibility of results arising from the TNA. Inter-comparison of weighted scores obtained for alternative technologies give their rank order, whereby the technology associated with the highest score is ranked top most and others follow in logical sequence. Sensitivity analyses of technology rankings are carried out when there is a marginal difference between ranked scores of two or more technologies or an answer is required to settle a hypothetical question. The procedure consists of MCA participants experimenting with non-random changes to criteria weights and evaluating the impact of specific changes on results previously obtained. In practice, MCA participants agree on changes to criteria weights following a blinding procedure in which a moderator denies participants access to performance matrix of alternative technologies, to curtail bias, when proposals for changes in criteria weights are made or being discussed. Criteria weights agreed by consensus are used to compute a new score for each technology, and inferences drawn accordingly.

Chapter 3: Technology prioritization for Energy Sector

3.1 GHG emissions and existing technologies of energy sector

The Government of Vanuatu is currently pending on the development of a national strategy for the development of statistics (NSDS), or measuring, reporting and verification (MRV) mechanism that was recently agreed by the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC, 2018). The GHG inventory is prepared using methodologies developed in the refined 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (Eduardo, et al., 2019). The UNFCCC software "Non Annex 1 National Greenhouse Gas Inventory Software, Version 1.3.3" has been used for the estimation of GHG. The preparation of GHG inventory in Vanuatu was coordinated by the Department of Energy, and was prepared with support from relevant departments namely Bureau of Statistics, Customs Department, Utility Regulatory Authority (URA), Department of Environment, Department of Forestry, Department of Agriculture, Department of Livestock and electricity utility companies UNELCO and Vanuatu Utility Infrastructure (VUI) through data compilation and reporting (NSDS, 2014). The key steps carried out in inventory preparation include:

- Team Formation to work on Inventory
- Team Capacity Building/ Training
- Data Collection for sectors covered under the Inventory
- Identification of Gaps
- Documents / Data Review for quality assurance
- Report (inventory) writing

Sectorial data for GHG estimation was compiled from various sources primarily using national data collected from annual reports, statistical reports, studies and brochures of related department/ institutions. Where actual data was not available judgment of sector experts was relied on. A number of assumptions were used to represent the local conditions of the country. These assumptions have been verified with the local sector experts and crosschecked with other resources for correctness. Sparsely populated cities/regions wherein no formal data is available are not considered in the study (SNC, 2014).

To this effect, findings of the most recent national GHG inventory published in the Second National Communication (SNC) under the UNFCCC dates back to the year 2000. In the SNC, the energy sector, excluding the non-electricity sub-sectors (i.e. transport and domestic biomass burning) is shown to generate a wide spectrum of GHGs including 69.61Gg of carbon dioxide (CO_2), 0.02Gg of methane (CH_4), and 0.000Gg of nitrous oxide (N_2O) (SNC, 2014).

3.2 Decision context

The public policy on energy security is spearheaded by the Department of Energy (DOE) under the Ministry of Climate Change and Adaptation (MCCA) (Corporate Plan, 2015). In carrying out its objectives, DOE benefits through the collaborations with the departments responsible for environmental management (DEPC), regional integration and investment authorities (VIPA), amongst other key players, engages to ensure the operation of robust and efficient markets governed by the Vanuatu Ministry of Climate Change Corporate Plan (2016), Forestry Act (2006), Electricity Supply Act (2006), Vanuatu National Energy Framework Policy (2015), and other existing legislations. Except for state-owned enterprises, importers, producers and distributors of energy products conduct their business in accordance with the respective companies Act (2012). The two state-owned enterprises, UNELCO and VUI have legal authority for the generation of electricity on the island of Efate, Tanna, Malekula and Santo concession and UNELCO also

develops and provides the water supplies for domestic, public, industrial and agricultural purposes in Efate. Forest biomass products are harvested by operators licensed in the Forestry Act (2006) and sold to households through a vast network of intermediaries and retailers in the urban and peri-urban neighborhoods. Compliance with the law including safeguarding of service standards, public safety, private sector participations and stakeholder engagement is monitored by the Vanuatu Utility Authorities (URA) and the Department of Local Authorities (DLA), that oversee and facilitate the exchange of good practices in the local government structures and services.

As alluded to in the previous paragraph, Vanuatu has twin energy markets built around traditional and modern energy fuels and carriers, operating in parallel. On one hand, forest biomass fuels are predominantly used to satisfy a large part of household energy needs countrywide. By contrast, modern energy markets are constructed around direct and indirect use of petroleum products in automotive applications and electricity generation, respectively. According to IRENA, forest in biomass in Vanuatu accounts for about 60% of the country's energy supply and more than 90% of household energy consumption, petroleum products for 36%, and electricity for about 4% of energy supply (IRENA, 2015) .

In light of the government's recent policy stances on the greening the country's economy and global efforts towards reducing GHG emissions, the TNA analysis offers further insights into potential technological interventions, guided by a raft of performance metrics mutually agreed by key stakeholders. Specifically, analyses carried out under the TNA project helped identify technologies that are critically important for successful implementation of the country's LECRDS and INDC. Notwithstanding technological interventions, it is important to put in place complementary measures including policy changes/legislative amendments, institutional frameworks, economy-wide energy conservation measures, routine operation and maintenance (O&M) embedded within dynamic asset management processes. Moreover, positive behavioral responses to climate change education could significantly augment the environmental impact of climate-friendly energy generations solutions that might be introduced in the future (SNC, 2014), (NDC-IR, 2019).

3.3 An overview of possible mitigation technology options in the energy sector

The technology for the energy sector may vary that is due to the type of fuel used for power generation. For Vanuatu, the main fossil fuels are the petroleum oil. There are also the renewable sources such as vegetable oils, sunlight, the wind and hydropower. Additionally the geothermal energy may come as an alternative source of RE source with feasibility studies currently done to determine its reliability, affordability, accessibility and impacts on the environment. Several considerations may require to be utilized for understanding the desirability of one option over the other. Some of which are generic and some are due to specific national circumstances (Vanuatu Monthly Energy Market Snapshot, 2019).

Work needed to overcome challenges mentioned in the previous section might be aptly viewed as discovery, prioritization, implementation and impact assessment of climate friendly and sustainable energy solutions. In addition to improved planning processes and implementation modalities in the electricity sub-sector, the body of evidence in recent studies and appraisals, highlighted the need for technological innovations making less use of primary energy sources, and/or harvesting of renewable and less-polluting energy sources (IRENA, 2015). Currently, fossil fuel-fired utility-scale generators dominate power generation in the electricity sub-sector, which is the subject of analysis.

In the light of the mitigation options, the Government of Vanuatu has been actively developing a range of frameworks and plans to guide the country and its stakeholders, towards a low emissions development

trajectory. The range of acts, policies, plans and strategies of relevance to deal with climate change threats were developed and enacted. The Vanuatu's Nationally Determine Contribution (NDC) aims to achieve an ambitious mitigation contribution with a transitioning to close to 100% renewable energy in the electricity sector by 2030. This contribution would reduce emissions in the energy sector by 72Gg by 2030. Emissions in this sector recorded around 130Gg in 2010 but are expected to rise to 240Gg by 2030 (3% per annum) (NDC-IR, 2019).

The tables 3.1 and 3.2 below presents possible technologies for the energy sector and their climate change mitigation benefits.

No.	Technologies	Climate Change Mitigation Benefits	Applicability and Potential
1	Biodiesel/Internal Combustion Technology	Reduction in GHG Emissions by about 83.4 % of gCO_2e/GJ and Low Carbon Credits[1]	This technology is already operational at a non-commercial scale at the Vanuatu Oil Production Company in Santo, Vanuatu. The Technology may be limited due to low availability of feedstock for generating vegetable oils/biodiesel and Vanuatu Government incentives to introducing policies and standard to drive this technology.
2	Blending Fossil with Biodiesel	Reduction in GHG Emission	Technology does not need modification to the original CI engines that is widely used in many countries. Technology also used RE sources of energy such as Tamanu Oil. The Tamanu tree can be found in all coastal areas in Vanuatu.
3	Efficiency Wood Stove	Reduce GHG emissions by 210,000 tCO_2/year[2]	Technology is proven and available in Vanuatu. Market is undeveloped and production is low scale. Market can be improved if enabling environment is in place (awareness, financial incentives, policy and regulation, etc.)
4	Battery Electric Vehicle	GHG emission reductions. Currently almost no GHG savings but forecasting 39.1- 52.7% GHG savings for 2030[3]	BEVs implementation could not start immediately. A specific recharging infrastructure is requested. Many efforts are invested toward creating universal safe standard recharging stations. Different pilot projects are ongoing worldwide to ensure the well operation of the BEV concept, and learn lessons from driver's behaviors, charging time, charging frequency, charging location, daily driving mileage, mileage between charging events, and other influencing parameters. BEV concept is expected to becoming a mature expandable technology on the short to medium terms.
5	Solar Electric Boat	Reduction in GHG emission, approximately 6 mt of CO_2/month or 72 mt of CO_2/year[4]	Relatively sunny area, operation profiles to match the performance of our vessels or design to be adapted to match operation profile, within the limit of the laws of physics. We train local manpower to be able to intervene on the vessels' electrical system. Systems are simple and low voltage thus do not require a high electrical expertise to be looked after but it is advised to have someone assigned to that task (typically the captain or a crew). The vessels are designed to be single handed. For ferries, it is however advised to have a captain and one or two crew to manage the berthing and the passengers. Wind/Sea condition in the area of operation should be on average below Force 4.

[1], IEA, 2011 [2], FAO-RWEDP, 1999 [3], Auka, 2019 [4], UNDP Report 2018

Table 3.1 Overview of Technologies for Energy Sector and their Climate Change Mitigation Benefits

No.	Technologies	Gender Benefits	Economic Benefits	Social Benefits	Environmental Benefits
1	Biodiesel/Internal Combustion Technology	Job creation and revenue generation for low income woman and the disadvantage population in the remote rural areas	Promotion of artisanal industry, nonagricultural incomes. Option of hybrid with solar, wind and biomass.	Energy security at different scales	Application of techniques for lowering the carbon emissions is a prerequisite condition for environmental benefit.
2	Blending Fossil with Biodiesel	Job creation and revenue generation for low income woman and the disadvantage population in the remote rural areas	Income generation to the producers and contributes to the economic development by saving hard currency for diesel importation.	Create new job opportunities	Reduces pollution due to better combustibility.
3	Efficiency Wood Stove	Improve health and prolonged life expectancy of woman in the rural remote areas	Cost savings for low-income rural residents.	Create new job opportunities and prevent urban drift.	Reduction in consumption of wood and improve local air quality.
4	Battery Electric Vehicle	Potential gender impacts	Annual operating saving costs when compared to new vehicles as a function of fuel price, with an annual mileage estimated 10000 km and electricity tariff of 0.15USD/kWh.	Create new job opportunities.	Pollutant emission reduction thus substantially contribute to improving local air quality.
5	Solar Electric Boat	Potential gender impacts.	Virtually maintenance free as far as propulsion and energy systems are concerned, do not require refueling.	Create new job opportunities.	Zero emission and nil impact on the environment.

Table 3.2 The co-benefits of the possible technologies

3.4 Criteria and process of technology prioritization for the energy sector

During the organized consultation workshops, the respective stakeholders and the mitigation technical working team identified the eleven criteria as presented in the table 3.3 below. During the stakeholder's consultation the team were involved with brainstorming possible criteria and taken into account the interests group perspectives. These criteria are identified to gauge the relative merits of the energy sector technologies earlier mentioned. These criteria shown in Table 3.3 are categorized under anticipated costs, economic incentives, social implications, environmental aspects and/or corresponding impacts of their deployment, as well as climatic attributes mirroring performance of the specific technologies. The criteria are grouped into categories (Cost, Benefits, GHG Mitigation, Technology Related, Institution) and sub-categories (Capital, O&M, Economics, Social, Environmental) for easing the process of calculating criteria weights.

Criteria	Units	Category	Description
Capital Cost	USD	Cost	Expenditure required to purchase fixed assets
Operational & Maintenance Cost	USD	Cost	Expenditure required to procure initial, additional, or replacement equipment, to meet specific operational objectives of entity making the investment accountable and reliable
Job Creation Opportunities	Ordinal	Economic	New employment opportunities created by the introduction of a particular technology
Reduce Diesel Importation	Tonnage/year	Economic	Reduction on the importation of the petroleum products as a result of using RE sources
Income Generation	USD	Economic	Prospect of driving a daily income for our Vanuatu population
Health Benefits	Ordinal	Social	Describes the condition of freedom from perils and injury. Exposure to health hazards may be acute or chronic
Energy Security	Ordinal	Social	Source of energy is accessible and independent of the technologies
Capacity Building Potential	Ordinal	Social	Level of competence of national workforce required to sustain

			satisfactory operation of specific technologies
Reduction of CO_2 Emission	tCO_2/year	Environmental	Quantity of CO_2 gas emitted into the atmosphere from the respective introduced technology
Reduction of Environmental Degradation	ha	Environmental	Exclusion area required to install and extraction from our natural environment to operate the specific technology
Reduction of GHG Emission	tCO_2e/year	Climate Related	Quantity of non-fluorinated greenhouse gases released into the atmosphere by a particular activity serving specific societal and economic functions

Table 3.3 Evaluation Criteria for ranking the energy sector technologies

3.5 Results of technology prioritization for the energy sector

Results presented in this section of the report emanate from implementation of procedures for technology prioritization described in section 2.3. For the energy sector, a weighted sum of scores computed for five alternative technologies are shown in column 12 of Table 3.4, in which efficiency wood stove and battery electric vehicle are ranked as the top two technologies (See Annex III for computation details).

Sector	Technology Needs	Cost of Technology - 34%		Total Score	Benefits - 66%				Total Score	OVERALL (Total Cost x 34) + (Total Benefit x 66)	Ranking
		Capital	M&O		Economic	Social	Environmental	Climate Related			
		41%	59%	100%	14%	21%	29%	36%	100%	100%	
Energy	Biodiesel/Internal Combustion Technology	28	27	55	8	13	18	29	68	64	4TH
	Blending Fossil with Biodiesel	16	28	44	8	14	19	22	63	57	5TH
	Efficiency Wood Stove	25	35	60	9	16	20	28	73	69	1ST
	Battery Electric Vehicles	6	28	34	10	14	24	34	82	66	2ND
	Solar Electric Boat	7	27	34	9	14	24	34	81	65	3RD

Table 3.4 Results of multi-criteria analysis (MCA) matrix of the energy sector technology options

Table 3.4 presents the results of multi-criteria analysis (MCA) matrix for the base case of the energy sector technology options. Option Weighted Score Rank Biodiesel/Internal Combustion Technology 66%, Blending Fossil with Biodiesel 57%, Efficiency Wood Stove 69%, Battery Electric Vehicle 66% and Solar Electric Boat 65%.

To test the robustness of findings reported in Table 3.4, sensitivity analyses driven by selective and deliberative modifications of category and individual weight of costs, economic, social, environmental and climate related criteria shown in Table 3.5 were conducted. In the first of two sensitivity analyses (i.e., Run 1), aggregate economic and environmental criteria weights were downgraded compared to Cost, social and climate related criteria under the Base Case (i.e., input data resulting in Table 3.5). In Run 2, MCA participants assigned economic and technical criteria with higher aggregate weights, whilst keeping the overall weight of environmental and climate related criteria unchanged vis-à-vis the Base Case. MCA results based on two sets of modified criteria weights and recorded as Run 1 and Run 2 in Table 3.6 show some changes in the ranking of competing technology options. (See Annex III for detailed computations).

The MCA matrix, thus concludes by confirming that Efficiency Wood Stove is the top mitigation technologies in the energy sector, under the current TNA and followed by Battery Electric Vehicle and Solar Electric Boat respectively under certain conditions.

Criteria	Category	Base Case		Run 1		Run 2	
		Category Weight	Individual Weight	Category Weight	Individual Weight	Category Weight	Individual Weight
Capital Cost	Cost	34%	14%	35%	15%	25%	5%
Operational & Maintenance Cost	Cost		20%		20%		20%
Job Creation Opportunities	Economic	9%	3%	5%	1%	25%	8%
Reduce Diesel Importation	Economic		3%		3%		9%
Income Generation	Economic		3%		1%		8%
Health Benefits	Social	14%	5%	15%	6%	7%	2%
Energy Security	Social		7%		7%		4%
Capacity Building Potential	Social		2%		2%		1%
Reduction of CO_2 Emission	Environmental	19%	15%	15%	13%	19%	15%
Reduction of Environmental Degradation	Environmental		4%		2%		4%
Reduction of GHG Emission	Climate Related	24%	24%	30%	30%	24%	24%

Table 3.5 Changes in category weights feeding into sensitivity analysis of MCA results reported in Table 3.4 (Base Case)

Option	Weighted Score (Table 3.2)	Sensitivity Analysis	
		Run 1	Run 2
Biodiesel/internal combustion Technology	642	656	629
Blending Fossil with Biodiesel	586	581	597
Efficiency Wood Stove	706	712	702
Battery Electric Vehicle	663	672	714
Solar Electric Boat	661	671	707

Table 3.6 Sensitivity analysis of MCA findings on the energy-sector technology options

Chapter 4: Technology prioritization for Waste-to-Energy sector.

Domestic, agriculture, livestock and industry waste generated from consumption of natural capital, or production of manufacturing capital by units of production and consumption, often have potential effects on the environment and human health. Under particular circumstances, a fraction of specific waste might be reused for some purpose, but the generality of waste debris and matters are eventually disposed of. The fate of waste either being disposed or stored depends on the receiving/repository medium's capacity to break down and disperse waste into more environmentally benign concentrations or components through natural or biological means and transformation processes. For pragmatic reasons, the focus of the analysis that follows is on municipal solid waste (MSW) in the urban centers in Vanuatu, where management challenges linked to this waste disposal has reached epic proportions. Compared to homogenous waste from industrial and agricultural activities, it is noted that MSW comprises a complex assortment of wastes. Vanuatu is currently strengthening the local authorities and municipal planning authorities to enact and enforce land use planning laws and regulations (NSDP 2016 - 2030, 2016).

In Vanuatu, air quality protection is constrained by the absence of emission standards, inadequate technical assets, a weak workforce of scientific and engineering professionals, and economic agents' disengaged commitments to environmental education (SNC, 2014).

4.1 GHG emissions and existing technologies of waste sector

It is worth noting that emissions of carbon dioxide (CO_2), carbon monoxide (CO), and nitrous oxides (NOx) from waste burning, a low intensity form of incineration, is not included in the Vanuatu Second National Communication due to the lack of pertinent data (SNC, 2014).

GHG emissions from the waste sector in Vanuatu are estimated for the following sub sectors;

- Solid Waste Management and Disposal
- Domestic and Commercial Wastewater Handling

Waste management sector emissions have been estimated using data for two major cities Port Vila and Luganville, which are the main population centers of the country and respectively contain 20% and 6%of the total Vanuatu population. The remaining islands in Vanuatu are sparsely populated and are not included in the estimation due to lack of reliable data on waste generation. Data for waste sector has been largely sourced from published literature on MSW management, study on Port Vila urban development projects for Promotion of Regional Initiative Solid Waste Management (J-PRISM PROJECT REPORT, 2011) Department of Environmental Protection and Conservation data, and results from the population census (SNC, 2014).

Table 4.1 presents GHG emissions from waste disposal in Vanuatu for the year 2000. The emissions from waste sector were not estimated in 1994 under the first national communication. Emissions from this sector are a total of 12.21Gg CO_2, that is 2.1% of Vanuatu's total GHG emission. Solid waste disposal on land accounted for 51% of total waste related GHG emissions followed by domestic wastewater handling that accounts for the remaining 49%.

Source	1994 CO_2 emissions ($GgCO_2e$)	2000 CO_2 emissions ($GgCO_2e$)
Solid Waste Management and Disposal	NE	6.3
Domestic and Commercial Wastewater Handling	NE	5.92
Total GHG Emission	**-**	**12.21**

Table 4.1 CO_2 emissions from waste sector in Vanuatu ($GgCO_2e$) (SNC, 2014)

Table 4.2 presents emissions of different gases in the waste sector in Vanuatu. Methane is the most prominent gas emitted from the waste sector. Unmanaged solid waste and wastewater sites, lead to methane emissions. The methane emitted is estimated using the quantity of waste generated by the management of the waste, the proportion of carbon that may be transformed into methane, etc.

Source	CO_2	CH_4	N_2O	Total CO_2e
Solid Waste Management and Disposal	-	0.3	-	6.3
Domestic and Commercial Wastewater handling	-	0.12	0.11	5.92
Total GHG Emissions	**-**	**0.42**	**0.01**	**12.21**

Table 4.2 GHG Emissions from Waste Sector in Vanuatu (Gg) (SNC, 2014)

4.1.1 Solid Waste Management and Disposal

The key source of methane emissions from solid waste management and disposal include emissions from anaerobic decomposition of waste disposed at Bouffa landfill site, Port Vila and Luganville solid waste disposal site. Solid waste disposal constitutes 41% of GHG emissions from waste sector in Vanuatu and is one of the major concerns for the country. The problem of solid waste disposal is particularly pronounced in the urban areas as the waste from rural areas is generally scattered and does not pose much hazard. The Government of Vanuatu (GoV) is currently working with Japan International Corporation Agency (JICA) to improve the solid waste management situation in the country (SNC, 2014). The waste composition considered for the current inventory calculation is provided in Table 4.3.

Type	Waste Composition (%)
A. Paper and Textiles	4.6
B. Garden and park waste and other (non-food) organic putrescible	0.0
C. Food waste	72.6
D. Wood and Straw waste	0.0
E. Other	22.8

Table 4.3 Break-up of Waste Composition in Vanuatu (SNC, 2014)

4.1.2 Domestic and Commercial Waste Water Handling

The sanitation system in Vanuatu is largely decentralized, consisting of private managed household and commercial septic tanks for the collection of human waste. These allow the decomposition of the waste but the process leaves sludge as a by-product. Periodically the residual sludge is removed by private service providers through tankers and disposed of at a designated site. Emissions from this sub-sector constitutes 59% of GHG emissions from the waste sector and are quite significant. GoV, with support from ADB is currently considering developing a sludge treatment facility at Port Vila.

4.2 Decision context

In spite of their ubiquitous presence in all economic sectors, waste management activities and related challenges are acknowledged for the first time in countries national accounts in ISIC Revision 4 (UN , 2007). Reflecting its distributed character in Vanuatu, waste management is federatively carried out with some success by public institutions working at the intersection of public health, natural resources and environmental management, and land use policies.

In theory, supported by law, sitting and sizing of MSW disposal facilities depends on the composition and quantity if waste. Key decisions in this matter lies jointly with ministries responsible for public health, spatial planning, environmental quality and sub-national government. The Public Health Act (2006) requires the Ministry of Health (MoH) to undertake measures to ensure the sanitary disposal of waste, which action calls into play land acquisition procedures under relevant provisions of the Municipality Act (1980) and Physical Planning and Development Control Act (1986), and possibly the Land Acquisition and Compensation Act (2006), administered by subsidiary agencies of the Ministry of Lands (MoL). However, and allocation decisions cannot be finalized without subjecting potential facility locations to environment and social impact assessments as required under EIA Regulations (2002) in accordance with EIA Guidelines (2017). In this regard, decisions are jointly shaped by objectives and constraints articulated by technical institutions, regulatory institutions, administrative bodies, and communities within the vicinity of planned facilities, paying particular attention to probable consequences and risks of particular decisions and reversibility of those decisions. There are two waste disposal facilities in Port Vila and Luganville that has gone through an EIA process. Further synergies between the Public Health Act (2006) and Local Government Act (2002) strengthens Local Government Authorities' mandates in providing public services including waste management. In Port Vila, a fraction of solid waste from homes/businesses/offices are collected and disposed by Port Vila and Luganville municipalities using a small fleet of tractors and flatbed trucks inter-mingled with a few specialized waste-handling transport assets. Under an unwritten arrangement that provides convenience and relief to stakeholders, part of the solid waste that are not collected by municipal services is picked up by public health and other service providers and offloaded at the official dumpsites, for a mutually agreed fee. Illegal dumping on land is prohibited under the Environmental Management and Conservation Act (2002) and Public Health Act (2006). Although anti-littering regulations serve to restrain reckless tossers, they fail to eliminate a persistently litter-blighted landscape, attenuated in both the cities by street cleaning, and monthly voluntary cleanup exercises. Waste disposal facilities, implicitly owned and operated by Port Vila Municipal Council and the Luganville Municipal Council, currently function as open dumps. Municipalities do have security employees on site, and has a perimeter fence. The overwhelming bulk of MSW is allowed to build up and decay without any form of treatment. Deposited waste is often burnt in open fires and occasionally compacted to augment

dumpsite capacity and extend its service life, but monitoring of waste deposits for hazardous substances is not perceived to be any particular institution's responsibility. Long-term monitoring programmes or studies on environmental quality and human exposure to toxic substances emanating from waste treatment and disposal at the dumpsites in particular, do not exist either. In general, waste emplaced at disposal facilities is not inventoried. What little is known about municipal solid waste (MSW) composition and quantities comes from an audit done by the Japan International Corporation Agency (JICA) in 2011, for daily household waste in Port Vila shows a rate of 0.427 kg. A further study in 2014 established an average household daily waste generation in Luganville of 6.8 kg. Both studies shows that the majority of waste is organic of 72.6%, followed by plastic of 7% (J-PRISM PROJECT REPORT, 2011). Yet another study, taking account Tafea Province, established a per capita waste generation rate of approximately 0.5 kg a day on islands with populations of less than 5,000 and 0.8 kg a day on islands of more than 5,000. Likewise, waste burning by households in pits, barrels, or open fires constitutes significant health hazards. All facts considered, the most pressing challenges for solid waste management include inter alia the following:

- timely waste evacuation from least accessible built-up areas without proper storage facilities;
- developing a business model for the waste sector;
- attracting private sector investments to the waste sector;
- continual improvement of local and central government entities' capacities for waste collection, handling and management;
- environmental quality and public health policy integration, implementation, enforcement and monitoring on relevant sub-domains and;
- stimulation/reinforcement of positive behavioral changes towards waste minimization, waste separation, casual littering.

In a bid to protect its marine life and manage the problem of plastic litter and pollution around its islands, the Vanuatu government passed a legislation to ban the manufacture and importation of single use plastic bags in the country. The legislation, which came into effect on 1 February 2019, also extends to polystyrene takeaway food containers. Vanuatu has implemented long-term policies and strategies for the environment, pollution control, and waste management. Limited resource capacity and lack of access to government funding, however, are challenges that continue to hamper attempts to govern waste management. Improved domestic shipping services and infrastructures, as a result of the inter-island shipping support project, will offer significant opportunities to recover recyclable materials from the outer islands. Communities also will be able to participate in future CDSs and extended producer responsibility schemes. On the livestock waste front, it is thought that mitigation measures will be difficult without reducing animal numbers. It is envisaged GoV intends a planned cooperation with New Zealand and other nations interested in mitigating methane (CH_4) and associated emissions for ruminant and pasture management.

In the absence of a specific policy for the management of solid and liquid waste streams, the general drift of policy on waste management, informed by the Waste Management Act (2014), Public Health Act (2006), Public Health Regulations(1975), Environment Management and Conservation Act (2002), and Local Government Act (2002) is towards relocation of old dump sites to more appropriate locations and creation of landfills to better manage the ever-increasing solid waste streams generated especially in the two main centers in Vanuatu. However, the earlier part of this report and challenges enumerated above suggest that existing policy instruments still fall short of providing efficient multi-agent solutions to MSW management problems experienced in the country and in capturing a more nation-wide implementation.

Analogous to other mitigation sectors in this report, one of the key objectives of the TNA assessment in the waste sector is to identify and prioritize a limited set of technologies capable of providing long-term

solutions to MSW management problems in the municipal centers, and by extension, other growth poles in the rural remote areas in Vanuatu. Doubtless, proposed technological solutions can always be enhanced by effective community engagement, economic incentives and additional policy measures.

4.3 An overview of possible mitigation technology options in the waste Sector

Currently, waste disposal facilities within the municipal centers do not possess or employ any form of technology for purposeful waste treatment. As earlier mentioned, MSW deposited at officially designated dumpsites is allowed to build up and decay without any intervention. Waste that is not transferred to dumpsites but left on household premises is often burnt in pits, barrels, or open fires. This analysis proposes landfill technologies, anaerobic digesters and aerated pile composting as means of curbing fugitive methane emissions from large primitive dumpsites that do not incorporate safeguards for climate protection. In addition to groundwater protection, elimination of nuisance factors and minimization of health risks, sanitary landfill technology makes it possible to safely capture methane gas (from decomposing MSW) for use as an energy fuel, or, if not needed, oxidized using a flare system. However, emissions reduction largely depends on the efficiency of leakage control measures and methane capture sub-systems.

Anaerobic digester technology replicates waste decomposition processes under anaerobic conditions. Thus, the technology is able to reduce landfill spatial requirements, reduce methane ordinarily emitted from primitive dumpsites and produce recyclable products. Moreover, anaerobic digesters can be deployed on a variety of scales and significantly reduce transportation costs. Diverting compostable material from landfill to composting operations, as a way of avoiding CH_4 emissions, could potentially deliver GHG emission reductions of about 83% (Brown et al. 2008). Aerated static pile composting is particularly suited for facilities processing wet organic materials and large feedstock volumes.

4.4 Criteria and process of technology prioritization for the waste sector

A criterion set containing four (4) categories have been identified to gauge the relative merits of MSW management technologies earlier mentioned. Individual criteria reflect economic, social, environment and climate related impacts of technology deployment, as well as costs attributes mirroring the advantages of individual technologies. Context-specific definitions of selected criteria are shown in Table 4.4.

Criteria	Units	Category	Description
Capital Cost	USD	Cost	Expenditure required to purchase fixed assets
Operational & Maintenance Cost	USD		Recurrent expenditure on fuel/power for operations, maintenance and or leasing of equipment, and other service fees, made by owner/operator of productive technical assets

Job Creation Opportunities	Ordinal	Economic	New employment opportunities created by the introduction of a particular technology
Reduce Diesel Importation	tonnage	Economic	Reduction on the importation of the petroleum products as a result of using RE sources
Income Generation	USD	Economic	Prospect of driving a daily income for our Vanuatu population
Health Benefits	Ordinal	Social	Describes the condition of freedom from perils and injury. Exposure to health hazards may be acute or chronic
Capacity Building Potential	Ordinal	Social	Level of competence of national workforce required to sustain satisfactory operation of specific technologies
Reduction of CO_2 Emission	tCO_2/year	Environmental	Quantity of CO_2 gas emitted into the atmosphere from the respective introduced technology
Reduction of CH_4 Emission	tCO_2e/year	Environmental	Quantity of CH_4 gas emitted into the atmosphere from the respective introduced technology
Reduction of GHG Emission	t/year	Climate Related	Quantity of non-fluorinated greenhouse gases released into the atmosphere by a particular activity serving specific societal and economic functions

Table 4.4 Evaluation criteria for ranking waste-to-Energy technologies

4.5 Results of technology prioritization for the waste sector

Results presented in this section of the report derive from MCA procedural steps described in section 2.3. According to weighted scores and corresponding rank order of waste-to-energy technologies reported in Table 4.5, Manure Based Biogas Digester and Compact Biogas Digester for Urban Households technologies symbolize the two top prospective mitigation technologies identified in the waste-to-energy sector.

Sector	Technology Needs	Cost of Technology - 26%		Total Score	Benefits - 74%				Total Score	OVERALL (Total Cost x 26) + (Total Benefit x 74)	Ranking
		Capital	M&O		Economic	Social	Environmental	Climate Related			
		58%	42%	100%	24%	19%	34%	23%	100%	100%	
Waste -to-Energy	Mechanical Biological Treatment	1	4	5	17	12	28	21	78	59	4TH
	Manure Base Biogas Digestors	22	23	45	17	12	28	20	78	69	1ST
	Compact Biogas Digestor for Urban Households	24	21	45	18	12	26	20	76	68	2ND
	Anaerobic Digestion - Biogas Plant	27	24	51	18	12	26	18	72	67	3RD

Table 4.5 Results of multi-criteria analysis (MCA) matrix of waste-to-Energy sector technology options

To test the robustness of findings reported in Table 4.5, sensitivity analyses underpinned by selective and deliberative amendments of category and individual weight of economic and environmental criteria shown in Table 4.6 were conducted. In the first of two sensitivity analyses (i.e., Run 1), the category weight assigned to environmental criteria was about four times heftier than the corresponding value for economic criteria. In Run 2, category weights for environmental and economic criteria were roughly equal, whilst, costs, social and climate related criteria weights did not vary from their Base Case values in both analyses. MCA results based on these modified criteria weights yield the similar set of results in Table 4.6 (See Annex III for detailed computations) to that of the base case.

The MCA thus concludes and confirming that Manure Based Biogas digester is the top mitigation technologies in the waste-to-energy sector, under the current TNA and followed by Compact Biogas Digester for Urban Household and Anaerobic Digestion – Biogas Plant respectively under certain conditions.

Criteria	Category	Base Case		Run 1		Run 2	
		Category Weight	Individual Weight	Category Weight	Individual Weight	Category Weight	Individual Weight
Capital Cost	Cost	26%	15%	26%	15%	26%	15%
Operational & Maintenance Cost	Cost		11%		11%		11%
Job Creation Opportunities	Economic	18%	6%	9%	2%	21%	7%
Reduce Diesel Importation	Economic		10%		6%		11%
Income Generation	Economic		2%		1%		3%
Health Benefits	Social	14%	9%	14%	9%	14%	9%
Capacity Building Potential	Social		5%		5%		5%
Reduction of CO_2 Emission	Environmental	25%	2%	34%	4%	22%	2%
Reduction of CH_4 Emission	Environmental		23%		30%		20%
Reduction of GHG Emission	Climate Related	17%	17%	17%	17%	17%	17%

Table 4.6 Changes in criteria weights feeding into sensitivity analysis of MCA results reported in Table 4.5 (Base Case)

Option	Weighted Score (Table 4.5)	Sensitivity Analysis	
		Run 1	Run 2
Mechanical Biological Treatment	589	593	587
Manure Based Biogas Digesters	704	713	701
Compact Biogas Digester for Urban Households	680	683	680
Anaerobic Digestion-Biogas Plant	673	682	670

Table 4.7 Sensitivity analysis of MCA findings on waste sector technology options

Chapter 5: Summary and Conclusions

Selection of TNA mitigation sectors was an administrative decision consistent with national efforts to chart a trajectory for green development and to bolster the country's image of responsible global citizenship. Indeed, the energy and waste-to-energy sectors are among highest GHG emitting sectors, and constitute the focus of nascent mitigation policy and strategic priority actions. In this report, the consultant's task conceptually began with a situation analysis that zeroes in on pressing challenges and identifying gaps for each sector. Considering the raison that may impinge for the TNA however, challenges preeminently linked to the scale and trends of sectorial greenhouse gas (GHG) emissions are used to posit the inadequacy of existing technologies vis-à-vis emerging policies thereby triggering the discovery process of best available technologies for GHG emissions reduction in conformity with climate policy targets.

To date, relevant stakeholders drawn from the public, private and civil sectors formulated the Technical Working Group (TWG) for the mitigation aspects. They were brought together under the TNA National Committee and inclusive of the NAB and supported by the National Coordinator and consultants. They held deliberations on the subject matter so as to pool their ideas and information; filter out behavioral responses, regulatory and associative measures; synthesize and short-list technological options on which further information was to be developed through the formulation of Technology Factsheets in anticipation of preference ranking and prioritization using the multi criteria analytical methods.

In the process, stakeholders had to observe two important caveats: 1) proposed technologies for each sector needed to have a demonstrable function of GHG emissions reduction, and 2) proposed technologies needed at least three other alternatives with the same function for comparison. In order to make transparent decisions jointly, stakeholders also collectively identified criteria sets for each sector and assigned weights to each criterion based on consensus. In sum, almost nine criteria were identified across the two mitigation sectors, of which most were common to the two sectors. In general, the reduction of GHG and reduction of CH_4 criteria sets were larger than other sets by a factor of two, but stakeholders had and used opportunities to set, in their judgment, the desired balance between the costs, economic, social, environmental and climate related considerations by assigning and distributing group criteria weights accordingly. Due diligence was exercised to ensure that criteria sets had the requisite properties of effectiveness and cogency. Alternative technology options were evaluated using the additive model of multi-attribute utility theory, implemented in the TNA with an Excel worksheet programmed for such a task. Limiting factors of the analytical tool include the maximum number of criteria it could handle, and perhaps more significantly stakeholders' use of qualitative assessment of criteria scores where quantification would have been less biased.

With the facilitation of the consultant and the stakeholders, the multi-criteria analytical exercises confirmed: 1) efficiency wood stove and battery electric vehicle as the top two technologies in the TNA for the generation and transport sub-sector of the energy sector; and 2) manure based biogas digester and compact biogas digester for urban households as the top two technologies in the TNA for the waste-to-energy sector under most conditions.

The results obtained from the sensitivity analysis conforms that the efficiency wood stove and battery electric vehicle are the two top technologies similar to the results for the base case studies. The significance of this analysis is to decide if there may be discrepancies from the base case that is due to data uncertainties and difference in opinion. The results were presented and well received by the National TNA Committee

and including the TWG, copies were circulated thereof for their deliberation prior to the consultant's report dissemination.

At first glance, some of the results that surfaced from the multi-criteria analytical exercises appear counter-intuitive, notably the strong performance of the efficiency wood stove (energy sector) and manure based biogas digester (waste sector), vis-à-vis other technology that stakeholders are more familiar. Still, it is important to note that current rankings do not stop decision-makers from including biodiesel/internal combustion technology and compact anaerobic digestion- biogas plant in further technology assessments, or strategic deployment of specific technologies on different (management) scales. Although not materially affecting the results of the MCA, the case for bridging/reducing knowledge gaps and uncertainties in GHG emissions is a compelling one that requires urgent attention.

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Legal and Policy Instruments

National Laws

Forestry Act (2006)
Electricity Supply Act (2006)
Companies Act (2012)
Public Health Act (2006)
Municipality Act (1980)
Physical Planning and Development Control Act (1986)
Land Acquisition and Compensation Act (2006)
Local Government Act (2002)
Environmental Management and Conservation Act (2002)
Waste Management Act (2014)

National Regulations

EIA Regulation (2002)
Public Health Regulations (1975)

National Policies

Vanuatu National Energy Framework Policy (2015)
Vanuatu Climate Change and Disaster Risk Reduction Policy (2015)

International Treaties and Conventions

United Nations Framework Convention on Climate Change, UNFCCC (2018)

Annex I: Technology Fact Sheets for the selected technologies

Energy Technology Fact Sheets

Biodiesel/Internal Combustion Technology

1. Introduction

1.1. Historical

Due to the discovery of petroleum resources and their thermal and fuel characteristics or properties, electric generators driven by an engine based on internal combustion became popular just after the coal-based technologies - Thus, since the first decades of the 20th century, internal combustion and steam boiler started to play role in industrial development - This technology became more and more popular when fuels like ethanol, methane and biogas were found suitable for use in the Internal Combustion Engines.

1.2. Location of Resources

Up to now, petroleum products are imported to Vanuatu.

Alternatives of replacing oil/petroleum in IC engines by biofuels, biodiesel.

1.3. Variability of Resources

Fossil fuels are imported.

But biodiesel based among others on vegetal oils can be locally produced.

2. Brief Description

2.1. Conditions

Considering the option of replacing Gasoline/diesel by vegetable oils for driving engines generators, Production of vegetable oils and biofuels without any competition susceptible of affecting food security and agriculture sector

2.2. Characteristics

Fuels for a diesel engine: coconut oil, virgin coconut oil, nangae oil, tamanu oil (biodiesel).

Internal combustion results in rotation of the electrical generator in fact driven by a shaft output of the gasoline/diesel engine

Range of power capacity: 2 kW up to 20 MW

Electrical efficiency (up to 45%) is higher than the case of gas-fired combustion turbine (34%)

Capacity factor: 80% for the high capacity

Lifespan = 20 years for a range of 100 kW to 20 MW; 10 years for lower capacity

3. Applicability and Potentialities in Vanuatu.

3.1. Applicability

This technology is already operational at very small scale for demonstration at SOPV (Santo Oil Production Vanuatu Ltd) in Santo.

3.2. Potentialities

Limited due to low availability of feedstock for generating vegetable oils/biodiesel and Vanuatu government incentives to introducing policies and standard to drive the technology.

3.3. Limitations

Biodiesel fuel may face serious constraint such as natural disasters and farmers diverging into other agricultural cash crops.

4. Status of the Technology in Vanuatu

4.1. Local Production

Still at preliminary steps

4.2. Shared Power Plants

Not available

4.3. Projects

Not Available

5. Benefits to Development

5.1. Social

Energy security at different scales

5.2. Economic

Promotion of artisanal industry, nonagricultural incomes,

Option of hybrid systems with solar, wind and biomass

5.3. Environmental

Application of techniques for lowering the carbon emissions is a prerequisite condition for environmental benefit

In case of biodiesel fuel, mitigation and environmental requirements are fulfilled

6. Climate Change Mitigation Benefits

6.1. Reduction GHG Emissions

Optional biodiesel and blends diesel are expected to contribute in mitigation scenario

Its emission factor is quite low and hence it can result in an important rate of decreasing GHG emissions: 94% compared to the oil power plants

6.2. Low Carbon Credits

Development of options based on engine driven by biodiesel fuels is suitable for benefitting from the carbon credits

7. Financing Requirements and Costs

7.1. Private Sector Involvement

It is obvious that specific funds for supporting private sector interested in developing technologies based on biodiesel and on techniques of lowering carbon emissions can result in wider involvement of smaller companies

7.2. Capital Cost

For a 5 MW: about 600 USD/kW and 550 USD/kW respectively in years 2005 and 2015

7.3. Generating Costs

For the case of a 5 MW base-load, the generating cost (the sum of levelized capital cost, O & M costs and fuel cost) is 9.25 US cents/kWh and 17.7 US cents/kWh respectively in the years 2005 and 2015 with 38% for the O & M costs and 53% for the fuel cost

7.4. GHG Emissions

Emission factor of biodiesel: only about 43 kg/MWh

Replacing the gasoline and diesel fuels by the biodiesel can contribute in avoiding the below emissions;

Gasoline engine:

- Very small emission of SO_2
- High emission of CO_2: about up to 1900 kg/net MWh
- High emission of NO_x: about 1 400 mg/Nm3, while the standard acceptable NO_x is 460 mg/Nm3 in case of oil fuel (ESMAP, 2007)1

Diesel Engine:

- Up to 2 000 mg/Nm3 of NO_x
- Up to 4 700 mg/Nm3 of SO_x while 2000 mg/Nm3 are acceptable standard
- Up to 650 kg/net MWh of CO_2

Compared to above scenarios of diesel/gasoline, biodiesel and vegetal oils are renewable and very low-carbon fuels

7.5. Capability Building

Given that such a technology is requiring a large diffusion within both rural areas and urban cities, a high number of skilled technicians is recommended.

Blending Fossil Fuel with Biodiesel

1. Introduction

Biodiesel blend is a well-known technology worldwide it comprises blending of the vegetable oil especially the non-edible oil such as Tamanu oil with diesel fuel with different ratios to make a homogeneous blend that can be used in the diesel engines without any modification to the engine.

2. Technology characteristics

The main characteristic of this technology is that it does not need any modification to the original diesel engine (at specific blend ratio), and it is widely applicable in many countries. The technology also uses a renewable source of energy (tamanu oil) thus, emission sequestration state is attained

3. Country specific / applicability

The blend biodiesel technology can be applied in the country because of simplicity of the technology. The tamanu tree may be found in all the coastal areas in Vanuatu.

4. Status of technology in country

The technology is not applied yet but still under research.

5. Barriers

- Technical know- how especial in issues of converting to biodiesel and blending
- Lack of local values required to design a sustainable project
- There are no legislations that regulate the application of the technology.
- No investment in the technology yet.
- The cost may be higher.
- There is no enough awareness to use the technology.

6 Benefits to economic / social and environmental development

- Income generation to the producers.
- Create new jobs opportunities.
- Reduces pollution due to better combustibility.
- Contribute to the economic development of the country by saving hard currency for diesel importation.

7. Costs

The cost of using the bio fuel is not estimated yet in Vanuatu.

Efficiency Wood Stove

1. **Scale:**
   Small scale (applicable only in rural areas)

2. **Availability:**
   Short term

3. **Background/notes (short description of the technology option)**

Currently about 60% of families in rural areas use inefficient stoves. Intensive consumption of wood resources leads to deforestation and deficit of wood in some regions.

Figure 1: Efficient Stove often referred to as Rocket Stove[1]

Replacement of inefficient wood stoves with efficient ones (Figure 1) provides saving on wood fuel that can reduce deforestation. Efficient (80% efficiency) stoves require up to 4 times less wood logs per heating season. Leveled cost of energy in such stoves is the lowest. This creates an incentive for people not to switch to gas for heating and helps to avoid increase in CO_2 emissions. Additionally, this stove is more comfortable and safe that can reduce number of accidents. It burns wood more effectively, so the amount of dangerous particles that might be released is reduced.

4. **Implementation assumptions (how the technology will be implemented and diffused across the sub-sector)**

Information campaign is needed prior to implementation of efficient wood stoves to inform people of all benefits that the stove can bring. Additionally, incentive campaigns are needed, such as loan schemes to help people to finance purchase of efficient stoves and to assist producers of stoves, assist market development through providing training, tax incentive schemes, grants, etc.

[1] Energy Efficiency Wood Stove designed for Vanuatu by a certified designer and fabrication company

5. Reduction in GHG emissions:

GHG emission are expected to be reduced by 210,000 tCO_2/year.

6. Impact statements

Country social development priorities:

The project directly benefits individual households through installation of efficient stoves which will result in energy savings and lower expenditures, and contribute to national objectives to reduce poverty and deforestation.

Country economic development priorities:

Sustainable economic development, rural development. Implementation of efficient stoves can assist rural development through job creation, cost-saving for low-income rural residents, and prevent migration of people from villages.

Country environmental development priorities:

The major benefit of energy efficient wood stoves is reduction in consumption of wood. In addition, use of such stoves lead to cost-savings for the consumer over the life-cycle of the appliance, and improve local air quality

Other consideration and priorities such as market potential:

This technology is proven and available in Vanuatu. The market is undeveloped and production is low scale. The market can be considerably improved if enabling environment is in place (awareness, financial incentive, policy and regulation, etc.).

7. Costs (US$)

Capital costs

The capital cost of the traditional inefficient stove is about 20USD. The cost of the energy efficient stove is 30USD depending on the capacity. With the average lifetime of 10 years the annualized capital cost would be reduced.

Operational costs over 10 years:

This measure saves the fuel costs to consumers compared to current usage of inefficient stoves. Thus the effect on operation costs is positive.

Other costs over 10 years:

N/A

Battery Electric Vehicle

Technology characteristics	
Introduction	Battery Electric Vehicles (BEV) are propelled by an electric motor (or motors) powered by rechargeable battery packs. They derive all the power from the battery packs and thus have no internal combustion engine, fuel cell, or fuel tank (figure1).  **Figure 1. Battery Electric power train**[1]
Technology characteristics	BEV is a real medium to long-term solution to today's environmental and noise pollution issues in cities. Technological innovations now make it possible to mass market an electric vehicle at reasonable cost. In addition, changes in vehicle use make electric cars ideal for the majority of trips, with 87% of Europeans currently driving less than60 km a day. **Powertrain** There are three main technical differences between the powertrains of an ICE vehicle and a BEV; The internal combustion engine is substituted by an electric motor· The electric motor is powered by a controller· The controller in turn is connected to rechargeable batteries, by which it is powered **Battery energy storage** Battery energy capacity depends on vehicle requested mileage before re charging. As an example, the capacity of Renault Fluence Z.E.'s lithium-ion battery is 22kWh for185 km of autonomy, estimated on the New European Driving Cycle (NEDC). BEV batteries operate as energy storage device rather than power buffers as in conventional HEVs. Hence, BEVs typically require deeper battery charging and discharging cycles than conventional HEVs. Because the number of full cycles influences the battery life, this may be less than in traditional HEVs, which do not fully deplete their batteries. However, advanced battery technology is underdevelopment, particularly L-ion technology, promising greater energy densities by both mass and volume, and battery life expectancy is expected to increase.

[1] New Strategies for the massive introduction of electric vehicles in the operation and planning of smart power systems, 2018

Operation and Maintenance	Maintenance of BEV is simpler and cheaper than conventional thermal vehicles and HEVs. However, special technician trainings are required in order to perform adequate and safe maintenance and repair. BEVs may need a battery change over the vehicle life. Battery costs range between 800 USD/kWh and 1000 USD/kWh. The long-term battery costs are expected to be 300-500 USD/kWh by 2015.
Endorsement by experts	BEVs are endorsed by automotive manufacturers, in order to avoid paying excess emissions penalties.
Advantages	**Energy Efficiency:** Electric motors convert 75% of the chemical energy from the batteries to power the wheels, where internal combustion engines only convert 20-30% of the energy stored in gasoline on highway and less than 15% in urban area. **Environmentally Friendly:** BEVs emit no tailpipe pollutants, although the power plant producing the electricity may emit them. Electricity from nuclear, hydro, solar, or wind-powered plants causes no air pollutants. **Performance Benefits:** Electric motors provide quiet, smooth operation and stronger acceleration and require less maintenance than ICEs (estimated by Renault to be half of an equivalent ICE). **Reduce energy dependence:** Electricity is a domestic energy source. **Lower operating costs:** though BEVs will cost more than comparable conventional vehicles, operating costs will be less since electricity is much cheaper than gasoline, but it is unclear whether these savings will offset the vehicle cost when BEVs are first introduced. Incentives will play a decisive role in promoting BEVs
Disadvantages	**Driving range:** Most BEVs can only go about 160 km before recharging, where gasoline vehicles can go over 500 km before refueling. The low driving range of BEVs is mainly affected by the low specific energy of batteries compared to gasoline. **Recharge time:** Fully recharging the battery pack can take 4 to 8 hours. Even a "quick charge" to 80% capacity can take 30 min. However, the concept of quick drop in battery swap stations is under study. **Battery cost:** The large battery packs are expensive and may need to be replaced. To reduce the cost impact, some automotive manufacturers will be renting the batteries. As an example, Renault Fluence Z.E. will be sold in certain countries at prices similar to those of comparably diesel versions. In France, for example, prices will start at 20900 Euros (5000 Euros tax incentive deducted). Regarding the batteries, customers will have to subscribe to a monthly lease starting from 82 Euros including VAT (assistance included) to cover the battery at a level of 10000km/year. **Bulk and weight:** Battery packs are heavy and may take up considerable vehicle space.

	Recharging infrastructure: It is assumed that BEV recharging will take place overnight at home. However, residents of cities, apartments, dormitories, and townhouses do not have garages or driveways with available power outlets, and they might be less likely to buy BEVs unless recharging infrastructure is developed. Electrical outlets or charging stations near their places of residence, or in commercial or public parking lots or streets or workplaces are required for these potential users to gain the full advantage of BEVs. However, this infrastructure is not in place today and it will require investments by both the private and public sectors.
Capital Costs	
Additional cost to implement mitigation technology, compared to "business as usual"	Additional costs must be considered at two levels: **Batteries:** current lithium-ion batteries cost around 15000 Euros in BEV prototypes, and are expected to be reduced to 3000 USD by 2020. This requires the battery to be about 200-250 USD/kWh. **Recharging infrastructure:** in addition to the battery extra costs, there is a need for investment into the recharging infrastructure: – a simple recharging point at a private house or at an office costs about 1800 USD – a public recharging station, with the necessary electronics to make contact with the bank costs about 18000 USD. A considerable advantage of BEVs is that the operating costs are considerably lower than the costs of a conventional vehicle. However, it depends strongly on the fuel and electricity prices to decide whether it is worth to invest the additional costs compared to a conventional gasoline powered vehicle.
Development Impacts, Direct and Indirect Benefits	
Cost benefits	Figure 2 illustrates the operating cost savings of BEV, HEV and PHEV, compared to the average new vehicle fleet operating cost of 2005. The total vehicle kilometers traveled per year is estimated 10000km, and the electricity tariff 0.15 USD/kWh. · With the current fuel price trend (~1.2 USD/liter), savings of the Nissan Leaf are 600 USD/year, comparing to the average fuel consumption cost of the 2005 world new car fleet. · These savings can reach 750 USD/year with other BEVs presenting better vehicle efficiency. Note that additional savings are achieved by comparing to the average fuel consumption cost of the whole 2005 Lebanese car fleet, since the average consumption far exceeds the 2005 world average of 8.07 l/100km. Figure 3 highlights the influence of electricity tariff increase with a fuel price estimated at 1.2 USD/liter and 10000 km/year. As electricity tariff increases, operating cost saving of BEVs are lowered, and PHEVs and HEVs would become more beneficial. As an example, the plug-in Prius presents better cost savings than the Nissan Leaf as electricity tariff exceeds 0.2 USD/kWh; same for the HEV Prius as electricity tariff exceeds 0.25 USD/kWh.

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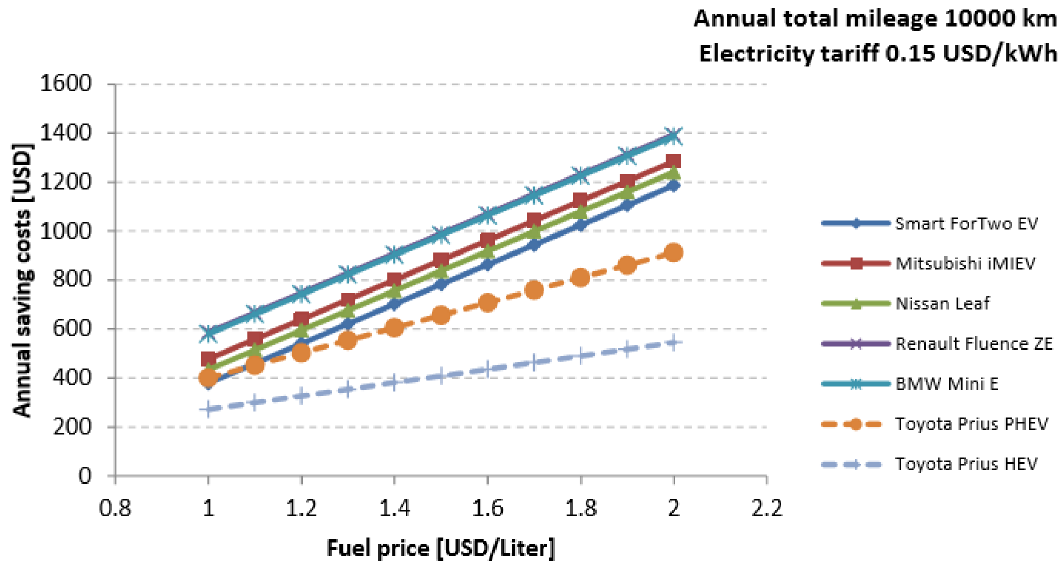

Figure 2. Annual operating saving costs of BEVs comparing to 2005 new fleet world average, as function of fuel price, with an annual mileage estimated 10000 km and electricity tariff of 0.15 USD/km.[2]

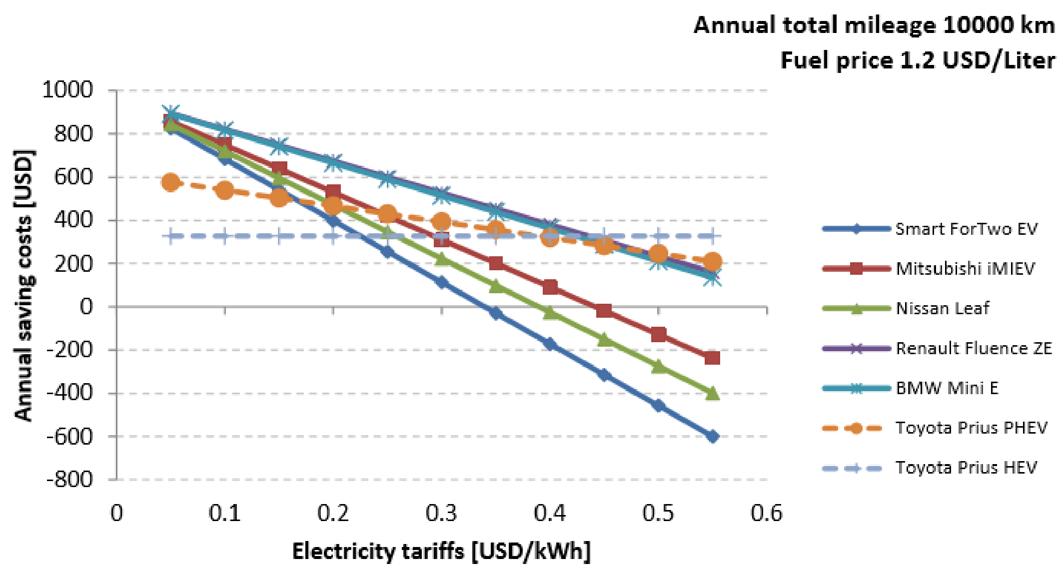

Figure 3. Annual operating saving costs of BEVs comparing to 2005 new fleet world average, as function of electricity tariffs, with an annual mileage estimated 10000 km and fuel price of 1.2 USD/liter[3].
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<td>Environmental benefits</td>
<td>GHG emissions reduction

Figure 4 outline the Well-to-Wheel (WTW) GHG emissions change of a typical BEV comparing to a 2005 mid-size conventional vehicle that consumes 10 l/100 km</td>
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[2] How expensive are electric vehicles?, 2013

[3] How expensive are electric vehicles?, 2013

- With the current electricity production mix, almost no GHG savings are observed with BEV (0-2%)
- However, 39.1 and 52.7% of GHG savings are observed with mitigation scenarios for 2030.

Pollutant emissions reduction

BEVs have no tailpipe emission of air pollutants, which means that they can substantially contribute to improving local air quality, especially in urban areas. The global improvement of the air quality however, is determined by the way the electricity used is produced. For example, Lebanon electricity mix of 2010, the power plants have substantial emissions of NOx and PM, as illustrated in Figure 5.

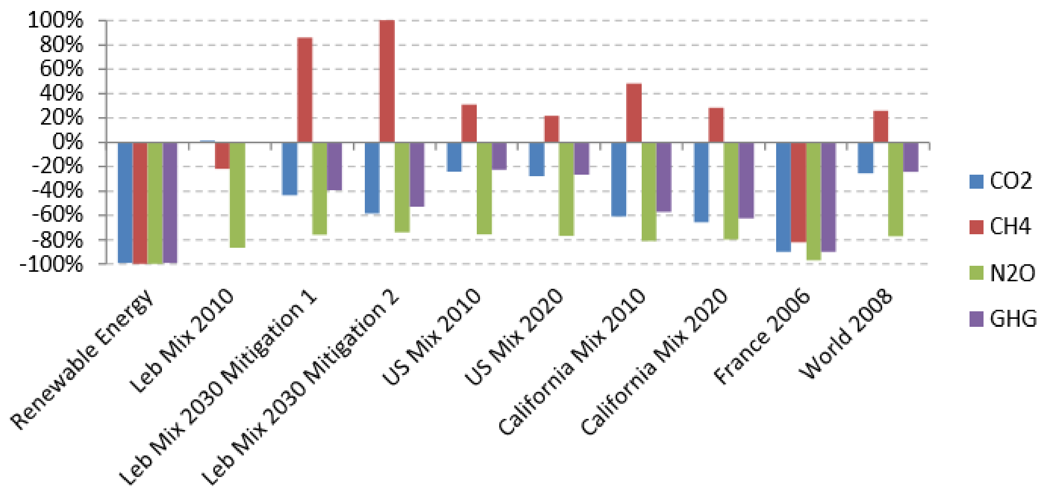

Figure 4. WTW GHG emissions change of BEV and HEV comparing to 2005 conventional vehicle[4].

[4] Environmental impacts of hybrid, plu-in hybrid, and battery electric vehicles - what can we learn from life cycle assessment?, 2014

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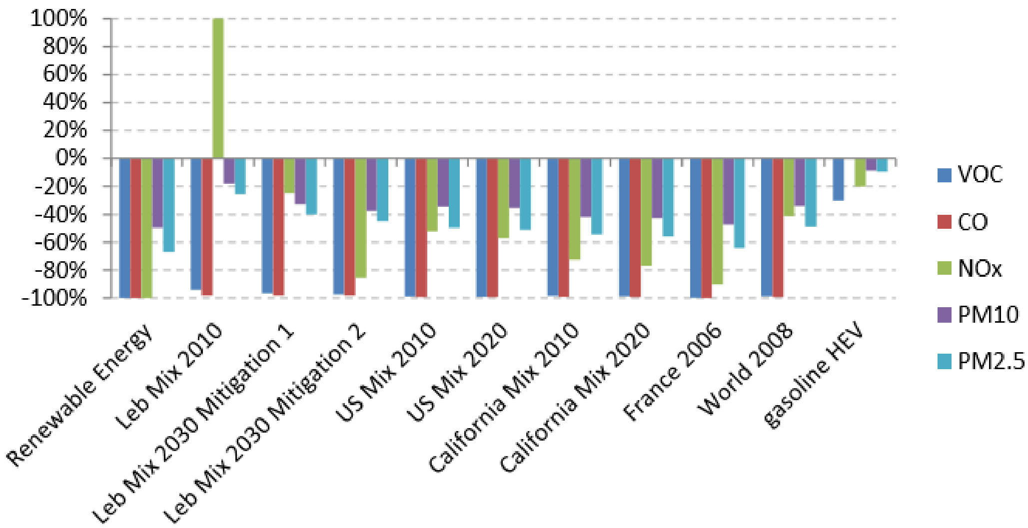
<tr><td></td><td>

Figure 5. WTW pollutants change of BEV and HEV comparing to 2005 conventional vehicle under urban driving conditions[5].</td></tr>
<tr><td colspan="2">Local context</td></tr>
<tr><td>Status</td><td>No BEV are available in the Vanuatu car fleet. BEVs are expected to be on the market worldwide in the medium term.</td></tr>
<tr><td>Timeframe</td><td>Medium long term implementation

BEVs implementation could not start immediately. A specific recharging infrastructure is requested. Many efforts are invested toward creating universal safe standard recharging stations. Different pilot projects are ongoing worldwide to ensure the well-operation of the BEV concept and learn lessons from driver's behaviors, charging time, charging frequency, charging location, daily driving mileage, mileage between charging events, and other influencing parameters. BEV concept is expected to become a mixture expandable technology on the short to medium terms.</td></tr>
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[5] Environmental impacts of hybrid, plu-in hybrid, and battery electric vehicles - what can we learn from life cycle assessment?, 2014

Solar Electric Boats

Technology characteristics	
Introduction	Solar boats, Figure 1 have zero emission, are virtually maintenance free as far as propulsion and energy systems are concerned, do not require any refueling, are free of noise, vibrations and oil leaks. The hull structure is built in aluminum, thus sturdy, easy to repair and 100% recycle. They harvest solar energy with their great area of solar panels installed on their roof. This energy is monitored and managed by an in-house developed energy management system and stored in large Li-Ion battery banks as a reserve for lesser solar irradiance or night time sailing.  **Figure 1. Solar Energy Boat**[6] The propulsion equipment of our boats comprises of ultra-high efficiency maintenance-free low direct voltage brushless motors, specifically designed low RPM and no cavitation propellers. The vessels have been designed from the ground up as solar boats, hence the hull shape and structure has been specifically optimized for this purpose, using super-computer technology and top hydrodynamicists to reach the highest possible efficiency. Although our vessels have proven to be self-contained and run perfectly only on solar power without any need for refueling, a backup/emergency generator can be installed on demand.
Implementation Assumptions	Relatively sunny area, operation profiles to match the performance of our vessels or design to be adapted to match operation profile, within the limit of the laws of physics. We train local manpower to be able to intervene on the vessels' electrical system. Systems are simple and low voltage thus do not require a high electrical expertise to be looked after but it is advised to have someone assigned to that task (typically the captain or a crew). Our vessels are designed to be single handed. For ferries, it is however advised to

[6]Energy and Propulsion Systems of Aquanima 40 E-Ferry

	have a captain and one or two crew to manage the berthing and the passengers. Wind/Sea condition in the area of operation should be on average below Force 4.
Implementation Barriers	Sufficient sun, suitable infrastructure (same jetties as any boats), operation profiles can be adapted to use a 100% eco-friendly vessel. During monsoon season, it is advised to have a plug in charger available at the dock/berth/jetty.
Reduction in GHG emission	Approximately 6 MT of CO_2 per month; 72 MT of CO_2 per annum
Life Time	Solar Electric Boats are designed for continuous operation for 20+ years with potential upgrades (software and hardware) to further their operation and life span of 40 years with solar panel and battery bank upgrade.
Market Potential	Maritime transport, goods and people. Between islands. Eco tourism platforms. Eco-Diving, Ocean watch without any impact on the environment.
Capita; Cost	Depending on the model (11.5 m and 12.5 m) would be around USD450,000 to USD600,000 for the purchase, delivery, on site crew and maintenance training, spare parts, warranty.
Operational and Maintenance cost	Estimated to be less than USD2,500 per annum (mainly hull cleaning and painting)
Cost of GHG Reduction	GHG are reduced at no cost

Waste-to-Energy Technology Fact Sheets

Mechanical Biological Treatment

1) Introduction

A mechanical biological treatment system is a waste processing facility that combines a waste sorting facility with biological treatment methods e.g. anaerobic digestion and/or composting. MBT plants are designed to process mixed household waste as well as commercial and industrial waste. Therefore, MBT is neither a single technology nor a complete solution, since it combines a wide range of techniques and processing operations (mechanical and biological) dictated by the market needs of the end products. Thus, MBT systems vary greatly in their complexity and functionality.

The products of the Mechanical Biological Treatment technology are:

- Recyclable materials such as metals, paper, plastics, glass etc.
- Unusable materials (inert materials) safely disposed to sanitary landfill
- Biogas (anaerobic digestion)
- Organic stabilized end product
- Refuse derived fuel **-** RDF (High calorific fraction).

MBT systems can form an integral part of a region's waste treatment infrastructure. These systems are typically integrated with curbside collection schemes. In the event that a derive fuel is produced as a by-product then a combustion facility would be required. Alternatively, MBT practices can diminish the need for home separation and curb side collection of recyclable elements of waste. This gives the ability of local authorities and councils to reduce the use of waste vehicles on the roads and keep recycling rates high (DEFRA, 2007).

A key advantage of MBT is that it can be configured to achieve several different aims. Some typical aims of MBT plants include the:

- Pre-treatment of waste going to landfill;
- Diversion of non-biodegradable and biodegradable MSW going to landfill through the mechanical sorting of MSW into materials for recycling and/or energy recovery as refuse derived fuel (RDF);
- Diversion of biodegradable MSW going to landfill by:
  o Reducing the dry mass of organic waste prior to landfill;
  o Reducing the biodegradability of organic waste prior to landfill;
- Stabilization into a compost-like output for use on land;
- Conversion into a combustible biogas for energy recovery; and/or
- Drying materials to produce a high calorific organic rich fraction for use as RDF

MBT plants may be configured in a variety of ways to achieve the required recycling, recovery and biodegradable municipal waste (BMW) diversion performance. Figure 1 illustrates configurations for MBT and highlights the components within each.

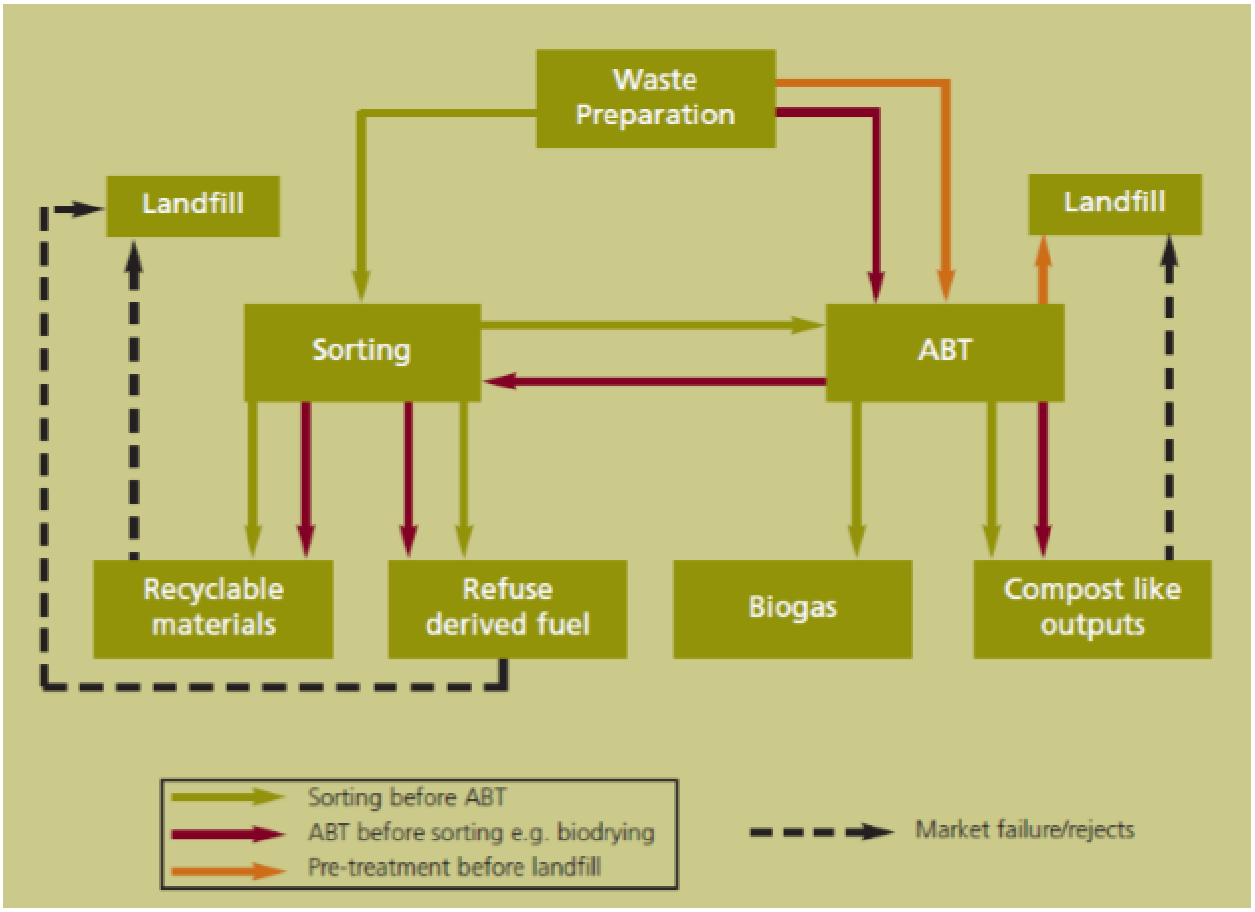


Figure 1. An illustration of the potential mechanical biological treatment options[7]

2) Technical requirements

A) Waste Preparation

MSW requires preparation before biological treatment or sorting of materials can be achieved. Initial waste preparation may take the form of simple removal of contrary objects, such as mattresses, carpets or other bulky wastes, which could cause problems with processing equipment downstream. Further mechanical waste preparation technique may be used which aim to prepare the materials for subsequent separation stage. The objective of these technique may be to split open refuse bags, thereby liberating the materials inside; or to shred and homogenize the waste into particle sizes suitable for a variety of separation processes, or subsequent biological treatment depending on the MBT process employed (DEFRA, 2007).

[7] Source, DEFRA, 2007

Ref	Technique	Principle	Key Concerns
A	Hammer Mill	Material significantly reduced in size by swinging steel hammers	Wear on Hammers, pulverising and 'loss' of glass / aggregates, exclusion of pressurised containers
B	Shredder	Rotating knives or hooks rotate at a slow speed with high torque. The shearing action tears or cuts most materials	Large, strong objects can physically damage, exclusion of pressurised containers
C	Rotating Drum	Material is lifted up the sides of a rotating drum and then dropped back into the centre. Uses gravity to tumble, mix, and homogenize the wastes. Dense, abrasive items such as glass or metal will help break down the softer materials, resulting in considerable size reduction of paper and other biodegradable materials	Gentle action – high moisture of feedstock can be a problem
D	Ball Mill	Rotating drum using heavy balls to break up or pulverise the waste	Wear on balls, pulverising and 'loss' of glass / aggregates
E	Wet Rotating Drum with Knives	Waste is wetted, forming heavy lumps which break against the knives when tumbled in the drum	Relatively low size reduction. Potential for damage from large contraries
F	Bag Splitter	A more gentle shredder used to split plastic bags whilst leaving the majority of the waste intact	Not size reduction, may be damaged by large strong objects

Table 1. Waste Preparation Techniques[8]

B) Waste Preparation

A common aspect of many MBT plant used for MSW management in the sorting of mixed waste into different fractions using mechanical means. The sorting of material may be achieved before or after biological treatment. No sorting is required if the objective of the MBT process is to pre-treat all the residual MSW to produce a stabilized output for disposal to landfill. Sorting the waste allows an MBT process to separate different materials which are suitable for different end use. Potential end uses include material recycling, biological treatment, energy recovery through the production of RDF, and landfill. A variety of different techniques can be employed, and most MBT facilities use a series of several different techniques in combination to achieve specific end use requirements for different materials. Separation technologies exploit varying properties of the different materials in the waste. These properties include the size and shape of different objects, their density, weight, magnetism, and electrical (DEFRA, 2007).

[8] Source, DEFRA, 2007

	Separation Technique	Separation Property	Materials targeted	Key Concerns
1	Trommels and Screens	Size	Oversize – paper, plastic Small – organics, glass, fines	Air containment and cleaning
2	Manual Separation	Visual examination	Plastics, contaminants, oversize	Ethics of role, Health & Safety issues
3	Magnetic Separation	Magnetic Properties	Ferrous metals	Proven technique
4	Eddy Current Separation	Electrical Conductivity	Non ferrous metals	Proven technique
5	Wet Separation Technology	Differential Densities	Floats - Plastics, organics Sinks - stones, glass	Produces wet waste streams
6	Air Classification	Weight	Light – plastics, paper Heavy – stones, glass	Air cleaning
7	Ballistic Separation	Density and Elasticity	Light – plastics, paper Heavy – stones, glass	Rates of throughput
8	Optical Separation	Diffraction	Specific plastic polymers	Rates of throughput

Table 2. Waste Separation Techniques[9]

C) Biological Treatment

The biological element of an MBT process can take place prior to or after mechanical sorting of the waste. In some processes all the residual MSW is biologically treated to produce a stabilized output for disposal landfill and no sorting is required. The biological processes used are either:

- Aerobic Bi-drying
- Aerobic In-vessel composting
- Anaerobic digestion

There are variety of different biological treatment techniques which are used in MBT plant. Table 3 below outlines the key categories of biological treatment (DEFRA, 2007).

[9] Source, DEFRA 2007

Options	Biological Treatment
I	Aerobic - Bio-drying / Biostabilisation: partial composting of the (usually) whole waste
II	Aerobic - In-Vessel Composting: may be used to either biostabilise the waste or process a segregated organic rich fraction
III	Anaerobic Digestion: used to process an segregated organic rich fraction

Table 3. Biological Treatment Options[10]

3) Status of the technology and its future market potential

The concept of MBT originated in Germany where it is an established waste treatment method. Regulatory restrictions on landfill space, the search for alternatives to incineration and increased costs of landfill disposal have been the major drivers for the development of these technologies. The largest European markets for established MBT plant include Germany, Austria, Italy, Switzerland and the Netherlands, with others such as the UK growing fast. Furthermore, other countries outside Europe are also using this technology.

Since the early 1990s, MBT processes have changed significantly, so today, numerous configurations of plant have developed, and these are provided by a variety of companies. There are over 70 MBT facilities in operation in Europe, with over 40 MBT facilities operating in Germany.

The Mechanical-Biological-Treatment (MBT) methodologies are more compatible with the demanding management requirements coming into effect in the E.U. and this explains the recent significant impetus on their development and use. By 2005, 80 plants with capacities ranging from 20.000 to 480.000 t/y and a cumulative capacity of 8.500.000 t/y had been constructed by 27 companies. By 2006, 123 plants are expected to be operating with an installed capacity of 13.000.000 t/y.

Most of these plants (and the largest) use Mechanical treatment and aerobic composting, followed by plants with mechanical treatment and anaerobic digestion and by a limited number of plants with aerobic drying followed by mechanical separation. The latter is only a pretreatment of MSW yielding a Solid Recovered Fuel (SRF).

Among the MBT alternatives, the mechanical treatment and aerobic composting is by far the most proven and economic technology. This is well suited for source separated biodegradable wastes, as is the case with most plants in Germany, as well as for unsegregated MSW, as is the case with all plants in Italy and Spain. This flexibility is important for Greece, since source separation is not currently practiced and, even if it is adopted, it will take several years to be widely implemented. The above features make the MBT technology with MRF and aerobic composting particularly suitable for Greece. An additional reason is the particular suitability of this technology for MSW wastes rich in biodegradable materials.

4) Contribution of the technology to protection of the environment

[10] Source, DEFRA, 2007

The primary goal of MBT is to minimize the environmental burdens of waste disposal by way of extensive stabilization. MBT can also help to recover valuable materials.

In the mechanical stage, the first step is to sort out the disturbants (e.g. large pieces of metal), unwanted materials and - optionally - recyclables. Next, the residual waste is prepared for biological treatment by comminution, mixing and, if necessary, moistening. Then comes the biological stage, the purpose of which is to effect extensive biological stabilization of the waste. There are two basic methods of biological decomposition: aerobic decomposition, i.e. decomposition in the presence of atmospheric oxygen, and anaerobic digestion, i.e. decomposition the absence of atmospheric oxygen, also referred to as fermenting.

The biological decomposition and conversion of organic matter by microorganisms (bacterial, protozoa, fungi) is a natural form of recycling that takes place in landfilled waste.

As biological decomposition progresses in a landfill, anaerobic digestion generates a combustible, explosive gas referred to as sanitary landfill gas. This gas escapes from the landfill and contributes to global warming and hence to climate degradation. Water seeping into the landfill, together with water contained in the waste, becomes contaminated by the products of decomposition and by the leaching out of pollutants. To keep the leachate and the landfill gas from escaping to the environment, the landfill needs to be sealed so that they can be collected and treated systematically (Dilewski, G. and Stretz, J. 2003).

Through the controlled decomposition of organic substances, mechanical-biological waste treatment substantially reduces both the gas and water emissions which would otherwise be subsequently generated at the landfill and the volume of the residual waste requiring emplacement. Waste containing a large share of biodegradable organic material is most suitable for such treatment. This is generally the case for household and commercial waste. However, contaminated waste, e.g. hazardous industrial waste; infectious waste, e.g. waste from hospitals and slaughterhouses; and constructionsite waste are inherently unsuitable. The suitability of industrial waste needs to be determined in advance, e.g. by analyzing, on a caseby-case basis, its pollutant concentrations and biomass fractions (Dilewski, G. and Stretz, J. 2003).

5) Climate

Human activities have caused a considerable increase in the greenhouse-gas contents of the earth's atmosphere. As a consequence, the earth's surface is expected to become gradually warmer over the coming decades (global waming), in turn giving rise to attendant climatic changes. The greenhouse gases that are contributing most to the greenhouse effect are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide or laughing gas (N_2O). All three of them occur internal in connection with waste disposal.

Most of the greenhouse effect attributable to waste management can be ascribed to methane, which is produced by the anaerobic digestion of biodegradable waste in landfills. Approximately one-third of all anthropogenic CH_4 emissions within the EU derive from that source. By contrast, only 1 % of the N_2O emissions and less than 0.5 % of the CO_2 emissions can be traced to landfilled waste. Hence, reducing CH_4 emissions from landfills holds the greatest potential for reducing greenhouse gas emissions in the waste-management context. MBT allows methane generation to be greatly reduced. Well-ventilated, long-term aerobic decomposition emits only about 1 % of the methane generated by a comparably sized landfill full of untreated waste. Anaerobic processes offer certain advantages over aerobic processes with regard to climatic effects because the biogas they produce contains a large proportion of methane and is therefore a useful energy vehicle, and they produce only small amounts of exhaust air, i.e. off-gas, that can scrubbed before it is released to the atmosphere.

The net greenhouse gas flux from MBT (Smith et al, 2001):

- The net greenhouse gas flux -403 kg CO2 eq/tonne of MSW (high stabilize +landfill)
- The net greenhouse gas flux -329 kg CO2 eq/tonne of MSW (less stabilize +landfill)
- The net greenhouse gas flux -137 kg CO2 eq/tonne of MSW (high stabilize +landfill)

6) Financial requirements and costs

There are a wide range of costs dependent upon the complexity of the technology and the degree of mechanization and automation employed (DEFRA, 2007). The table below shown indicative capital expenditure (Capex) and operational expenditure (Opex) for aerobic and anaerobic MBT facilities. These costs provided are predominantly based on European examples. Cost in the Indonesia will involve different site specific issues as permitting labor, emission controls and other requirements.

	Aerobic processes		AD processes	
Capacity	Capex £/t/yr	Opex £/t	Capex £/t/yr	Opex £/t
<50,000	70 – 150	up to 140	160 – 420	From 23
>50,000	28 – 225	20 – 69	107 – 278	16 – 69

Table 4. Typical MBT cost using aerobic and anaerobic processes[11]

[11] Source, DEFRA, 2007

Manure Based Biogas Digester

Introduction
Manure-based biogas digesters are animal manure treatment and fermentation system which includes fermentation tanks, manure input and fermentation via anaerobic environment. The methane concentration of biogas is around 60%, so the recovery and utilisation of biogas from digested slurry in a biogas digester will reduce CH_4 emissions from the manure. In addition, the biogas can be used to provide electricity, d energy and reduce CO_2 emissions from fossil fuel (coal) displaced by biogas.
Technology Characteristics

A biogas digester is usually composed of six parts: fermentation chamber, gas storage, inlet tube, outlet chamber, removable or sealed cover, and a gas pipeline (see in Figure 1).

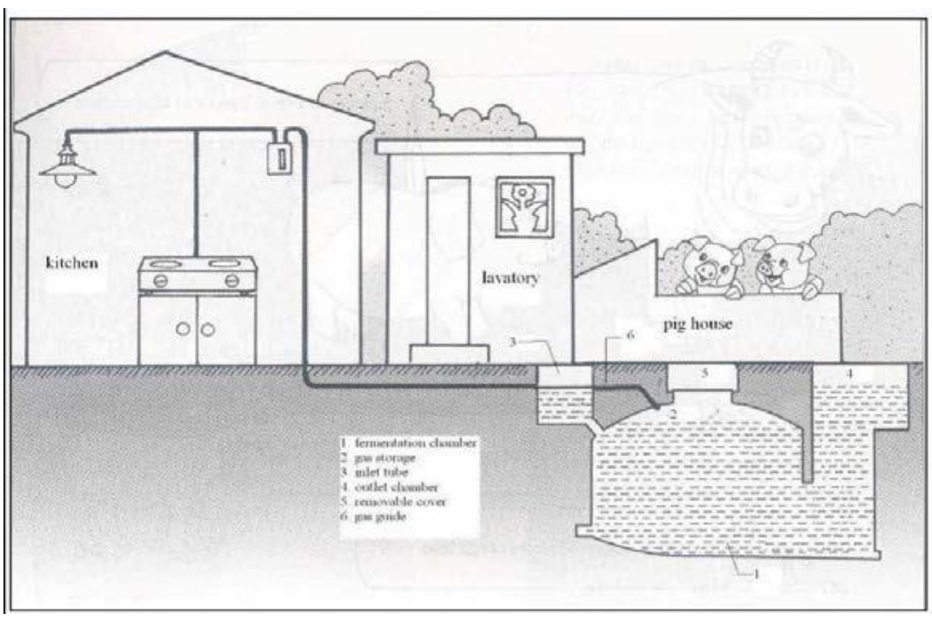


Figure 1. Example of a schematic of 'Three in One' combination of household biogas digesters[12]

The mechanics of biogas generation is similar to practice elsewhere which can be described as follows:

- The captured gas is stored in the upper part of the digester tank (gas storage area), which is constructed as an arc ship. The generation of biogas will gradually increase the pressure in the stored area. When the volume of the captured gas is larger than the amount consumed, the pressure in the gas storage will increase and slurry will be pushed into the outlet chamber. If the gas consumed exceeds gas availability, the slurry level drops and the fermented slurry flows back into fermentation chamber.

[12] Improved Design of Anaerobic Digesters for Household Biogas Prodcution in Indonesia: One Cow, One Digester, and One Hour of Cooking per Day, 2014

- The placement of the digester tank (underground fermentation) keeps the temperature in the tank relatively stable ensuring that the slurry can be fermented at adequate temperatures throughout the year without requiring additional heating.

- The bottom of the digester inclines from the material-feeding inlet to the material-outlet, allowing free flow of the slurry.
- The digester has been designed to allow the effluent to be removed without breaking the gas seal, taking the effluent liquid out through the outlet chamber. As pointed out in technology definition biogas fermentation is a process in which certain bacteria decompose organic matter to produce methane. In order to obtain normal biogas fermentation and a fairly high gas yield, it is necessary to ensure the basic conditions required by the methane bacteria are met for them to carry out normal vital activity (including growth, development, multiplication, catabolism etc.).

1) Strict anaerobic environment

Microbes that play a major role in biogas fermentation are all strict anaerobes. In an aerobic environment, the decomposition of organic matter produces CO_2, however, in an anaerobic environment, it results in CH_4. A strict anaerobic environment is a vital factor in biogas fermentation. Therefore, it is essential to build a well- sealed, air-tight biogas digester (anaerobic digester) to ensure a strictly anaerobic environment for artificial biogas production and effective storage of the gas to prevent leakage or escape .

2) Sufficient and suitable raw materials for fermentation

Sufficient raw materials for biogas fermentation constitute the material basis for biogas production. The nutrients that methane bacteria draw from the raw materials are carbon (in the form of carbohydrates),nitrogen (such as found in protein, nitrite, and ammonium), inorganic salts, etc. Carbon provides energy, and nitrogen is used in the formation of cells. Biogas bacteria require a suitable carbon-nitrogen ratio (C:N).The suitable carbon-nitrogen ratio for rural biogas digesters should be 25~30:1. The carbon-nitrogen ratio changes with different raw materials, and one must bear that fact in mind when choosing a mix of raw materials for the digester.

3) Appropriate dry matter concentration

The appropriate dry matter concentration in the raw materials for biogas fermentation in rural areas should be 7%~9%. Within this range, a low concentration of raw materials may be selected in summer, while in winter a higher value is preferred.

4) Appropriate fermentation temperature

Biogas fermentation rates depend greatly on the temperature of the fermenting liquid in the digester. Temperature directly affects the digestion rate of the raw materials and gas yield. Biogas fermentation takes place within a wide temperature range (XuZengfu, 1981). The higher the temperature, the quicker the digestion of the raw materials will be, and the gas production rate will also become higher. Based on real fermentation conditions, we have identified the following three temperature ranges for fermentation:

- High temperature fermentation: 47°C~55°C
- Medium temperature fermentation: 35°C ~38°C
    - Normal temperature fermentation: ambient air temperature of the four seasons. Selecting the temperature range for biogas fermentation depends on the type, sources, and quantities of raw materials; the purposes and requirements of processing organic wastes; and their economic value. Most household biogas digesters are normal temperature fermentation.

5) Appropriate pH Value The pH value of the fermenting liquid has an important impact on the biological activity of biogas bacteria. Normal biogas fermentation requires the pH value to be between 7 and 8. During the normal process of biogas fermentation in a rural digester, the pH value undergoes a naturally balanced process, in which it first drops from a high value to a low value, then rises again until it almost becomes a constant. This process is closely related to the dynamic balance of three periods of biogas fermentation. After feeding the biogas digester, the time that the pH value takes to reach its normal level depends on the temperature and the kinds and amounts of raw materials that are fed in.
Country Specific applicability and potential
Vanuatu had greater potential to adopting this technology and may be applied to residence that has septic tanks buried under and close to the house. All residence in the urban or rural areas do have existing tanks that can be utilized for this purpose.
Status of technology in the country
Few Vanuatu homes has tried to erect such system but was not sustained due to their designs.
Benefits to development
The Manure Based Digester will definitely reduce waste that has to be transported out of site and be dumped on the designated area allocated by the municipal council.

Compact Biogas Digester for Urban Households

Introduction
The conventional biogas digesters occupy too large to be accommodated in an urban household. More over the amount of conventional feed materials such as cow dung or perished vegetable materials are difficult to find in an urban area. An urban housewife would not like to handle such materials in such large volumes to generate biogas for cooking. On the other hand, use of a solid fuel such as fuel wood is very cumbersome for an urban household. Even the best solid fuel stove developed and sold is not elegant enough to satisfy a modern urban housewife. The lighting up and controlling the heat outputs of such stoves are very tedious. For these reasons, LPG is the most preferred fuel for household cooking, despite the very high cost of LPG.
Technology Characteristics
The volume of this digester is 1.5 m3. It essentially consists of two plastic tanks. The larger tank acts as the digester vessel, while the smaller tank acts as the gas holder. The smaller tank is inserted into the larger tank with the mouth downwards. See Figure 1. Capital cost including all materials and labour and a gas burner is US$ 500 (58,200 VUV). 2 kg of starchy material is needed as the feed stock to produce 500 g of methane required to cook a day's meals for a family. If proper feed materials are used, the retention time in the digester is expected to be 72 hours. Figure 1 shows the biogas reactor.  **Figure 1. Biogas Reactor[13].** As starchy materials may be difficult to or too expensive to obtain, studies were conducted and trials on various materials to determine the output of biogas generation. This research study revealed that leaves of Gliricidia is the most effective material to be used as the feed material for biogas production. We may therefore propose to demonstrate the feasibility of using Gliricidia leaves as the primary feed material along with food wastes generated in households in the digesters to generate adequate biogas for cooking purposes. It is also proposed to develop a suitable technology to process Gliricidia leaves and establish a supply chain to facilitate urban housewives to acces such materials at competitive prices.

[13] http://www.arti-india.org/index2.php?option=com_content&do_pdf=1&id=45

Figure 2 shows the use of biogas for cooking.

Figure 2: Use of Biogas for Cooking[14]

Country Specific applicability

Vanuatu's economy is growing at 3% in 2019 and forecasted at 2.8% in 2020. The annual per capita income is at 2846US$. This value is expected to increase in the next couple of years. With such growth rate, the demand for LPG as a fuel for household cooking is increasing. LPG is an elegant fuel. It can be lit instantaneously. The heat output of an LPG stove could be varied from zero to full rated value with in a fraction of a second. Combustion of LPG does not produce any smoke. As LPG is free of sulfur, SO_x emissions are nil. Hence every housewife who could afford the initial cost of switching from fuel wood to LPG and the operating cost of LPG has no hesitation in indulging in such changeover. The growth of LPG in the household and commercial sectors is remarkable. In fact, not only the urban sector, households in the semi-urban sector too are gradually switching from fuel wood to LPG.

Even the most elegant solid fuel based cooking stoves would not satisfy the requirements of a contemporary housewife in Vanuatu. On the other hand, LPG is either imported in its final form or is produced from imported petroleum fuels. The drain on foreign exchange resulting from this purchase is very severe. Hence there is an urgent need to develop an acceptable alternative to LPG.

Hence the challenge is many fold. Firstly, we need to develop a hardware which could be constructed in an urban household. Secondly, the device/ technology should be simple to operate by a non-technical housewife. Thirdly, there should be an established supply chain to deliver or make it easily purchasable for any consumable item required to operate the proposed system. And lastly, it should be cheaper than LPG.

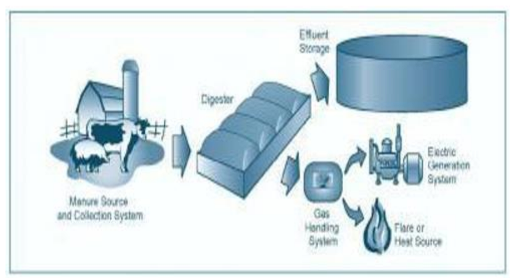
The proposed system meets all these requirements. ARTI of Pune, India has developed a simple reasonably priced hardware to produce biogas od adequate quantity for a household. University of Moratuwa (UOM) has identified a suitable material which could be used as the feed stock to generate the required amount of gas. UOM has found that Gliricidia leaves are an acceptable feed material for biogas production.

However, there is a need to organize the supply chain to provide regular supply of Gliricidia leaves to in a readily usable form to the households. This has not been done yet. R&D is needed to accomplish this task. Indications are that this could be achieved in the near future.

[14] GIZ HERA Cooking Energy Compendium

Status of technology in the country
Few Vanuatu homes has tried to erect such system but was not sustained due to their designs.
Benefits to development
The Manure Based Digester will definitely reduce waste that has to be transported out of site and be dumped on the designated area allocated by the municipal council.

Anaerobic Digester (Biogas Plants)

Introduction
The anaerobic digestion is decomposition of biodegradable material by micro-organisms in the absence of oxygen. Anaerobic digestion is often used for industrial or domestic purposes to manage waste streams. Three principal products are produced through the process of anaerobic digestion. First, the process produces a biogas, consisting mainly of CH_4 and CO_2, which can be used for energy production. Second, the process results in a nutrient -rich digestate. Finally, the process results in liquid liquor that can be used as a fertilizer**.**
Technology Characteristics
As illustrated in Figure 8, a biogas facility with an anaerobic digester has four main components: 1. A manure (or waste-water) collection system. 2. The anaerobic digester: The production of the biogas consisting of methane and CO_2 occurs here. 3. A biogas handling system: A device that puts the biogas to use such as a combined heat and power plant. There are two basic types of digesters: batch and continuous.  **Figure 8: Main components of anaerobic digester facility** **SOURCE: EPA, 2002** **Batch-type digesters** are the simplest to build. Their operation consists of loading the digester with organic materials and allowing it to digest. The retention time depends on temperature and other factors. Once the digestion is complete, the effluent is removed and the process is repeated. In a continuous digester, organic material is constantly or regularly fed into the digester. The material moves through the digester either mechanically or by the force of the new feed pushing out digested material. **Continuous digesters** produce biogas without the interruption of loading material and unloading effluent. They may be better suited for large-scale operations. Proper design, operation, and maintenance of continuous digesters produce a steady and predictable supply of usable biogas. Many different variations of anaerobic digesters exist. The three most common variations are: the covered lagoon, the completely mixed reactor, the plug flow anaerobic digester and the induced blanket reactor.
Country Specific applicability and potential

The recovery of biogas through anaerobic digestion systems is a proven technology. Both in the United States and the European Union the anaerobic digestion of animal waste streams has been used extensively. The technology has great potential in Vanuatu too.

Status of technology in the country

The Vanuatu Biogas Project was launched in 2016 with the aim of building capacity in the public and private sectors to construct and operate 3 biogas plants in two project areas, Onesua Presbyterian College on Efate and Vanuatu Agriculture College on Santo from February 2016 to June 2019 on a pilot basis.

Benefits to economic, social and environmental development

The sector in which the technology is mainly applied is the agriculture sector, which is the mainstay of Vanuatu economy. Projects using anaerobic digestion technology improve the viability of these rural enterprises. The technology is therefore capable of strengthening the backbone of the economy and subsequently improves social development.

The current waste stabilization technique most often used at farms and industrial locations is the open anaerobic lagoon. Next to emitting methane directly into the atmosphere, this technique has several disadvantages that would be solved by the introduction of anaerobic digester facility. The workplace at an open lagoon system is unhealthy and unpleasant to work at. Local air quality at such facilities is poor and strong odour is produced by the open lagoon. The implementation of an anaerobic digester facility makes the workplace safer and healthier. Local air quality is significantly improved.

Several economic development benefits arise from the energy production of the technology.

National energy self-sufficiency is increased due to the local energy production. This also would reduce Vanuatu's dependency on other countries for fossil fuel imports, which in turn would lead to an improved economic balance sheet of the country and a higher level of energy security.

Large amounts of animal waste can create serious environmental concerns. When animal manure enters rivers, streams or groundwater supplies it can have environmentally detrimental effects. In addition, decomposing manure causes air quality concerns associated with ammonia emissions, and the contribution of methane emissions to global climate change. The implementation of an anaerobic digestion offers a number of air and water quality benefits.

Digester systems isolate and destroy disease causing organisms that might otherwise enter surface waters and pose a risk to animal and human health. Moreover, anaerobic digesters help protect ground water. Synthetic liners provide a high level of groundwater protection for manure management systems (EPA,

2002). The concrete or steel in plug flow and complete mix digesters also effectively prevent untreated manure from reaching the ground water.

Biological treatment of waste, such as composting and anaerobic digestion reduces volume of waste and therefore the lowers landfill requirements. Recycling of the residual solids as fertilizer further reduces waste volume.

Climate Change Mitigation Benefits

The main climate related benefit of this technology is the prevention of methane emissions associated with conventional manure management practices. In addition, the energy produced by the biogas facility offsets energy derived from fossil fuels. Therefore, anaerobic digesters with a biogas recovery system can help reduce overall quantities of CO_2. For example, the Colorado based pork farm with an anaerobic digester was able to reduce fossil fuel derived CO_2 emissions by 409 tons per year and methane emissions on a CO_2eq basis by at least 3022 tons per year.

Costs

The similar system constructed in the U.S. can have average costs of US$ 470 per cow. More generally, anaerobic systems for digestion, solids processing, and generation are expected to cost US$ 500 to US$ 800 per cow in the U.S.

Table 28 illustrates the capital and operating costs of European digestion systems.

	Large 1 MW 5000 Cow Facility	**Small 25kW 125 Cow Farm**
Capital Cost	US$ 9.113.000	US$ 500.000
Annual Operating Cost	US$ 643.000	US$ 8.800
Power Sale $/kW	US$ 0.06	US$ 0.06
Heat Sales $/kW	US$ 0.01	US$ 0.01
Solid SALES	US$ 700.000	US$ 20.000

Table 28: Operating and Capital costs of European Digester Systems[15]

[15] https://energypedia.info/images/8/88/Costs_of_Anaerobic_Digestion.pdf

Annex II: List of stakeholders involved and their contacts

Table II.1 Contacts

Name	Affiliation	Designation	Email
Mr. Misel Sisi	Department of Energy	Manager, Energy Security Unit	msisi@vanuatu.gov.vu
Mr. Nelson Kalo	Department of Climate Change	Senior Mitigating Officer	nekalo@vanuatu.gov.vu
Mr. Johnlyn Regenvanu	Department of Woman Affairs	Protection officer	jregenvanu@vanuatu.gov.vu
Mrs Rolenas Tavue Baereleo	Department of Environmental Protection and Conservation	Principal Officer (Biodiversity and Conservation)	rbaereleo@vanuatu.gov.vu
Mr. Peter Iesul	Department of Agriculture and Rural Development	Principal Scientific Officer - South	piesul@vanuatu.gov.vu
Mrs.Phyllis Kamasteia	Department of Forestry	Mapping Officer	pkamasteia@vanuatu.gov.vu
Mr.Jimmy Lava	Department of Tertiary Education	coordinator	lajimmy@vanuatu.gov.vu
Mr. Jean Christophe Enock	Pacific Petroleum Ltd	Airport Terminal Supervisor	Jeanchristophe_enoch@pacificenergy.com
Mr. Leith Veremaito	Department of Local Authority	Director	lveremaito@vanuatu.gov.vu
Willy Missack	Oxfam Vanuatu	Climate Change Officer	wmissack@oxfam.org.au

Annex III: Detailed MCA computations

Table III.1 Explanation of MCA Results

Criteria Options	1	2	3	.	.	.	.	n	Weighted Scores of each options
Units Preferred value									
Weight	a_1	a_2	a_3	.	.	.	.	a_n	
Option 1	x_1	x_2	x_3					x_n	$\Sigma a_i x_i$
Option 2	y_1	y_2	y_3					y_n	$\Sigma a_i y_i$
Option 3	z_i	z_2	z_3					z_n	$\Sigma a_i z_i$

Where: i = 1, 2, 3, …….n are numbers assigned to assessment criteria: a_i is the i-th criteria weight; x_i, y_i, z_i are scaled performance scores (0 to 10) of options 1, 2 and 3, with respect to the i-th criteria; and $\Sigma a_i x_i$, $\Sigma a_i y_i$, $\Sigma a_i z_i$ are weighted scores (0 to 10) computed for technology options 1, 2 and 3 respectively.

Table III.2 Energy Sector; Power Generation and Land Transport subsector criteria weights and technology option scores – Base Case

Criteria Options	Costs		Economic			Social			Environmental		Climate Related	Weighted Scores of each option
	Capital Costs	**Operational & Maintenance Costs**	**Job Creation Opportunities**	**Reduce Diesel Importation**	**Income Generation**	**Health Benefits**	**Energy Security**	**Capacity Building Potential**	**Reduction of CO_2 Emission**	**Reduction of Environmental Degradation**	**Reduction of GHG Emission**	
Units	USD	USD	Ordinal	Ton/year	USD	Ordinal	Ordinal	Ordinal	t/CO_2/year	ha	t/CO_2e/year	
Preferred Value	Low	Low	High	High	High	High	High	High	High	High	High	
Weight	14%	20%	3%	3%	3%	5%	7%	2%	15%	4%	24%	
Biodiesel/Internal Combustion Technology	94.5	90	13.5	18.75	19.5	28.75	54.25	9.5	97.5	24	192	642.25
Blending Fossil with Biodiesel	56	95	17.25	17.25	18.75	23.75	64.75	11.5	116.25	22	144	586.5
Efficiency Wood Stove	84	120	20.25	18.75	21	41.25	59.5	13	120	23	186	706.75
Battery Electric Vehicle	21	95	15.75	26.25	20.25	36.25	45.5	13	131.25	31	228	663.25
Solar Electric Boat	24.5	90	14.25	26.25	19.5	32.5	50.75	12.5	131.25	32	228	661.5

Table III.3 Energy Sector, generation and land transport subsector criteria weights and technology option scores – Sensitivity Analysis 1 of 2

Criteria Options	Costs		Economic			Social			Environmental		Climate Related	Weighted Scores of each option
	Capital Costs	Operational & Maintenance Costs	Job Creation Opportunities	Reduce Diesel Importation	Income Generation	Health Benefits	Energy Security	Capacity Building Potential	Reduction of CO_2 Emission	Reduction of Environmental Degradation	Reduction of GHG Emission	
Units	USD	USD	Ordinal	Ton/year	USD	Ordinal	Ordinal	Ordinal	t/CO_2 e/year	ha	t/CO_2 e/year	
Preferred Value	Low	Low	High	High	High	High	High	High	High	High	High	
Weight	15%	20%	1%	3%	1%	6%	7%	2%	13%	2%	30%	
Biodiesel/Internal Combustion Technology	101.25	90	4.5	18.75	6.5	34.5	54.25	9.5	84.5	12	240	655.75
Blending Fossil with Biodiesel	60	95	5.75	17.25	6.25	28.5	64.75	11.5	100.75	11	180	580.75
Efficiency Wood Stove	90	120	6.75	18.75	7	49.5	59.5	13	104	11.5	232.5	712.5
Battery Electric Vehicle	22.5	95	5.25	26.25	6.75	43.5	45.5	13	113.75	15.5	285	672
Solar Electric Boat	26.25	90	4.75	26.25	6.5	39	50.75	12.5	113.75	16	285	670.75

Table III.4 Energy Sector, generation and land transport subsector criteria weights and technology option scores – Sensitivity Analysis 2 of 2

Criteria Options	Costs		Economic			Social			Environmental		Climate Related	Weighted Scores of each option
	Capital Costs	Operational & Maintenance Costs	Job Creation Opportunities	Reduce Diesel Importation	Income Generation	Health Benefits	Energy Security	Capacity Building Potential	Reduction of CO_2 Emission	Reduction of Environmental Degradation	Reduction of GHG Emission	
Units	USD	USD	Ordinal	Ton/year	USD	Ordinal	Ordinal	Ordinal	t/CO_2 e/year	ha	t/CO_2 e/year	
Preferred Value	Low	Low	High	High	High	High	High	High	High	High	High	
Weight	15%	20%	1%	3%	1%	6%	7%	2%	13%	2%	30%	
Biodiesel/ Internal Combustion Technology	33.75	90	36	56.25	52	11.5	31	4.75	97.5	24	192	628.75
Blending Fossil with Biodiesel	20	95	46	51.75	50	9.5	37	5.75	116.25	22	144	597.25
Efficiency Wood Stove	30	120	54	56.25	56	16.5	34	6.5	120	23	186	702.25
Battery Electric Vehicle	7.5	95	42	78.75	54	14.5	26	6.5	131.25	31	228	714.5
Solar Electric Boat	8.75	90	38	78.75	52	13	29	6.25	131.25	32	228	707

Table III.5 Waste-to-Energy criteria weights and technology options – Base Case

Criteria Options	Costs		Economic			Social		Environmental		Climate Related	Weighted Scores of each option
	Capital Costs	Operational & Maintenance Costs	Job Creation Opportunities	Reduce Diesel Importation	Income Generation	Health Benefits	Capacity Building Potential	Reduction of CO_2 Emission	Reduction of CH_4 Emission	Reduction of GHG Emission	
Units	USD	USD	Ordinal	Ton/year	USD	Ordinal	Ordinal	$t/CO_2/year$	$t/CO_2e/year$	$t/CO_2e/year$	
Preferred Value	Low	Low	High	High	High	High	High	High	High	High	
Weight	15%	11%	6%	10%	2%	9%	5%	2%	23%	17%	
Mechanical Biological Treatment	3	11	49.2	76	12	52.2	32	16.8	184	153	589.2
Manure Based Biogas Digesters	57	59.4	37.2	82	14.8	70.2	29	16.4	188.6	149.6	704.2
Compact Biogas Digester for Urban Households	63	55	43.2	74	14.8	64.8	26	15.2	174.8	149.6	680.4
Anaerobic Digestion – Biogas Plant	69	63.8	36	74	14.4	61.2	27	15.2	179.4	132.6	672.6

Table III.6 Waste-to-Energy Sector criteria weights and technology options – Sensitivity Analysis 1 of 2

Criteria Options	Costs		Economic			Social		Environmental		Climate Related	Weighted Scores of each option
	Capital Costs	Operational & Maintenance Costs	Job Creation Opportunities	Reduce Diesel Importation	Income Generation	Health Benefits	Capacity Building Potential	Reduction of CO_2 Emission	Reduction of CH_4 Emission	Reduction of GHG Emission	
Units	USD	USD	Ordinal	Ton/year	USD	Ordinal	Ordinal	$t/CO_2/year$	$t/CO_2e/year$	$t/CO_2e/year$	
Preferred Value	Low	Low	High	High	High	High	High	High	High	High	
Weight	15%	11%	6%	10%	2%	9%	5%	2%	23%	17%	
Mechanical Biological Treatment	3	11	16.4	45.6	6	52.2	32	33.6	240	153	592.8
Manure Based Biogas Digesters	57	59.4	12.4	49.2	7.4	70.2	29	32.8	246	149.6	713
Compact Biogas Digester for Urban Households	63	55	14.4	44.4	7.4	64.8	26	30.4	228	149.6	683
Anaerobic Digestion – Biogas Plant	69	63.8	12	44.4	7.2	61.2	27	30.4	234	132.6	681.6

Table III.7 Waste-to-Energy Sector criteria weights and technology options – Sensitivity Analysis 2 of 2

Criteria Options	Costs		Economic			Social		Environmental		Climate Related	Weighted Scores of each option
	Capital Costs	Operational & Maintenance Costs	Job Creation Opportunities	Reduce Diesel Importation	Income Generation	Health Benefits	Capacity Building Potential	Reduction of CO_2 Emission	Reduction of CH_4 Emission	Reduction of GHG Emission	
Units	USD	USD	Ordinal	Ton/year	USD	Ordinal	Ordinal	t/CO_2/year	t/CO_2e/year	t/CO_2e/year	
Preferred Value	Low	Low	High	High	High	High	High	High	High	High	
Weight	15%	11%	6%	10%	2%	9%	5%	2%	23%	17%	
Mechanical Biological Treatment	3	11	57.4	83.6	18	52.2	32	16.8	160	153	587
Manure Based Biogas Digesters	57	59.4	43.4	90.2	22.2	70.2	29	16.4	164	149.6	701.4
Compact Biogas Digester for Urban Households	63	55	50.4	81.4	22.2	64.8	26	15.2	152	149.6	679.6
Anaerobic Digestion – Biogas Plant	69	63.8	42	81.4	21.6	61.2	27	15.2	156	132.6	669.8