Liberia

TECHNOLOGY NEEDS ASSESSMENT REPORT MITIGATION

June 2019

TECHNOLOGY NEEDS ASSESSMENT REPORT
MITIGATION

TECHNOLOGY PRIORITIZATION

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Foreword

In September 2015, Liberia, as a signatory of the UN Climate Change Convention, submitted the Nationally Determined Contribution (INDC) in advance of the new climate change agreement reached at the UN Climate Conference in Paris in December. Liberia's INDC was designed as a platform to integrate its Low Carbon Development Strategy into the country's long-term sustainable development vision by 2030 (Agenda for Transformation). Liberia ratified the Paris Agreement in August 2018 and is working hard to revise its NDC for submission. Regardless of the many contributions to climate change, Liberia, like many other developing countries, is especially vulnerable to its impacts. The country is at this moment susceptible to the adverse effects of climate change such as shifting cultivation in the agriculture sector, unsustainable logging practices, unregulated coastal mining, high level of biomass consumption in the form of charcoal and fire wood for local energy use, and decreasing river flow due to high level of evaporation. The agricultural sector, which ensures the livelihoods of around 70% of the population, remains vulnerable to flooding and erosion with changing rainfall patterns putting lives at risk in a country where nearly 8 out of 10 people do not have secure access to food. Current climate change vulnerability in Liberia include; increase in extreme events (e.g., exacerbated floods, extreme drought), sea level rise, flooding and coastal erosion being experienced on an annual basis that eats up the coast as observed in Monrovia, Buchanan and Greenville.

I would like to add that Liberia has an overall lack of energy. In most rural areas in Liberia, less than 5% of the population has access to electricity while most homes run mini generators. The current energy situation in Liberia is characterized by a dominance of traditional biomass consumption, low access to poor quality and relatively expensive modern energy services. It is estimated that over 95% of the population rely on firewood, charcoal, and palm oil for their energy needs.

The EPA of Liberia is overly happy with the level of the assessment done by the Technology Needs Assessment Team (TNA) through a national stakeholder's participatory process emulating from the identification and prioritization of environmentally sound technologies to the diffusion of these technologies to mitigate and adapt to climate change. We would like to recognize the United Nations Environment Programme (UNEP), DTU Partnership and Global Environment Facility (GEF). Your contributions have resulted in this rich source of information and we hope that this report will spur parties into seeking out partnerships for the purpose of accelerating climate action and increasing ambition in Liberia.

Dr. Nathaniel T. Blama Sr.
EXECUTIVE DIRECTOR/CEO

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List of Acronyms

AfT	Agenda for Transformation
BAEF	Barrier Analysis and Enabling Framework
CCGAP	Climate Change Gender Action Plan
CEO	Chief Executive Officer
CO_2	Carbon dioxide
COP	Conference of Parties
CSET	Center for Sustainable Energy Technologies
DNA	Designated National Authority
EPA	Environmental Protection Agency
ERC	Energy Research Centre
EST	Environmentally Sound Technology
EVD	Ebola Virus Disease
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOL	Government of Liberia
INC	Initial National Communication
INDC	Intended Nationally Determined Contributions
KfW	Kreditanstalt für Wiederaufbau
LEC	Liberia Electricity Company the
LPRC	Liberia Petroleum Refining Corporation
LULUCF	Land Use, Land-Use Change and Forestry
MCA	Multi-Criteria Analysis
MGCSP	Ministry of Gender, Children and Social Protection
MLME	Ministry of Lands, Mines and Energy
MoA	Minister of Agriculture
MoF	Minister of Finance
MoLME	Minister of Lands, Mines and Energy
MoPEA	Minister of Planning and Economic Affairs
MoT	Ministry of Transport
MSWG	Mitigation Sectoral Working Group
NCCS	National Climate Change Secretariat
NCCSC	National Climate Change Steering Committee
NDMP	National Disaster Management Policy
NEP	National Energy Policy
NESF	National Energy Stakeholders Forum
NGOs	Non-Government Organizations
NOCAL	National Oil Company of Liberia
O&M	Operation and Management
PAPD	Pro-Poor Agenda for Prosperity and Development
PRS	Poverty Reduction Strategy
PV	Photovoltaic

RE	Renewable energy
RREA	Rural Renewable Agency of Liberia
SDGs	Sustainable Development Goals
SWGs	Sectoral Working Groups
TAP	Technology Action Plans
TFS	Technology factsheets
TNA	Technology Needs Assessment
UDP	United Nations Environment Programme and Technical University of Denmark Partnership
UNEP	United Nations Environment Programme
UNEP-DTU	United Nations Environment Programme and Technical University of Denmark
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

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Executive Summary

Liberia is already experiencing the effects of climate change as a result of rising sea level, increased intensity in rainfall, and soaring temperatures. As the country grapples with challenges posed by climate change, its economic, social, political and environment development remain threatens. Liberia is one of 23 countries participating in Phase III of the Technology Needs Assessment (TNA) within the framework of the United Nations Framework Convention on Climate Change (UNFCCC).

This report focuses on the TNA process which was carried out in Liberia to identify and prioritize, through country-driven participatory processes, technologies for mitigation aimed at reducing the greenhouse gas (GHG) emissions in the country's energy sector. The TNA project is funded by the Global Environment Facility (GEF) and implemented by the United Nations Environment Programme (UNEP) and the Technical University of Denmark Partnership - UNEP-DTU Partnership (UDP) and technical support is provided by the Energy Research Centre (ERC) at University of Cape Town. The Environmental Protection Agency (EPA) of Liberia is responsible for the execution of the project in the country.

The national TNA team of Liberia consist of the core group of persons engaged in the TNA project and it includes the National Climate Change Steering Committee (NCSSC), the National TNA Coordinator, the National Consultants for Mitigation and Adaptation, and three (3) Sectoral Working Groups (SWGs) (one for mitigation and two for adaptation). Stakeholder consultations took place during each stage of the TNA process.

From the onset of the TNA project, it was ensured that a gender sensitive approach was used to make the process participatory, inclusive and gender responsive. This approach was carried out with respect to the composition of the mitigation sectoral working group, identifying and prioritizing technologies, and developing scoring criteria for the various identified technologies. The group have a 40% female membership.

Key stakeholders drawn from government ministries, departments and agencies, non-government organizations (NGOs), the private sector, technical experts and academics were involved identifying two sectors for adaptation and one sector for mitigation; reviewing technology factsheets and recommending other mitigation technologies applicable in the local context; developing scoring criteria for the identified technologies; and participating in the multi-criteria exercise. In addition to the formal workshops, the National Consultants also conducted sectorial working sessions, informal meetings with experts and resource persons from various ministries, institutions and NGOs who could not attend the workshops.

After a lengthy deliberation where stakeholders presented their views and opinions, stakeholders of the energy sector working group finally agreed that the criteria for selection be categorized as cost, economic, social, environmental and climate related. The MCA exercise enables the selection of priority technologies for Liberia in an objective way and based on consensus. The MCA selected the following technologies in the energy Sector in order of their priority: Solar Home PV System, Solar PV Grid-tied System, Small Hydropower, Improved clean cook stove, Solar dryer, Briquette Production, Solar Lantern, Biodiesel, Biogas Digester, and Methane Capture from Landfill.

Hence the following three top ranked technologies in the energy sector selected in order of priority were Solar Home PV system, Solar PV Grid-tied System and Small Hydropower. The technologies selected as priorities for TNA will contribute to reduction of greenhouse gas emissions in the energy sector, which is the largest source of GHG emissions in Liberia. They will also contribute to provision of electricity in both urban and rural areas, where currently less than 7 percent of the population in Monrovia has regular access to electricity and less than 2 percent of the population has access in rural areas. The next phase of the TNA project will concentrate on understanding the different barriers and limitations to the implementation and diffusion of the prioritized technologies in the country.

Chapter 1 Introduction

1. 1 About the TNA project

Climate change is one of the most important global challenges humanity faces today. Despite having contributed little to climate change, Liberia, like many other developing countries, is especially vulnerable to its impact due to low mitigation and adaptation capacities. The country is already experiencing sea-level rise, soaring temperatures and increased rainfall which threatens its economic, social, political and environment development (UNDP, 2018). These conditions have a bearing on energy production and consumption of the country. The energy sector in Liberia is vulnerable to the negative impacts of climate change owing to its potential for infrastructural harm to power plants and power transmission, as well as inaccessibility to biomass fuel sources that can be caused by rising sea levels and flooding (Republic of Liberia, 2018).

Technology Needs Assessments (TNAs) are a set of country-driven activities that identify and determine the mitigation and adaptation technology priorities of developing countries to climate change (Haselip *et al*., 2019). In response to the Thirteenth Conference of Parties (COP 13) request, the Global Environment Facility (GEF) proposed the Poznan Strategic Program on Technology Transfer, which was endorsed by the Fourteenth Conference of the Parties (COP 14). It consists of three funding windows: (i) technology needs assessments; (ii) piloting priority technology projects; and (iii) dissemination of successfully demonstrated technologies (Charlery & Trærup, 2019). The current Global TNA (TNA Phase III), derived from window (i) of the Strategic Program on Technology Transfer, is designed to support 23 countries including Liberia to carry out new or improved Technology Needs Assessments within the framework of the United Nations Framework Convention on Climate Change (UNFCCC) (GEF, 2018). The TNA project is funded by the Global Environment Facility (GEF) and implemented by the United Nations Environment Programme (UNEP) and the Technical University of Denmark Partnership - UNEP-DTU Partnership (UDP) and technical support is provided by the Energy Research Centre (ERC) at the University of Cape Town. Liberia started the TNA project in May 2018 and scheduled to complete in February 2020. The Environmental Protection Agency (EPA) of Liberia is responsible for the execution of the project in the country.

The purpose of this TNA project is to assist Liberia identify and analyse priority technology needs, which can form the basis for a portfolio of Environmentally Sound Technology (EST) projects and programmes to facilitate the transfer of, and access to the ESTs and know-how in the implementation of Article 4.5 of the UNFCCC which states that developed country Parties and other developed Parties included in Annex II *“shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention”* (UN, 1992). Hence TNAs are central to the work of Liberia on technology transfer and present an opportunity to track an evolving need for new equipment, techniques, practical knowledge and skills, which are necessary to mitigate greenhouse gas (GHG) emissions and/or reduce the vulnerability of sectors and livelihoods to the adverse impacts of climate change.

The main objectives of the TNA project are:

1. To identify and prioritize through country-driven participatory processes, technologies that can contribute to mitigation and adaptation goals of Liberia, while meeting its national sustainable development goals and priorities (Haselip *et al*., 2019).
2. To identify barriers hindering the acquisition, deployment, and diffusion of prioritized technologies (Haselip *et al*., 2019).
3. To develop Technology Action Plans (TAP) specifying activities and enabling frameworks to overcome the barriers and facilitate the transfer, adoption, and diffusion of selected technologies in Liberia (Haselip *et al*., 2019).

Further, the TNA process will develop Concept Notes for attracting funding to implement selected technologies in priority areas of national relevance.

The Technology Need Assessment report on Mitigation has been prepared by the National Consultant on Mitigation. This report is in fulfilment of the first objective of the project and presents the assessment of prioritized technologies for mitigation in the energy sector.

1.2 Existing national policies on climate change mitigation and development priorities

The Government of Liberia (GoL) has shown its commitment to tackling climate change challenges through several national policies and strategic interventions. An overview of some key national policies related to development priorities and climate change mitigation for the energy sector is outlined below.

National Environmental Policy of 2003

The National Environmental Policy of Liberia is a legal instrument that provides a broad framework for the implementation of national environmental objectives and plans (EPA, 2003). The primary objective of the policy is to "ensure a sound management of resources and the environment, and attempts to avoid any exploitation of these resources in a manner that might cause irreparable damage to the environment". This primary objective of the policy is expected to be pursued and achieved through the harmonization and enforcement of relevant laws on environment protection. The policy also seeks to integrate environmental considerations in sectoral, structural, regional, and socio-economic planning at all levels.

Electricity Law of Liberia of 2015

The Electricity Law provides the legal and regulatory framework for the production, transportation, distribution and sale of energy products and services in Liberia. The Law further regulates the import and export of energy products and defines the rights and obligations of all entities and parties involved in or affected by the energy activities. The law aims to facilitate the implementation of the goals of the National Energy Policy (Republic of Liberia, 2015a).

National Energy Policy of Liberia 2009

Activities in Liberia's energy sector are guided by a National Energy Policy (NEP) that was adopted by cabinet in 2009 (Republic of Liberia, 2009). The policy articulates the country's national vision for the energy sector of Liberia and set clear development goals for the short, medium and long term in the energy sector at the urban, rural and regional levels. The primary objective of the NEP is to ensure universal and sustainable access to affordable and reliable modern energy supply in order to foster the economic, political, and social development of Liberia. The four pillars of the NEP are:

(i) universal energy access, including the development of an energy master plan;

(ii) least-cost production of energy and protection of the most vulnerable households;

(iii) the adoption of international best practices in the electricity sector; and

(iv) the acceleration of public and private partnership in the sector.

The NEP also calls for:

(i) the creation of an Energy Regulatory Board (ERB) and the RREA;

(ii) reorganization of the Ministry of Lands, Mines and Energy (MLME) to expand its capacity in and focus on energy;

(iii) creation of a Saint Paul River authority or other river authority; and

(iv) changes to the legislation establishing the Liberia Electricity Company (LEC), the National Oil Company of Liberia (NOCAL), and Liberia Petroleum Refining Corporation (LPRC), to separate policy making from operational functions and, in the case of the LEC, to clarify jurisdiction over generation, transmission, and distribution according to geographic area, generation type, and size.

Agenda for Transformation 2012 - 2017

The Agenda for Transformation (AfT) is the GoL five-year development plan which articulates the country's goal and aspirations of attaining middle income status by 2030 through sustained and inclusive economic growth (Republic of Liberia, 2012a). The plan focuses on five strategic pillars to increase productivity, boost economic growth, and improve social inclusion, particularly by creating jobs, specifically for its young population. The pillars are:

- Economic transformation through investing in infrastructure.
- Human development.
- Peace, security, and the rule of law.
- Governance and public institutions.
- Cross-cutting issues.

The AfT was adopted as a framework or roadmap for meeting the goals set out in Liberia Rising 2030 which is the country's long-term vision of socio-economic transformation and development (Government of Liberia, 2010). The GoL expectation is that the flow of aid to the AfT will be consistent with the Paris Declaration, the Accra Agenda for Action and the New Deal for Engagement in Fragile States. The AfT also considers climate change as one of its strategic objectives. It expresses the need for increase access to renewable energy services and affordable power for community and economic transformation. In this regard, the Energy Technical Committee, Liberian Electrical Corporation (LEC) and the Rural Renewable Energy Agency (RREA) is expected to work with development partners to plan, finance and carry out the reconstruction and rehabilitation of key power infrastructure for centralized generation and decentralized rural power supply. One of the strategic objectives contained in the AfT is for the energy sector to increase its environmental sustainability and at the same time reducing the use of charcoal and wood as fuel. Among the priority interventions set out in the AfT is for Government to support communities without access to power from the grid with the development of alternative energy such as small-scale thermal- hydro- and solar- energy.

Other priority interventions set out in the AfT for the Energy Sector are as follows:

- Distribution of electrical power to communities and connection of customers
- Reconstruction of Monrovia – RIA – Firestone 115 kV power transmission line
- Reconstruction of Monrovia – Kakata – Gbarnga 115 kV power transmission line
- Reconstruction of Monrovia – Tubmanburg – 115 kV power transmission line
- Reconstruction of 64 MW Mount Coffee Hydropower Facility + Planning of SPRA Hydropower Scheme
- Construction of 15 MW Heavy Fuel Oil plant

Rural Energy Strategy and Master Plan (RESMP) of 2016

The Rural Energy Strategy and Master Plan (RESMP) of Liberia for the period until 2030 major objective is to set clear targets, to identify least-cost projects and technologies, to propose concrete investments for funding and implementation, with appropriate institutional framework and capacity to increase energy access and renewable energies to the country's rural areas and population – meaning all areas and population outside of greater Monrovia (RREA, 2016). The Master Plan identifies 92 projects and investments to electrify 265,000 homes and 1.34 million people outside Monrovia until 2030. The action plan and rural energy projects are structured under 5 key programs:

- *GTG: Growing the Grid Program*: Expanding Medium Voltage grid from the three planned corridors outside of Monrovia (Kakata, Kle and RIA), from new proposed corridors starting from Gbarnga and from the Côte d'Ivoire, Liberia, Sierra Leone and Guinea interconnection (CLSG) sub-stations and Shield Wire, representing a total investment of USD 308 million dollars and the electrification of 16,4300 homes. Additionally, GTG includes additional USD 242 Million Dollars investment in on-grid renewable generation to be installed outside Monrovia.
- *DG: Decentralized Grids Program*: Building large decentralized grids supported by renewable generation, cross border inter-connections and Medium Voltage grids (Voinjama, Pleebo/Fishtown, Zwedru and Greenville); guaranteeing the electrification of the 10 largest settlements in each County, if not under GTG program, than through the development of transitional solar/diesel low voltage mini-grids. Represents a total investment of USD 292 Million Dollars and the electrification of 96,800 homes.
- *BTG: Beyond the Grid Program*: Electrifying community services, households and public buildings where the grid is not expected before 2025 through 100% solar based off-grid solutions, prioritizing health, education (secondary schools) and security (police stations, checkpoints, courthouses and public lighting); electrifying 75 future off-grid settlements in an equitable way across counties mainly through Solar Home Systems (SHS) while promoting the sale and rental of solar portable lamps or smaller Solar Home Systems across the country. Represents a total investment of USD 16 million dollars and the electrification of 4,000 homes.
- *OTP: Other than Power Program*: Promoting efficiency in buildings, appliances and cooking; developing Liquefied Petroleum Gas (LPG) storage and filling infra-structure while promoting availability of cooking gas in all county capitals; promoting efficient charcoal production and efficient cook stoves requires a total investment of USD 24 million dollars.

- *BC: Building capacity*: Creating the capacity, the institutional framework, the organization, the information and management systems and the infra-structure to implement the Master Plan requires a total investment of USD 52 million dollars.

The RESMP sets achieve the following targets until 2030 (RREA, 2016):

- Electrification rate for the population outside of Monrovia of 10% in 2020, 20% in 2025 and 35% in 2030, electrifying the largest cities and towns of the country first.
- All county capitals, health facility and secondary schools electrified already before 2025.
- 10 largest settlements in each County to be electrified by 2030 with minimum electrification of 15% per County.
- More than 75% of all electricity generated from renewables by 2030 with 19% coming from other than large hydro: Mini-hydro, Solar and Biomass.
- Universal access to affordable solar lamps, efficient appliances and cook stoves.
- Cooking gas available in all county capitals and efficiently produced charcoal widespread across the country.

National Policy and Response Strategy on Climate Change of 2018

The National Climate Change Policy and Response Strategy is a framework to establish specific provisions for dealing with climate change issues, understanding the extent of the threat and putting in place specific actions to mitigate potential impacts (Republic of Liberia, 2018). The policy and strategy is intended to guide national response measures in addressing climate change. The strategy further provides guidance on incorporating climate change issues into national development planning efforts at national, county, district and local levels for effective implementation. It also highlights adaptation and mitigation policies in key sectors in the country. The policy and strategy aims at enabling better coordination of climate change work in Liberia, providing cooperation and collaboration opportunities between the government and stakeholders, and enhancing ongoing efforts related to Liberia's National Adaptation Plan (NAP) and Nationally Determined Contribution (NDC).

Pro-Poor Agenda for Prosperity and Development 2018 to 2023 (PAPD)

The Pro-Poor Agenda for Prosperity and Development 2018 to 2023 (PAPD) is the second in the series of 5-year National Development Plans (NDP) anticipated under the Liberia Vision 2030 framework (Government of Liberia, 2018). It follows the Agenda for Transformation 2012-2017 (AfT). It is informed as well by lessons learned from the implementation of the Interim Poverty Reduction Strategy 2007 (iPRS) and the Poverty Reduction Strategy (2008-2011).

The objectives of the PAPD are:

1. To build a stable, resilient, and inclusive nation embracing our triple heritage and anchored on our identity as Africans.
2. To lift an additional one million Liberians out of absolute poverty over the next six years (and reduce absolute poverty by 23 percent across 5 of the 6 regions) through sustained and inclusive growth driven by scaled-up investments in agriculture, in infrastructure, and in human capital development.

These objectives are intended to be realized through four key pillars which form the pathways for the next five years:

1. *Power to the People*: To reduce developmental inequalities so the people can prosper;
2. *Economy and Jobs*: Economic stability and job creation through effective resource mobilization and prudent management of economic inclusion;
3. *Sustaining the Peace*: Promoting a cohesive society for sustainable development and;
4. *Governance and Transparency*: An inclusive and accountable public sector for shared prosperity and sustainable development.

Each pillar has an objective and a set of development outcomes to be produced over the next five years in support of the two high level national objectives.

Renewable Energy and Energy Efficiency Policy and Action Plan of Liberia (2006)

The purpose of this Policy is to increase national awareness on renewables and energy efficiency and remove barriers to investment and market development through a national policy instrument (Republic of Liberia, 2006). According to the renewable energy and energy efficiency policy, its primary objective is "to support the development process in Liberia by exploiting renewable energy resources to attract investment, develop the market, transfer technology and build local capacity in the renewable energy sub-sector".

The GoL has outline a number of measures intended to make the policy operational. These measures include the following:

- Make renewable energy services accessible; this implies that the infrastructure for the supply of renewable energy would be extensive to the extent that the electricity produced from it can be easily procured by any person or institution when needed;
- Make renewable energy services reliable so they can meet all demands at any particular time in the future;
- Make renewable energy services affordable with the view to improving the living conditions of the population, especially the poor;
- Ensure that renewable energy is produced and supplied in an acceptable form so that its production, supply and use have no adverse health and environmental impact;
- Ensure that renewable energy is used in the most efficient manner.

1.3 Sector selection

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

Liberia ratified the United Nations Framework Convention on Climate Change (UNFCCC) in November 2002. As a non-Annex I party to the UNFCCC, the country prepared and submitted its National Adaptation Programme of Action (NAPA) in 2008 to the UNFCCC followed by its Initial National Communication (INC) in 2012. Liberia's INC included the national and sectoral estimates of GHG emissions with the year 2000 taken as the base year. Liberia total greenhouse gas (GHG) emissions were 8,022 gigagrams (Gg) carbon dioxide equivalent (CO_2eq) in 2000. The total CO_2 removal for the land use change and forestry (LULUCF) sector was -96,811 resulting in a net sink of -88,789 GgCO_2eq (Environmental Protection Agency, 2010). A summary of GHG emissions by sectors in Liberia without land use change and forestry (LULUCF) is shown in Table 1.1.
Table 1.1 Liberia Greenhouse gas emissions by sectors (without LULUCF), (Environmental Protection Agency, 2013)

GHG Source and Sink Categories	**Total Gg CO_2eq**	**Sector Share (%) ***
Energy	5,414	67.5
Industrial processes	NO	NO
Solvent and other product use	NE	NE
Agriculture	2,562	31.9
LULUCF	-96,811	
Waste	46	0.6
Total without (LULUCF)	8,022	100
Total (with LULUCF)	-88,789	

*Sector share is without Land Use Change and Forestry (LULUCF)

The largest contribution to GHG emissions came from the energy sector at 67.5% followed by the agriculture sector and waste sector at 18.9% and 0.6% respectively.

By gas, the largest contribution of GHG in Liberia came from methane (CH_4), which contributed 51.6% of the total national GHG emissions, followed by carbon dioxide (CO_2) and nitrous oxide (N_2O) at 44.5% and 3.9% respectively. The high methane emissions reflect the predominantly agrarian nature of the Liberian economy (Environmental Protection Agency, 2013).

Table 1.2 GHG emissions by gas (without LULUCF), 2000 (Environmental Protection Agency, 2013)

GHG Source and Sink Categories by Gas	Gg CO_2 eq.	Share by Gas (%) (without LULUCF)
CO_2	3,571	44.5
CH_4	4,141	51.6
N_2O	310	3.9
TOTAL	**8,022**	**100**

Table 1.3 summarizes the results of emissions estimates for the energy sector. In the energy sector CO_2, CH_4 and N_2O accounted for 66%, 28.3% and 5.7% of GHG emissions respectively. Moreover, transport (road vehicles) contributed 40.1% to the total energy sector emissions, making it the largest emitting category. Most of the vehicles in the country tend to be over aged, poorly maintained and dilapidated. In addition, vehicles use fuel which tends to be of low-grade which is coupled with the very bad nature of the roads in the country.

Table 1.3 Summary reports of emissions estimations for the energy sector (Environmental Protection Agency, 2013)

GHG Source and Sink Categories	CO_2	CH_4	N_2O	Year 2000	Contribution to National Total (%)	Contribution to Sector (%)
	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.		
Total National Emissions	3,571	4,141	310	8,022		
(1) Energy	3,571 (66%)	1,533 (28.3%)	310 (5.7%)	5,414 (100%)	67.5	
A. Fuel combustion (by sector)						
1. Energy industries	1,117	0	0	1,117	13.9	20.6
2. Manufacturing industries and construction	105	0	0	105	1.3	1.9
3. Transport (road vehicles)	2,152	21	0	2,173	27.1	40.1
4. Other sectors	197	1,512	310	2,019	25.2	37.3
5. Other: please specify						
B. Fugitive emissions from fuels						
1. Solid fuels		NO	NO	NO		
2. Oil and natural gas		NO	NO	NO		
C. Other sectors (biomass, gas and other fuels)						

1.3.2 Process and results of sector selection

The sector prioritization was done at the Inception workshop held from 23rd to 26th October 2018 at the EPA Conference Hall located on 3rd Street Sinkor in Monrovia, Liberia. At the workshop, the TNA project was presented to the all stakeholders present. The key sectors proposed for prioritization were those in the Intended Nationally Determined Contributions (INDC) of Liberia (Republic of Liberia, 2015b). They are the energy and waste sectors for mitigation; coastal erosion and flooding, and agriculture for adaption. These were sectors that are responsible for most of the GHGs emissions in the country. From the list of proposed sectors, two sectors were selected for adaptation and one sector for mitigation.

The selected sectors are:

- Agriculture and Coastal Zone sectors for adaption
- Energy sector for mitigation.

Factsheets for the prioritized technologies were to be produced by the national consultants in consultation with the relevant stakeholders.

The energy sector was selected because it is the highest emitter of GHG in the country. The energy sector is also the sector with the highest potential for the application technologies for mitigation against climate change.

Chapter 2 Institutional arrangement for the TNA and the stakeholder involvement

The National Climate Change Steering Committee (NCCSC) has overall responsibility for climate change policy in Liberia (Republic of Liberia, 2018). The National Climate Change Secretariat (NCCS) is housed in the EPA and it is responsible for carrying out and coordinating the daily operations of the NCCSC. The Environmental Protection Agency (EPA) of Liberia which is the Designated National Authority (DNA) for the UNFCCC and the Kyoto Protocol coordinates, along with other ministries and agencies, the full implementation of major activities under the policy. The EPA is the lead agency responsible for the TNA process in Liberia. It spearheaded the launch of the TNA project on October 23 to 26, 2018 in the presence of representatives from the UNEP DTU Partnership (UDP) and the Regional Centre (University of Cape Town) in Monrovia, Liberia. The following sections outline Liberia's institutional arrangement for the implementation of the TNA project and the stakeholder involvement process which followed the guidebook provided by UNEP-DTU Partnership for countries conducting TNA.

2.1 National TNA team

Figure 2.1 shows the institutional arrangements adopted from the UNEP DTU Partnership TNA guidebook *(TNA Step by Step – A guidebook for countries conducting a Technology Needs Assessment and Action Plan)* to manage the TNA project in Liberia (Haselip *et al*., 2019). Liberia's national TNA team comprises the core group of persons engaged in the TNA project and it includes the NCSSC, the National TNA Coordinator, the National Consultants for Mitigation and Adaptation, and three (3) Sectoral Working Groups (SWGs) (one for mitigation and two for adaptation).

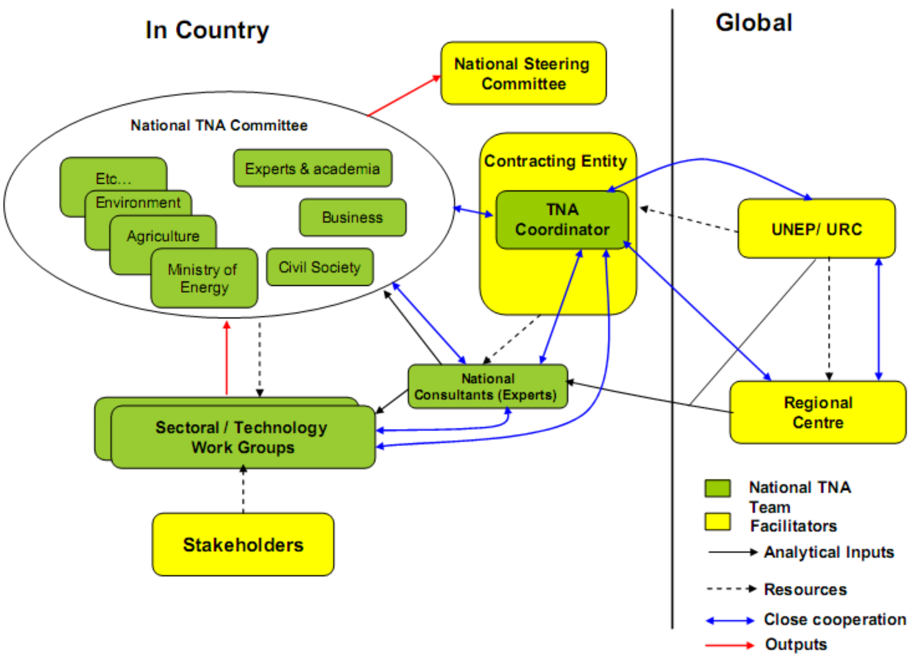

Figure 2.1 Institutional Arrangements for the TNA Project in the Republic of Liberia

- ***The National Climate Change Steering Committee (NCCSC)***

The NCCSC is the high-level policy coordination body for the overall climate change activities in Liberia. It was established in 2010 by the President of the Republic of Liberia. It comprises the President of Liberia, Ministers of Government, Directors of Governmental Agencies, National Energy and Climate Change Advisers to the President, private sector, civil society and international partners (Republic of Liberia, 2018). The NCCSC is expected to provide guidance and leadership to the TNA project. The principal role of the NCCSC is to provide high-level guidance to the national TNA team and help secure political acceptance for the Technology Action Plan (TAP). Table 2.1 shows the current and proposed composition of the NCCSC.

Table 2.1: Current and Proposed Composition of the NCCSC (Republic of Liberia, 2018)

1. President of the Republic of Liberia – Ex-official
2. Energy, Environment and Climate Change Advisor to the President of Liberia
3. Heads of Standing Committees on Environment and Natural Resources of the Senate and the House of Representatives
4. Minister of Planning and Economic Affairs (MoPEA)
5. Minister of Lands, Mines and Energy (MoLME)
6. Minister of Agriculture (MoA)
7. Minister of Finance (MoF)
8. Minister of Gender and Development
9. Minister of Transport
10. Minister of Finance & Development Planning
11. Managing Director of the Forestry Development Authority
12. Executive Director of the Environmental Protection Agency
13. Chairman, National Investment Commission
14. Commissioner of Liberia Maritime Authority
15. World Bank
16. University of Liberia
17. Civil Society
18. Fauna & Flora International
19. NCCS Coordinator

- ***The National TNA Coordinator***

The appointment of the National TNA Coordinator was done by the Environmental Protection Agency of the Republic of Liberia. The TNA Coordinator is the focal point for the effort and management of the overall TNA process. This involves providing guidance, leadership and vision for the overall TNA process; facilitating communication tasks among the National TNA Committee members, National Consultants and stakeholders groups, forming networks, information acquisition, and the coordination and communication of all work products; providing guidance and support for the successful implementation of the TNA project according to the agreed Work Plan; and serving as the official contact point for the country, communicating progress and/or any queries directly with the Country Coordinators at UNEP DTU Partnership and the Regional Centres.

- ***The National Mitigation Consultant***

The National Mitigation Consultant works in close collaboration with the National TNA Committee and the mitigation sectoral group, and is directly responsible to the TNA Coordinator. The National Mitigation Consultant overall task is to support the entire TNA process.

However the specific responsibilities of the National Mitigation Consultant include:

- organizing consultative stakeholder meetings;
- providing support to identify and prioritize mitigation technologies for Liberia's Energy sector through a participatory process with the broad involvement of relevant stakeholders;
- leading the process of analysing, along with the mitigation stakeholder group, how the prioritized technologies can be implemented in Liberia and how implementation conditions can be improved by addressing the barriers and developing an enabling framework based, inter alia, on undertaking local market and other assessments, as may be required;
- preparing deliverables, including the TNA, BAEF and TAP reports for Liberia's Energy sector ;
- preparing working papers and other TNA-related documents as may be required to ease the consultative process;
- harnessing inputs from stakeholders during meetings and workshops, among others;
- participate in capacity-building workshops;
- work in close partnership with the National Coordinator to facilitate communication within the national TNA Team (coordinator, consultants, sectoral working groups), engage with stakeholders, form networks, and coordinate and communicate all deliverables.

- ***Sectoral Working Groups***

The stakeholders are essential to the TNA process. The Sectoral Working Groups (SWGs) are intended to allow stakeholders to play an active role in the TNA. The Mitigation Sectoral Working Group (MSWG) consists of stakeholders who contribute their technical expertise and input into technology prioritization, the barrier analysis, and ideas or inputs for the enabling framework for the Energy sector. The following institutions and organizations represented on the MSWG are shown in Table 2.2.

Table 2.2 Institutions and organizations represented on mitigation sectoral working group

Energy Working Group
1. Environmental Protection Agency (EPA)
2. Green Gold Liberia Limited
3. Ministry of Gender, Children and Social Protection (MGCSP)
4. Rural Renewable Agency of Liberia (RREA)
5. Ministry of Transport (MoT)
6. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
7. Ministry of Mines and Energy

2.2 Stakeholder Engagement Process followed in the TNA – Overall assessment

Engagement with stakeholders is a fundamental element for the success of the TNA project. Stakeholder consultations took place during each stage of the TNA process. The TNA project in Liberia officially kicked off with an Inception Workshop held on 23rd – 26th October 2018 at the EPA Conference Hall located on 3rd Street Sinkor in Monrovia, Liberia. Participants at this workshop comprised key stakeholders drawn from governmental ministries, departments and agencies, non-government organizations (NGOs), the private sector, technical experts and academics. (See Appendix I for list of participants.) The stakeholders included both male and female.

Opening remarks were given by the Executive Director and CEO of Environmental Protection Agency of Liberia Dr. Nathaniel T. Blama, Sr. The inception workshop was facilitated by representatives from the UNEP-DTU Partnership and the Energy Research Centre (ERC) who were in the country on a scoping mission. During the workshop stakeholders were presented background information on the project's goals, objectives, draft work plan and institutional arrangements. Stakeholders were provided the opportunity to ask questions on issues such as scope and timing of the TNA, TNA tools and methodologies, types of barriers and stakeholder's involvement, role of government, technology types and maturity, participation of youth, disabled and gender inclusion. Stakeholders then chose three prioritised sectors for TNA based on the country's INDC, national development plans and climate strategies and priorities. The sectors are:

- Energy for mitigation,
- Agriculture & Coastal erosion and flooding for adaptation.

After the Inception Workshop a series of activities were implemented to successfully enhance the execution of the TNA project. These included the appointment of three (3) TNA National Consultants, participation of two (2) National Consultants and the National Coordinator at the 1st African Regional Capacity Building Workshop for the Technology Needs Assessment (TNA) III Project in Entebbe, Uganda from 26th to 28th February 2019 and the finalization of the detailed work plan for the implementation of the TNA project.

On 1st of April 2019, a national stakeholder's TNA engagement workshop for the prioritization of technologies in Liberia was held at the Lutheran Church Compound 13th Street in Sinkor, Monrovia. Prior to the technology prioritization workshop, the National Consultants prepared technology factsheets based on the prioritized sectors agreed upon at the Inception Workshop. The factsheets were prepared with reference to information and data from the climate techwiki website (http://climatetechwiki.org/) and the TNA project website (www.tech-action.org). Stakeholders reviewed the factsheets and recommended other mitigations technologies that might be applicable to Liberia's local context other than those the consultants had proposed. These factsheets were used by the stakeholders to prioritize technologies through a participatory process using Multi-Criteria Analysis (MCA). Participants came from the relevant stakeholders' organizations including government ministries, agencies, institutions and NGOs. The full list of participants is in Annex II.

In addition to these formal workshops, the National Consultants also conducted sectorial working sessions, informal meetings with experts and resource persons from various ministries, institutions and NGOs who could not attend the workshops. Figure 2.2 shows stakeholders at the TNA workshop for prioritization of technologies in Liberia. Details of stakeholders involved in TNA process is provided in Annex II of the report.

Figure 2.2 Stakeholders at the TNA workshop for prioritization of technologies in Liberia

Opening remarks on behalf of Hon. Dr. Nathaniel T. Blama, Sr., Executive Director and CEO of EPA were made by Mr. Levi Z. Piah, the Chief Technical Advisor, EPA. In his welcome remarks, Mr. Piah stated that TNA is crucial to supporting the Government of Liberia's Pro Poor Agenda for Prosperity and Development (PAPD) as well as the UN Sustainable Development Goals. He urged participants to build and foster national capacity that promotes prioritized climate sensitive technologies. He further indicated that by understanding the technology needs of the country, Liberia can make a determination of proactive options to reduce greenhouse gas emissions levels and adapt to the adverse impacts of climate change. He reaffirmed the EPA's fullest commitment to working with the TNA Team, UNEP-DTU Partnership and Energy Research Center in the implementation of the TNA Project in Liberia.

2.3 Consideration of Gender Aspects in the TNA process

In Liberia there is an existing framework which guarantees that issues of gender are mainstreamed in all climate change mitigation and adaptation efforts across the country as a means of promoting inclusiveness, equity and adequate participation of all (Republic of Liberia, 2018). This framework is set out in the Climate Change Gender Action Plan (CCGAP) for the Government of Liberia (Republic of Liberia, 2012b). The overall objective of the CCGAP is to ensure that gender equality is mainstreamed into Liberia's climate change policies, programs and interventions so that both men and women have equal opportunities to implement and benefit from mitigation and adaptation initiatives in combating climate change and positively impact on the outcome of "Liberia Rising 2030" (Government of Liberia, 2010).

Women, children and youth are the most vulnerable groups to the adverse effects of climate change and gender has a critical role to play in the TNA process. It is important to ensure that climate change mitigation and adaptation technologies in Liberia are gender sensitive. Gender consideration has been included through the various phases of the TNA process in Liberia using guidelines provided by UDP in *'Guidance for a gender-responsive Technology Needs Assessment'* available on www.tech-action.org. Consideration of gender sensitivity was ensured in order to address the needs and priorities of women, men, youth and children during the identification and prioritization of technologies for mitigation in the energy sector.

From the onset of the TNA project, it was ensured that a gender sensitive approach was used to make the process participatory, inclusive and gender responsive. This approach was carried out with respect to the composition of the mitigation sectoral working group, identifying and prioritizing technologies, and developing scoring criteria for the various identified technologies. The group has a 40% female membership.

Chapter 3 Technology prioritisation for the Energy Sector

This chapter of the report provides an overview of the existing technologies for climate change mitigation in Liberia's Energy Sector. It also outlines stakeholders' identification of applicable technologies for implementation in the country and stakeholders participation in the prioritization of these identified technologies using the MCA Excel template tool provided by the UNEP DTU Partnership.

3.1 GHG emissions and existing technologies of Energy Sector

Liberia's Intended Nationally Determined Contribution (INDC) (Republic of Liberia, 2015b) reports that energy is the leading source of GHGs due primarily to the use of traditional fuels such as firewood, charcoal and palm oil and the use of fossil fuels, mainly petroleum products. The country's Initial National Communication (INC) on climate change which was submitted in 2013 to the UNFCCC concluded that the country is a net carbon sink since it removes more carbon dioxide than it emits (Environmental Protection Agency, 2013). The energy sector is the largest contributor of GHG in the country, accounting for about 67% in 2000 (Figure 3.1). Using 2000 as the base year, the INC states that the country's emissions amounted to 8,022Gg of equivalent CO_2 while the uptake from the Land Use, Land-Use Change and Forestry (LULUCF) sector was 96,811Gg Co_2eq resulting in net emissions removal of -88,789 Gg Co_2eq.

Most of the emissions from this sector come from petroleum products (primarily gasoline and diesel, and some jet fuel and kerosene) which supply over 95% of the country's main energy. Consumption of petroleum products increased by 66% from 1999 to 2008, with transportation consuming 61% and electricity generation (which uses gasoline and diesel oil) 29% in 2008 (EPA, 2013). Most vehicles in the country are often poorly maintained and consume low grade diesel and mixed petroleum fuel that have a high potential for GHG emissions.

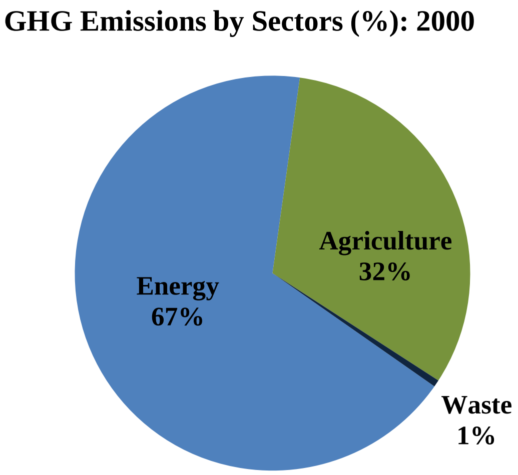

Figure 3.1 GHG emissions by Sectors without LULUCF (Environmental Protection Agency, 2013)

According to the INDC, GHGs of concern in Liberia emanate from the energy, agriculture and waste sectors with a composition are mainly Methane (CH), contributing 51.6%; Carbon dioxide (CO_2), contributing 44.5%; and Nitrous oxide (NO) contributing 3.9%.

Over the years, Liberia has started implementing some mitigation technologies in the energy and transport sectors to further limit its greenhouse gas emissions. Liberia's overall contribution to global GHG emissions is estimated to be about 1.89 Mt CO_2eq, which represents a negligible percent of the global total. The country has committed itself to do more to further reduce its GHG emissions and looks forward to receiving support from the international community to further this endeavor.

- **Solar Power:** Liberia is endowed with significant renewable energy (RE) resources, which include solar, biomass and hydropower resources. Solar energy is one of the most promising and abundant RE source in Liberia especially in the central and northern parts of the country (Goanue, 2010). Liberia's location near to the equator (between latitudes 15°S and 15°N) provides good prospects for the utilization of its high solar radiation with little monthly variation for the generation of energy. Figure 3.2 shows that the monthly average daily solar radiation is about 4 – 6 kWh/m^2/day (Goanue, 2010). On average, the solar potential of Liberia ranges between 1,665 and 1,771 kWh/m^2 /year (Figure 3.3).

Over the years, small-scale renewable solar power technology has been mainly implemented in the country by donor organizations to boost access to energy and stimulate socio-economic development. Currently solar energy interventions in the country are increasing. However, these interventions have been primarily the installation of solar power systems mainly in rural communities on a pilot basis.

With funding from the United States Agency for International Development (USAID), small isolated photovoltaic (PV) mini-grid systems have been deployed at the Gbarngway Village in Lofa County, a solar system at the Brooker Washington Institute in Kakata, and a few other systems supplying individual buildings such as dispensaries, clinics, and schools. Liberia currently does not have any large scale grid-tied solar PV plants even though there are potentials of them being economically and technically feasible. There is no major public sector investment in new solar power infrastructure specifically designed to mitigate climate change in Liberia at the moment.

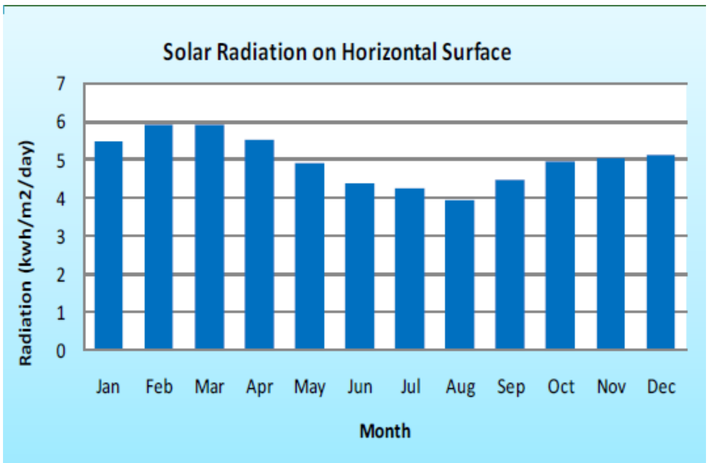

Figure 3.2: The Monthly Average Daily Solar Radiation in Liberia (Goanue, 2010).

Figure 3.3: The Global Solar Irradiation in Liberia (The World Bank, 2017)

- **Hydropower:** Two major hydropower stations with a total generating capacity of 68 MW or 17% of the total installed capacity of 412 MW existed in the country prior to the 14-year civil war (Republic of Liberia, 2009, Republic of Liberia 2006). They were the Mount Coffee and Firestone hydropower plants with installed capacities of 64 MW and 4 MW respectively. A 30 kW community micro hydropower facility located at Yandohun in Lofa County also existed.

With the exception of the Harbel plant owned by the Firestone Rubber Plantation Company, the Mount Coffee and Yandahun hydropower plants were destroyed during the war. However, in May 2013 the Yandohun micro hydropower plant was rehabilitated and commissioned to serve over 240 households. The project was implemented by the Rural Renewable Energy Agency (RREA) with funding provided by the World Bank. The rehabilitation of the Mount Coffee hydropower plant with installed capacity of 88 MW was initiated in May 2012. However, the Mount Coffee hydropower plant had to wait until December 2016 before it was finally rehabilitated and commissioned. Estimated cost for the rehabilitation is about $3830 million with financing coming from the Liberian government, the European Investment Bank, Kreditanstalt für Wiederaufbau (KfW) and the Norwegian government (Fashina *et al*., 2018).

Hydropower resources are the most researched and analysed of the known renewable energy sources in Liberia. Studies show that Liberia with hydropower potential of about 2,300 MW could be a net exporter of electricity if its hydroelectric potentials are substantially developed (Table 3.1) (Sandikie, 2015; USAID, 2015; World Bank, 2011). Liberia has abundance of well-distributed precipitation, rivers and streams across the nation. Some of the major rivers are the Cavalla, Cestos, Lofa, Mano, Saint John and the Saint Paul rivers. Small hydropower systems are usually useful because they can be developed exclusively off the national grid. The Government of Liberia intend to pursue the development of mini and micro hydro dams on its numerous rivers and streams. Hydropower which is acquired from various rivers and streams depends on rainfall that is susceptible to variation in climate. Consequently, the country suffers from reduced hydropower energy generation during periods of drought or low rainfall and therefore returns to the use of thermal plants to generate energy which leads to emissions of carbon dioxide (CO_2).

Table 3.1 Hydropower potential of six major rivers in Liberia (Sandikie, 2015)

Potential Site /Project	Capacity (MW)	Total Area (sq km)	Area in Liberia (sq km)
St Paul River	1,200	8,460	4,950
Lofa–Mano Diversion	518	4,100	3,550
St. John River	225	6,650	5,700
Cavalla River (jointly with Cote d'Ivoire)	250	11,670	5,300
Mano River (jointly with Sierra Leone)	150	3,200	2,440
Total	**2,343**	**34,080**	**21,940**

Biomass: Liberia is endowed with an abundance of biomass resources such as rich forest, oil palm and rubber plantations, cassava, sugarcane, rice, and other crop residues (Sandikie, 2015). The country's present energy production and use is dominated by the household energy sector whose main source of energy is traditional woody biomass for household cooking and heating. In Liberia, woody biomass from forest residue is the major biomass resource available (Figure 3.4). About 95 percent of all energy supply in the country is generated from biomass (Sandikie, 2015). In 2009 it was estimated that 70% of the urban population use charcoal for cooking as compared to 5% of the rural population; 91% of the rural population use firewood for cooking as compared to 21% of the urban population (Environmental Protection Agency, 2015). Hence, charcoal is used mainly in urban areas and firewood in the rural areas and among poor households in urban centres. A survey conducted by the Center for Sustainable Energy Technologies (CSET) in 2004, found that annual consumption of woody biomass was estimated at about 10.8 million m^3 for firewood, and 36,500 tons for charcoal. In the same survey, CSET found that firewood scarcity was a serious problem in most parts of Liberia. They also estimated that about 960,000 trees are cut down yearly for charcoal production to serve Monrovia alone.

Despite significant biomass resources in Liberia, there is no consensus on the amount of power that can be sustainably generated. Milbrandt (2009) estimated that Liberia has an energy production potential of 27,452 GWh per year from biomass. Other independent studies identified five sites of rubber plantations with the potential to support 80 MW of biomass-fired power plants, which require around 2,500 hectares of rubber trees per year (Missfeldt-Ringius, 2011). However, the economic and financial viability of biomass power, which relies on the sort of technology, the volume of the power plant and the expenses of fuel transport, has yet to be evaluated.

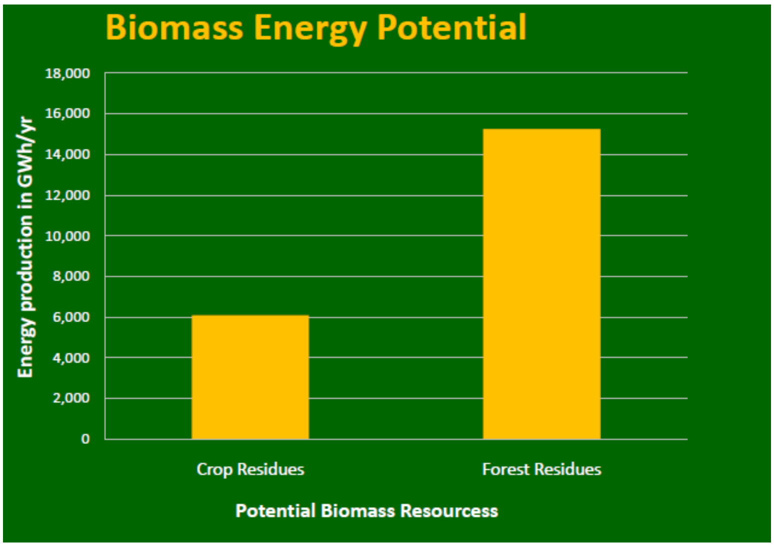

Figure 3.4 Biomass energy potential of Liberia (Goanue, 2009)

3.2 Decision context

The Republic of Liberia is committed to fulfilling its obligation for reducing greenhouse gas emission into the atmosphere. The numerous international conventions and protocols to which the country is signatory have demonstrated this commitment. In 2002, Liberia ratified the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol and has since implemented numerous programs related to climate change mitigation and adaptation. As a small country, Liberia is also a minor contributor to global warming. However, the country's susceptibility to the effects of the impending global and regional changes in addition to its commitment to protecting the global environment dictates the integration of national policies with international agreements.

The energy sector is Liberia's main contributor to GHG emissions followed by agriculture, which accounts for 31.9% Liberia’s GHG emissions while the remaining 0.6% of emissions is attributed to the waste sector (Environmental Protection Agency, 2013). The Initial National Communication research undertaken in 2013 showed a median annual growth of 14% in diesel and gasoline consumption since 2004. It is expected to grow by an approximately 10.3% until 2020 and by 3.4% between 2020 and 2028. Baseline electricity demand estimates range from 11 to 25 MW and will rise by an average of 10.3% annually by 2010 before slightly dropping to 3.4% annual growth by 2020 (Environmental Protection Agency, 2013). The Liberian government has chosen the energy sector as a key mitigation choice because of the country's fossil-fuel-dominated energy generation which is the primary source of GHG emissions.

The main decision context is based on the climate change vision and the targets set by the Liberia’s INC. Liberia's Initial National Communication (2013) strengthens the National Energy Policy with extra long-term objectives and associated operations, which includes:

- At least 10% reduction in GHGs by 2030,
- Improving energy efficiency by at least 20% by 2030,
- Raising share of renewable energy to at least 30% of electricity production and 10% of overall energy consumption by 2030,
- Replacing cooking stoves with low thermal efficiency (5-10%) with the higher efficiency (40%) stoves.

The TNA project's main objective is to identify and prioritize the use of renewable energy technologies to curtail the country's increasing GHG emissions from the energy sector. The decision context was agreed by stakeholders and the TNA team as previously mentioned in Chapter 2. Moreover, the decision context for the MCA exercise took into consideration the overall objective of the TNA project. Considerations such as the application of the technology, investment and operating costs, whether the technology will bring about social, economic, gender, and environmental benefits as well as the level of application and maturity of the technology in Liberia formed the criteria for the MCA exercise.

3.3 An overview of possible mitigation technology options in Energy Sector and their mitigation potential and other co-benefits

a) Solar PV for homes

Solar photovoltaic (PV), refers to the technology of using solar cells to convert solar radiation directly into electricity. Solar photovoltaic system for homes generates power especially in urban and rural areas where no connection to a grid or a local power station is available. A solar PV home system typically includes a PV module, a battery, a charge controller, wiring, light emitting diodes (LED) light bulbs, and outlets for other direct current (DC) appliances. A solar home system can eliminate or reduce the need for candles, kerosene, liquid propane gas, and/or battery charging, and provide increased convenience and safety, improved indoor air quality, and a higher quality of light than kerosene lamps for reading.

The size of such a system is typically from 10 to 100 Wp. For example, a 35 Wp solar home system provides enough power for four hours of lighting from four 7W lamps each evening, as well as several hours of television (Reiche *et al.*, 2000). Solar PV has a very low lifecycle cost of pollution per kilowatt-hour as compared to other technologies. Solar PV can play an important role in mitigating climate change because it has a lower GHG emissions lifecycle in the order of 30 to 70 gCO_2eq/kWh, as against more than 900 gCO_2eq/kWh for coal and more than 400 gCO_2eq/kWh for gas. Solar cells' major environmental impacts are linked to their manufacturing and decommissioning. Solar resources in Liberia are high and consistent across the country with an average level of 1,712 kWh/m^2 /year and potential for generation of 1,400 to 1,500 kWh/kWp.

b) Solar PV Grid tied

The technology involves installation of 1000 kW grid tied PV system. In contrast to solar thermal electricity generation, in the case of solar PV, solar energy is directly converted into electrical energy. The PV system uses numerous arrays of ground-mounted, fixed-tilt PV modules which directly convert incident solar radiation into DC electricity, which can then be inverted to AC.

Solar power generation has been limited to installation of rather small solar PV systems at homes and small establishments in rural and off-grid areas. The Government of Liberia is aware that despite limitations, there may be scope for power generation based on solar energy. The plants are small and therefore may be put up by the private sector with either a contract to sell the electricity to Liberia Electricity Company's grid; or, if put up enterprises, they may sell any surplus electricity to the grid.
Each of the small solar units will produce more or less 1000 kW. Being small, these may be suitable in off-grid areas for small communities as well as for commercial enterprises. This may allow a quality supply and ensure access of the people in poorer and remote region. With new supply of electricity, and consequent access to it, it may be used for all kinds of economic and domestic uses including lighting. The process of women's empowerment will be better served as with new access to electricity and they will enjoy facilities to which their access was limited previously. It can also

reduce their work on firewood collection. The negative aspect of solar PV is the high per unit cost. In fact, it is costliest in terms of capital requirement on a per MW basis.

c) Small hydropower plant

Small hydropower uses the flow of water to turn turbines connected to a generator for the production of electricity. Small hydro is divided into further categories depending on its size, such as mini- (less than 10 MW), micro-hydro (less than 100 kW) and pico-hydro (less than 5kW). Generating costs for mini hydro, micro hydro, and pico hydro range as follows 5-12, 7-30, and 20-40 US$ cents/kWh respectively and corresponding investments range between 1600-3500 US$/kW (Republic of Liberia, 2013).

Liberia has experience in construction of hydropower plants with a capacity of 60 kW. The Yandohun micro-hydro, implemented by RREA and financed by the World Bank, involved the rehabilitation of 60 kW to serve 240 households and was commissioned in May 2013. It is the country's first community-owned power system. The Mein River Hydropower Project in Suakoko District financed by USAID through the Liberia Energy Sector Support Project (LESSP), and the Nimba County project, supported by UNIDO and aiming to install multipurpose mini-hydro infrastructure, are still at the feasibility stage. These small-scale hydropower plants produce no carbon dioxide during operation, thus significantly contributing to GHG emission reduction efforts. They can also reduce air pollution and decrease the use of wood, charcoal and fossil fuels. In contrast to large-scale hydropower plants, small-scale plants barely alter the river flow; hence have few effects on the environment.

d) Solar lanterns

Solar PV systems including whole-home systems and lanterns that are charged from solar can be a clean source of lighting in homes and some institutions such as rural clinics and schools. Technology is mature but management of systems is still important. In rural areas where electricity is not available, this will be beneficial for many purposes e.g. providing lighting for students studying in schools and homes, lighting for women giving birth at night in clinics. Prices are still high for home systems and in case of institutions government provides systems but maintenance then requires local capacity.

e) Biodiesel

Biodiesel is used as a diesel substitute, and is generally blended with fossil diesel to various degrees. Biodiesel can be produced from various vegetable oils, such as rapeseed, palm, soybean and palm oil and animal fats (ECN, 2006). There are various routes to produce 1st generation diesel-type fuels from biomass. Transesterification, the most common route, is a catalytic process where fat or oil is combined with an alcohol (usually methanol). Two important by-products of this conversion route are glycerin and animal feed in the form of press cakes. The alternative route, hydrogenation, a process resembling oil refining, has so far seen limited deployment, although it produces a renewable diesel of superior quality (with higher blending potential) to that obtained via transesterification (IEA Bioenergy, 2009).

Most biofuels offer net GHG savings compared to fossil fuels, unless land area containing high carbon stocks (e.g. rainforest, peatland) is cleared to make way for biofuel feedstock plantations. Co-benefits include increasing energy security by producing and using biofuels locally, thus reducing the dependence on imported fossil oil; saving foreign currency by displacing fossil oil imports; earning foreign currency by producing biofuels for export and diversifying the industrial sector.

f) Methane Capture from Landfill

Organic waste at landfill sites is broken down by micro-organisms through the anaerobic (oxygen free) processes which result in the formation of landfill gas (LFG). LFG is a gaseous mixture which consists mostly of methane and carbon dioxide, but also of a small amount of hydrogen and occasionally traces levels of hydrogen sulphide (Tsave and Karapidakis, 2008). LFG capture projects aim at preventing the emissions of methane and other pollutants from landfills (Climate Tech Wiki, 2011). Methane capture from landfills entails the recovery and use of landfill gas (LFG) as an energy resource.

In Monrovia, the landfill sites are managed Monrovia City Corporation (MCC). The waste disposal method practiced in Liberia is open dumping and swampland reclamation (Milbrandt, 2009). There is a complete absence of engineered landfills. By gas, the largest contribution of GHG in Liberia comes from methane (CH_4), which contributes 51.6% of the total national GHG emissions (Republic of Liberia, 2015b).

The basic idea behind the technology is that the landfills are covered (e.g. by a layer of earth) and that LFG is extracted from landfills using a series of wells and a blower/flare (or vacuum) system. This system directs the collected gas to a central point where it can be processed and treated depending upon the ultimate use of the gas. From this point, the gas can be simply flared (thereby converting methane into CO_2) or used to generate electricity and/or heat, replace fossil fuels in industrial and manufacturing operations, or fuel greenhouse operations. The methane gas yield will depend on the nature of the landfill. For a large modern landfill, useable LFG may be generated for between 15 and 30 years.

g) Improved clean cook stove

A good improved clean cooking stove is one that meets technical, scientific and safety standards, and has high combustion quality, technical efficiency, minimal smoke emission, ergonomics and structural stability (Barnes *et al*., 1994). An improved clean cook stove is more comfortable and safe so that it can reduce a number of accidents. It also burns wood fuels more effectively, so the amount of dangerous particles that might be released is reduced (Climate Tech Wiki, 2006).

In Liberia, more efficient improved clean cookstoves are being promoted on the market but with limited patronage because of costs. According to Liberia's INDC, in 2004 it was estimated that over 95% of the population relied on firewood and charcoal for cooking and heating needs (Republic of Liberia, 2015b). In 2009 it was also estimated that 70% of the urban population use charcoal for cooking as compared to 5% of the rural population; 91% of the rural population use firewood for cooking as compared to 21% of the urban population. While charcoal and firewood are believed to be an affordable, available, and the most convenient fuel source for both urban and rural households in Liberia, their use in inefficient stoves produces significant amounts of indoor air pollution and makes them unsustainable.

h) Biogas Digester

Biogas capture and utilization presents an attractive opportunity for waste management in Liberia because it is a valuable renewable energy source that can be used to provide electricity while reducing methane emissions (Milbrandt, 2009). Biogas is the gaseous product of the anaerobic digestion process (decomposition in the absence of oxygen) using solid waste, organic waste, and other sources of biomass. Various types of microorganisms are involved in the process that finally produces biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2).

Methane has a very high global warming potential, which is 28 to 33 times higher than that of carbon dioxide. When burnt however, it becomes carbon dioxide. Since the organic matter can only release as much carbon (dioxide) as it previously took from the atmosphere, it is considered climate neutral and a form of renewable energy. The composition of biogas varies depending upon the origin of the anaerobic digestion process. Biogas digesters come in many forms and sizes, which may range from 1 m^3 for a small household unit to some 10 m^3 for a typical farm plant and more than 1,000 m^3 for a large installation (Energypedia, 2018). The use of waste as an energy source provides two important benefits for Liberia: environmentally safe waste management and disposal, as well as clean electric power generation. Waste-to-energy combustion reduces the volume of trash by about 90%, decreasing the amount of land required for garbage disposal by 90%.

i) Solar dryer

The principle of the solar drying technique is to collect solar energy by heating-up the air volume in solar collectors and conduct the hot air from the collector to an attached enclosure (JIN, 2006). Solar drying involves the removal of moisture from produce so as to provide a product that can be safely stored for longer periods. The solar drying method uses indirect solar radiation. The principle of the solar drying technique is to collect solar energy by heating-up the air volume in solar collectors and conduct the hot air from the collector to an attached enclosure.

Solar dryer technology can be utilized in small-scale food processing industries for producing hygienic, high-quality food products. It will also promote renewable energy sources as income-generating units, apart from saving the world from the ill effects of climate change. There is potential for applying solar dryers to dry cereals such as maize, wheat and rice after harvesting.

j) Briquette Production

Briquette production is becoming predominant in most developing countries since it serves as a substitute for charcoal and other fuel commodities. It also has an advantage of reducing deforestation which will eventually reduce greenhouse effects. It is also a means of providing clean environment since most waste will be used as resource for making these briquettes.

The transformation of organic wastes such as municipal solid waste, market waste and agricultural residues into briquettes, using simple and low-cost technology, has the potential to enhance sustainable development while raising the living standards of the poor in developing countries. Briquettes can be burned in the same ordinary wood stoves without loss of efficiency. Although several biomass-based energy projects have been undertaken in Liberia with various degrees of success, briquette businesses are not common in Liberia. In Liberia a company called Green Gold is piloting the commercial production of briquettes on the outskirts of Monrovia with its ‘Fayacoal’ brand by supplementing the bio-char with discarded charcoal dust salvaged from urban trading sites (World Bank, 2019).

3.4 Criteria and process of technology prioritisation for the energy sector

The workshop to prioritize mitigation technologies for the energy sector was held on April 1, 2019. The workshop was organized in two sessions. In the first session all participants were presented with a general overview of the TNA project and process. The second session was a breakout session where participants moved to their respective sectors for the prioritization of technologies exercise to commence. The prioritization was carried out using the MCA Excel template tool.

Prior to the MCA prioritization exercise, technology factsheets (TFS) prepared as mentioned in section 2.2 of this report were presented to all stakeholders of the Mitigation Sectoral Working Group (MSWG). They were allowed some time to critically review and discuss the TFS. Once the members of the group had reviewed, discussed and were satisfied with the TFS, a PowerPoint presentation was presented by the National Consultant for the Energy sector on the MCA process – the selection of criteria, the assignment of weights and proposed approach to scoring. After a lengthy deliberation where stakeholders presented their views and opinions, stakeholders of the group finally agreed that the criteria for selection will be categorized as cost, economic, social, environmental and climate related. These criteria were then inputted into the MCA Excel template.

The next step was the assignment of weights for each criterion. Weights were assigned using a participatory method where stakeholders took in to consideration the relative importance of each criterion. Stakeholders first allocated weights to the criteria categories and then later apportioned these weights to each of the criteria under the category. Table 3.2 shows the criteria, categories and weight distribution finally agreed by the stakeholders.

The scoring was the last step for deliberations. By consensus, members of the group agreed that the scoring matrix for each criterion's scores was from 0 to 100 where the most preferred option was assigned a score of 100, while the least preferred was given a score of 0. Hence, scores of 0 to 100 were given to each criterion during the evaluation of each technology using the MCA template. The results are provided in Table 3.3.

Table 3.2 Criteria category and criteria weights for MCA

Category	**Weight (%)**	**Criteria**	**Weight (%)**
Cost	20	Capital	15
		Operations & Maintenance	5
Economic	20	Job creation	10
		Increased Industrialization	5
		Attracting investment	5
Social	30	Improved health	5
		Gender sensitivity	10
		Skill & Capacity Development	8
		Energy security	7
Environmental	20	Reduced pollution	10
		Conservation of ecosystem	10
Climate related	10	Reduced GHG emissions	10

3.5 Results of technology prioritisation for energy sector

The MCA Excel tool used the inputted weights and scores to calculate the overall score for each technology. Results as provided in Tables 3.3 to 3.5. Table 3.3 provides results for MCA performance matrix of each technology in the energy sector as scored by stakeholders. Table 3.4 shows results for MCA scoring matrix including assigned weights for all criteria. Table 3.5 provides results for MCA decision matrix of technology prioritization in the energy sector.

Table 3.3: Results of MCA Performance Matrix for Technologies in the Energy Sector

Performance Matrix												
	Costs		Benefits									
			Economic			Social				Environmental		Climate related
	Capital	Operations & Maintenance	Job Creation	Increased industrialization	Attracting investments	Improved health	Gender sensitivity	Skill & Capacity Development	Energy security	Reduce pollution	Conservation of ecosystem	Reduced GHG emissions
Solar Home PV System	80	90	100	70	90	95	80	20	80	50	0	90
Solar PV Grid-tied	20	30	80	90	85	90	85	40	60	90	40	90
Solar Lantern	100	80	10	10	5	85	60	10	20	50	0	50
Biodiesel	10	20	90	80	30	40	50	60	55	50	30	50
Small Hydropower	40	60	50	90	50	60	55	60	60	60	75	90
Methane Capture from Landfill	5	5	10	20	5	50	5	40	30	70	60	80
Biogas Digester	40	60	20	20	10	30	5	20	5	50	60	60
Improved clean cook stove	50	80	55	50	35	90	85	60	70	70	40	45
Solar dryer	80	90	25	40	45	90	85	40	30	60	50	45
Briquette Production	70	60	60	20	30	70	70	50	55	70	70	65

Table 3.4 Results of MCA Scoring Matrix for Technologies in the Energy Sector

	Scoring Matrix (For each criterion scores should vary from 0 to 100)													
	Costs		Benefits											
			Economic			Social				Environmental		Climate related		
	Capital	Operations & Maintenance	Job Creation	Increased industrialization	Attracting investments	Improved health	Gender sensitivity	Skill & Capacity Development	Energy security	Reduced pollution	Conservation of ecosystem	Reduced GHG emissions		
Solar Home PV System	80	90	100	70	90	95	80	20	80	50	0	90		
Solar PV Grid-tied	20	30	80	90	85	90	85	40	60	90	40	90		
Solar Lantern	100	80	10	10	5	85	60	10	20	50	0	50		
Biodiesel	10	20	90	80	30	40	50	60	55	50	30	50		
Small Hydropower	40	60	50	90	50	60	55	60	60	60	75	90		
Methane Capture from Landfill	5	5	10	20	5	50	5	40	30	70	60	80		
Biogas Digester	40	60	20	20	10	30	5	20	5	50	60	60		
Improved clean cook stove	50	80	55	50	35	90	85	60	70	70	40	45		
Solar dryer	80	90	25	40	45	90	85	40	30	60	50	45		
Briquette Production	70	60	60	20	30	70	70	50	55	50	50	65		
Criterion weight	**15**	**5**	**10**	**5**	**5**	**5**	**10**	**8**	**7**	**10**	**10**	**10**	**100**	**should add to 100**

Table 3.5 Results of MCA Decision Matrix for Technologies in the Energy Sector

Decision Matrix: Weighted Scores														
	Costs		Benefits										Total score	
			Economic			Social				Environmental		Climate related		
	Capital	Operations & Maintenance	Job Creation	Increased industrialization	Attracting investments	Improved health	Gender sensitivity	Skill & Capacity Development	Energy security	Reduced pollution	Conservation of ecosystem	Reduced GHG emissions		
Solar Home PV System	1200	450	1000	350	450	475	800	20	560	500	0	900	6705	**1**
Solar PV Grid-tied	300	150	800	450	425	450	850	40	420	900	400	900	6085	**2**
Solar Lantern	1500	400	100	50	25	425	600	10	140	500	0	500	4250	7
Biodiesel	150	100	900	400	150	200	500	60	385	500	300	500	4145	8
Small Hydropower	600	300	500	450	250	300	550	60	420	600	750	900	5680	**3**
Methane Capture from Landfill	75	25	100	100	25	250	50	40	210	700	600	800	2975	10
Biogas Digester	600	300	200	100	50	150	50	20	35	500	600	600	3205	9
Improved clean cook stove	750	400	550	250	175	450	850	60	490	700	400	450	5525	4
Solar dryer	1200	450	250	200	225	450	850	40	210	600	500	450	5425	5
Briquette Production	1050	300	600	100	150	350	700	50	385	500	500	650	5335	6
Criterion weight	**15**	**5**	**10**	**5**	**5**	**5**	**10**	**8**	**7**	**10**	**10**	**10**	**100**	

As shown in Table 3.5, the results from the prioritization exercise for the three technologies prioritized (numbers in red colour) in order of score attained were:

1. Solar Home PV System
2. Solar PV Grid-tied System
3. Small Hydropower

Sensitivity analysis was carried out after the prioritization to determine whether rankings change significantly for small changes in the scores. No significant modifications in the ranking. It is interesting to note that the technologies that ranked as 4, 5 and 6 have scores that are quite similar to the technology ranked as number 3. Expert stakeholders at the workshop attributed this to the fact that these technologies are important for Liberia in terms of development and mitigation benefits especially since the country is still recovering from a protracted civil conflict and an Ebola virus outbreak. It is also important to note that the higher ranked technologies broadly correspond to Liberia development priorities.

Chapter 4 Summary and Conclusions

The technology needs assessment for climate change mitigation in the energy sector of Liberia has been conducted through a participatory stakeholders' engagement process. Firstly, the TNA process involved the selection of the energy sector by stakeholders at the inception workshop for mitigation and secondly identifying and prioritizing mitigation technologies for the sector. The main strategies used to identify and prioritize mitigation technologies were reviewing literature, applying multi-criteria analysis and applying expert judgment. The technology prioritization workshop to select three priority technologies was held on 1st April 2019. The workshop followed the steps and methodologies for technology prioritization from the UNEP DTU Partnership TNA guidebook *(TNA Step by Step – A guidebook for countries conducting a Technology Needs Assessment and Action Plan)*

The MCA exercise enables stakeholders to select priority technologies in an objective and consensus-based way. The three highest scored technologies for the energy sector were the Solar Home PV system, Solar PV grid-tied system and small hydropower. These prioritized technologies for reducing greenhouse gas emissions are consistent with Liberia's Initial National Communication and its national development agenda as expressed in the Pro-Poor Agenda for Development and Prosperity. The next phase of the TNA project will concentrate on understanding the different barriers and limitations to the implementation and diffusion of the prioritized technologies in the country.

List of References

Barnes, D.F., Openshaw, K., Smith, K.R. and Plasvander, R. (1994). What Makes People Cook with Improved Biomass Cookstoves: A Comparative International Review of Stove Programs. Technical Paper Number 242, World Bank.

Bioenergy, I. E. A. (2009). Bioenergy–a sustainable and reliable energy source. International Energy Agency Bioenergy, Paris, France.

Center for Sustainable Energy Technology (2004). Bridging the Energy Gap in Post-war Liberia: The Need for Alternative Energy Services.

Charlery, L. & Trærup, S. (2019). The nexus between nationally determined contributions and technology needs assessments: a global analysis, Climate Policy, 19:2, 189-205.
DOI: 10.1080/14693062.2018.1479957

ClimateTechWiki, http://climatetechwiki.org/

Climate Tech Wiki. (2006). Improved cook stoves. Retrieved from http://www.climatetechwiki.org /technology/imcookstoves.

Climate Tech Wiki. (2011). Methane Capture at Landfills for Electricity and Heat. Retrieved from: http://climatetechwiki.org/technology/lfg_cap.

Energy Information Administration (EIA). (2010). Updated Capital Cost Estimates for Electricity Generation Plants. Office of Energy Analysis. U.S. Department of Energy: Washington, DC.

Energypedia. (2017). Cooking with Biogas. https://energypedia.info/wiki/Cooking_with_Biogas

Energy Research Center of the Netherlands (ECN). (2006). Biodiesel, Retrieved from https://www.climatetechwiki.org/technology/biodiesel

Environmental Protection Agency (EPA). (2010). Nationally Appropriate Mitigation Actions for Liberia. Retrieved from
http://www.lr.undp.org/content/dam/liberia/docs/docs/Liberia_NAMA_Study%202013.pdf

Environmental Protection Agency (EPA). (2013). Liberia Initial National Communication, Liberia, Monrovia.

Environmental Protection Agency (EPA). (2015). Intended Nationally Determined Contributions, Liberia, Monrovia.

EPA (2003). The National Environmental Policy of Liberia, 2003. EPA, Monrovia.

Fashina, A. A., Akiyode, O. O., & Sanni, D. M. (2018). The Status Quo of Rural and Renewable Energy Development in Liberia: Policy and Implementation. doi: 10.14419/e.v1i1.14518 http://www.sciencepubco.com/index.php/E

GEF. (2018). Agency notification on amended FSP: Technology needs assessment – Phase III. Washington, DC: Global Environment Facility.

Goanue, A.V. (2009). Status of renewable energy in Liberia. Presentation of Rural and Renewable Energy Agency.

Goanue, A.V. (2010). National Issue Paper: Assessing and developing policy options for addressing climate change mitigation across the energy sector of Liberia. United Nations Development Programme (UNDP).

Government of Liberia. (2010). Liberia Rising 2030. Monrovia: Ministry of Planning.

Government of Liberia. (2018). Pro-Poor Agenda for Prosperity and Development [PAPD]. Retrieved from: https://www.emansion.gov.lr/doc/ProPoor%20Agenda%20For%20Prosperity%20And%20Development%20book%20for%20Email%20sending%20(1).pdf%20-%20Compressed.pdf

Haselip, J., Narkeviciute, R., Rogat, J., Traerup, S. (2019). TNA Step by Step – A guidebook for countries conducting a Technology Needs Assessment and Action Plan. UNEP DTU Partnership. Retrieved from http://www.tech-action.org/Publications/TNA-Guidebooks

Joint Implementation Network (JIN). (2006). Solar dryer. https://www.climatetechwiki.org/technology/jiqweb-edf

Milbrandt, A. (2009). "Assessment of Biomass Resources in Liberia." National Renewable Energy Laboratory (NREL). USA http://www.nrel.gov/docs/fy09osti/44808.pdf.

Missfeldt-Ringius, F., Romo, Z., Graham, E., Berlengiero, M., Mathews, B., & Park, J. S. (2011). Options for the development of Liberia's energy sector. Washington DC: The World Bank. African Energy Unit Policy Note series, (63735-LR), 717305-1266613906108.

Reiche, K., Covarrubia, J., Martinot, E., (2000). Expanding electricity access to remote areas: off-grid rural electrification in developing countries. World Power, 52–60.

Republic of Liberia. (2006). Renewable Energy and Energy Efficiency Policy and Action Plan of Liberia. Ministry of Land, Mines, and Energy, Monrovia, Liberia.

Republic of Liberia. (2009). National Energy Policy: an agenda for action and economic and social development. Ministry of Land, Mines, and Energy, Monrovia, Liberia.

Republic of Liberia. (2012a). Agenda for Transformation (AfT) (Vision 2030). Liberia, Monrovia.

Republic of Liberia. (2012b). Climate Change and Gender Action Plan for the Government of Liberia, Liberia, Monrovia.

Republic of Liberia. (2013). Liberia Investment Plan for Renewable Energy (IPRE). Monrovia, Liberia. Retrieved from: https://rrealiberia.org/forest/pg_img/Liberia%20IPRE%2010%2003%202013%20Final.pdf

Republic of Liberia. (2015a). Electricity Law of Liberia. Available at: https://www.rrealiberia.org/forest/doc_download/2015%20Electricity%20Law%20of%20Liberia.pdf

Republic of Liberia. (2015b). Intended Nationally Determined Contributions (INDC). Environmental Protection Agency of Liberia, Monrovia, Liberia.

Republic of Liberia. (2018). National policy and response strategy on climate change. http://www.epa.gov.lr/sites/default/files/National%20Policy%20and%20Response%20Strategy%20on%20Climate%20Change%20Final%20Document-min_0.pdf.

Rural Renewable Energy Agency (RREA) (2016). Rural energy strategy and master plan for Liberia until 2030. Republic of Liberia. Retrieved from http://gestoenergy.com/wp-content/uploads/2016/08/RESMP-Liberia_Brochure.pdf

Sandikie, J.S. (2015). Liberia Sustainable Energy for All (SE4ALL) Access Agenda Report 2015. Ministry of Lands, Mines, and Energy: Republic of Liberia.

Tsave, A.A., & Karapidakis, E.S. (2008). Landfill Gas (LFG) Plants: An application on energy regarding environmental impact. Journal of Optoelectronics and Advanced Materials, 10(5), 1277.

UN, 1992. United Nations Framework Convention on Climate Change. Available: http://unfccc.int/resource/docs/convkp/conveng.pdf. (Accessed on June 17, 2018).

UNDP (2018). Liberia ratifies Paris Agreement on climate change in 'milestone achievement' to foster low-carbon climate-resilient development. Available at: https://www.adaptation-undp.org/liberia-ratifies-paris-agreement-climate-change-%e2%80%98milestone-achievement%e2%80%99-foster-low-carbon-climate

USAID. (2015). Power Africa – Investment brief for the Electricity Sector in Liberia. Available at: https://www.usaid.gov/sites/default/files/documents/1860/Liberia%20_IG_2015_05_03.pdf

USEPA. (2015). LFG Energy Project Development Handbook. Landfill Methane Outreach Program (LMOP), Washington, DC.

World Bank. (2011). Options for the Development of Liberia's Energy Sector. AFTEG Energy Sector Policy Notes Series, Report No. 63735-LR. The World Bank Group, Washington D.C.

World Bank. (2017). Global Solar Horizontal Irradiation of Liberia. Solar resource data: Solargis. https://solargis.com/maps-and-gis-data/download/liberia. (Accessed July 2, 2019).

World Bank. (2019). Liberia Forest Sector Project - Opportunities for Charcoal and Sustainable Forest Management. Available online: http://documents.worldbank.org/curated/en/145661549384956090/pdf/134365-REPLACEMENT-134365-WP-P154114-PUBLIC-5-2-2019-16-19-14-LiberiacharcoalreportJanFINAL.pdf

World Development Indicator Data. The World Bank IBRD-IDA (2016). Forest area (percentageof land area). Food and Agriculture Organization, electronic files. Available online: http://data.worldbank.org/indicator/AG.LND.FRST.ZS. (Accessed on June 17, 2019).

Annex I: Technology Factsheets for selected technologies

Sector	**Power generation**
Technology Name	**Solar PV for homes**
Subsector GHG emissions	5,414 Gg CO_2 Equiv.
Background/Notes, Short description of the technology option	Solar photovoltaic, or simply photovoltaic (SPV or PV), refers to the technology of using solar cells to convert solar radiation directly into electricity. A solar cell works based on the photovoltaic effect. R&D and practical experience with photovoltaic have led to the development of three generations of solar cells: Crystalline silicon based solar cells, thin film solar cells and third generation PV. Solar PV is very likely to play a significant role in climate change mitigation in the future. However, today, inspite of significance decreases in the cost for solar PV systems, the majority of PV deployment is still driven by substantial subsidy schemes.
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Liberia is located near to the equator where the conditions are generally favorable for any kind of use of solar radiation. Estimates from satellite measurements suggest monthly average daily solar radiation between 6.02 kWh/m^2/d in February/March to 3.85 kWh/m^2/d in July/August which shows good prospects for photovoltaic systems. Total production of 1400 - 1700 kwh/kW peak (including losses) is a realistic figure for concept evaluations. There is potential for solar power generation especially in rural areas where no connection to a grid or a local power station can be made available. Possible solutions in combination with other sources and storage systems will be encouraged, taking into account that power generation by photovoltaic systems is not in accordance with times of maximum use of electricity.
Implementation barriers	• High investment cost for design and installation. • Need skilled accredited installers. • Need good solar insolation regime
Reduction in GHG emissions	No greenhouse gas (GHG) emissions
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	• Lighting for studies will improve leading to better education prospects as well as security. • The process of women's empowerment will be better served as with new access to electricity they may enjoy facilities to which their access was limited previously. • Training in the technology may lead to more training and spread of technology application.
Country economic development priorities -economic benefits	• Creation of jobs and the establishment of new enterprises. • Poverty will be reduced as more and more jobs are created and people are gainfully employed.

	• Far less costly than using gasoline/diesel generators or use of kerosene and batteries. Subsidies may be needed for affordability • Increases rate of access to electricity services and thus to good growth of economy • Reduction of exodus from rural to urban areas
Country environmental development priorities	• Solar PV is an environmentally friendly technology as there is no emission of GHGs or SO_2 or NO_x.
Costs	
Capital costs	The costs of a small stand-alone solar PV systems is US$ 12/Wp
Operational and Maintenance costs	Negligible operating and maintenance costs over lifetime of systems (25 years). Need to change electronics (e.g. inverter) maybe once during lifetime.
Cost of GHG reduction	The total cost of a solar PV is the cost of GHG reduction from plants that it replaces which is not unique by country. But as the capital costs are rather high, for equivalent power production the costs of zero emission under solar PV are rather high.
Lifetime	25 years

Sector	**Power Generation**
Technology Name	Solar PV Grid tied
Subsector GHG emissions	5,414 Gg CO_2 Equiv.
Background/Notes, Short description of the technology option	The following describes a nominally 1000 kW Grid tied Photovoltaic (PV) system. In contrast to solar thermal electricity generation, in case of solar photovoltaic, solar energy is directly converted into electrical energy. The PV system uses numerous arrays of ground-mounted, fixed-tilt PV modules which directly convert incident solar radiation into DC electricity, which can then be inverted to AC. the basic structure of a photovoltaic cell consisting of p-conducting base material and an n-conducting layer on the topside. The entire cell rear side is covered with a metallic contact while the irradiated side is equipped with a finger-type contact system to minimize shading losses. Also full cover, transparent conductive layers are used. To reduce reflection losses the cell surface may additionally be provided with an anti-reflecting coating. A silicon solar cell with such construction usually has a blue color. By the incorporation of inverse pyramids into the surface reflection losses are further reduced. The inclination of the pyramid surfaces is such that photons are reflected onto another pyramid surface, and thus considerably enhance the possibility of photon penetration into the crystal (EIA, 2010).
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Solar power generation has been limited to installation of rather small solar PV systems at homes and small establishments in rural and off-grid areas. The Government of Liberia is aware that despite limitations, there may be scope for power generation based on solar energy. Given that space is a constraint in this country; such facilities need to be small, such as the proposed plant here, so that solar panels do not take much space. The plants are small and therefore may be put up by the private sector with either a contract to sell the electricity to Liberia Electricity Company's grid; or, if put up enterprises, they may sell any surplus electricity to the grid. The negative aspect of the solar PV is the high per unit cost. In fact, it is costliest in terms of capital requirement on a per

	MW basis.
Implementation barriers	• High investment cost for design and installation. • Need skilled accredited installers. • Need good solar insolation regime
Reduction in GHG emissions	No greenhouse gas (GHG) emissions
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	• Each of the small solar units will produce more or less 1000 kW. • Being small, these may be suitable in off-grid areas for small communities as well as for commercial enterprises. This may allow a quality supply and ensure access of the people in poorer and remote region. • With new supply of electricity, and consequent access to it, it may be used for all kinds of economic and domestic uses including lighting. • The process of women's empowerment will be better served as with new access to electricity they may enjoy facilities to which their access was limited previously and reduce their work on firewood collection • Improved security and safety conditions.
Country economic development priorities -economic benefits	• Creation of jobs and the establishment of new enterprises. • Poverty will be reduced as more and more jobs are created and people are gainfully employed. • Increases rate of access to electricity services and thus to good growth of economy • Reduction of exodus from rural to urban areas • Reduced fossil fuel-based power generation and reduced dependency on fuel import costs • Less costly than diesel generation
Country environmental development priorities	• Solar PV is an environmentally friendly technology as there is no emission of GHGs or indirect GHGs e.g.SO_2 or NO_x. • Reduction in the use of wood, charcoal, and petroleum fuels consumed by households will reduce indoor pollution.
Costs	
Capital costs	Capital cost of grid-tied Solar PV for Liberia for projects in the range 500 to 1000 kW range is estimated at US$ 2,700/kW.
Operational and Maintenance costs	Unknown
Cost of GHG reduction	Unknown
Lifetime	25 years

Sector	Lighting
Technology Name	**Solar Lanterns**
Subsector GHG emissions	5,414 Gg CO_2 Equiv.
Background/Notes, Short description of the technology option	Solar PV systems including whole-home systems and lantern that are charged from solar can be clean source of lighting in homes and some institutions such as rural clinics and schools. Technology is mature but management of systems is still important. With only 1.2% of the rural population connected to the grid, the need for off-grid lighting and energy products in Liberia is immense. Solar lantern is a cheap alternative to a Solar Home System (SHS) providing 4-5 hours of high quality lighting service. It provides higher quality light than the use of candles or kerosene lamps. It uses a PV panel to charge up a 12-Volt lead-acid gel cell battery located in the base of the lamp which is designed to withstand many charge/ discharge cycles.
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Most people in rural Liberia have no access to electricity. The World Bank project Lighting lives in Liberia (LLL) imports solar lamps through Government´s Rural and Renewable Energy Agency (RREA) and supplies as well as supports (e.g. small loans, marketing support) selected business people, who can afford buying larger quantities of lamps and thus became solar lamp retailers. Most challenges of both retailers and sales agents clustered around transportation costs, reaching customers who are able and willing to pay and difficulties of their customers to pay cash at once. Many persons are interested in the lamps, but not many are able and/or willing to pay, finding the price for the lamp (35USD) rather high.
Implementation barriers	▪ High initial cost ▪ Lack of finance ▪ Lack of technical capacity ▪ Poor quality products in the informal markets
Reduction in GHG emissions	Reduction of 320 kg CO_2/household/year
Impact Statements – How this option impacts the country development priorities	
Country **social** development priorities	▪ Provision of good light in the evenings allows the following activities not usually available: • children can do their homework, • radio provides a link to engage people with the political process, • savings can be used for education or health care, • social gatherings can take place in the evening, • Night classes and economic activities are also possible. ▪ Teachers can make better teaching preparations if they had lighting in the evening.
Country **economic** development priorities -economic benefits	• Significant cost savings for households over the lifetime • Ability to undertake income-generating activities at night • Create new jobs and areas of employment

Country **environmental** development priorities	• GHG reduction • Replace the use of kerosene and diesel power • Reduce exposure to indoor air pollution from diesel generators, kerosene lamps and candles • reducing pollution, and dry cell batteries
Costs	
Capital costs	Solar lanterns cost end users between US$10 and US$45, depending on the model. Solar home and institutional systems depend on sizes but range from US$7-12/Watt.
Operational and Maintenance costs	No other running costs except for intermittent battery replacement
Cost of GHG reduction	Unknown
Lifetime	LEDs have a long lifetime of 100,000 hours or about 11 years.

Technology Name	**Biodiesel**
Subsector GHG emissions	46 Gg CO_2 Equiv.
Background/Notes, Short description of the technology option	Biodiesel is used as a diesel substitute, and is generally blended with fossil diesel to various degrees. In Europe, the fuel standard permits only up to 5% biodiesel blend, mainly due to limitations imposed by fuel and vehicle specifications. Using blends over 20% may require some modest vehicle adaptations. Higher biodiesel fuel blends are sometimes used in fleet vehicles (e.g. trucks and buses) (IEA Bioenergy, 2009). Depending on the feedstock and conversion route, we can distinguish 1st and 2nd generation biodiesel. 1st generation biodiesel can be produced from various vegetable oils, such as rapeseed, palm, soybean and palm oil and animal fats (Source: climatetechwiki.org). There are various routes to produce 1st generation diesel-type fuels from biomass. Transesterification, the most common route, is a catalytic process where fat or oil is combined with an alcohol (usually methanol). Two important by-products of this conversion route are glycerin and animal feed in the form of press cakes. The alternative route, hydrogenation, a process resembling oil refining, has so far seen limited deployment, although it produces a renewable diesel of superior quality (with higher blending potential) to that obtained via transesterification (IEA Bioenergy, 2009).
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Transesterification and hydrogenation are technically mature and commercially available 1st generation technologies that produce biodiesel from vegetable oil and animal fats. (IEA Bioenergy, 2009). The bulk of global biodiesel production is in Europe, which accounts for the largest part of the global biodiesel supply (with Germany and France the largest European producers), as a result of past support for domestic bio-fuel production. Most biofuels offer net GHG savings compared to fossil fuels, unless land area containing high carbon stocks (e.g. rainforest, peat land) is cleared to make way for biofuel feedstock plantations.

Implementation barriers	• Production of biodiesel depends mainly on sufficient provision of economical vegetable oils and animal fats used as feedstock. The production of biomass is limited by the availability of land and crop yields. Yield improvements require significant investment into fertilizers, mechanization and training of farmers to improve agricultural practices. • The specific properties of biomass: low energy density, often requiring drying and densification; seasonal availability and problematic storage; • Factors limiting the supply: availability and appropriateness of mechanized equipment; and inadequate infrastructure to access conversion facilities and markets.
Reduction in GHG emissions	110 thousand tons CO_2 in 2030
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	• Job creation in the agriculture and forestry sectors, which is particularly relevant for developing countries with significant unused land resources and a large pool of unskilled workers; • Job creation in the industrial sector (e.g. a 125 million liter ethanol plant would employ about 270 people (Gnansounou et al., 2005); • Increasing farm incomes: provided the additional income is distributed equitably, increasing the income in the primary sector, which employs the majority of the workforce, can support rural development and significantly improve living standards; • Increasing inclusion in the economic system: well-organized farmers unions can gain access to energy markets.
Country economic development priorities -economic benefits	• Increasing energy security by producing and using bio-fuels locally, thus reducing the dependence on imported fossil oil; • Saving foreign currency by displacing fossil oil imports;- Earning foreign currency by producing bio-fuels for export. • Diversifying the industrial sector.
Country environmental development priorities	• GHG emission reduction: most bio-fuels offer net GHG savings compared to fossil fuels, unless forest land areas are cleared to make way for bio-fuel feedstock plantations.
Costs	
Capital costs	Depending on the feedstock used and scale of the plant, production costs can differ significantly. Because of lower average costs, larger plants (of capacity greater than 200 million liters per year) have dominated among new installations. Production costs range from roughly \$0.50/l to \$1.60/l, (IEA Bioenergy, 2009). For a plant with a production capacity of 220 million liters / year investment costs are \$ 26.1 million.
Operational and Maintenance costs	Estimated at \$ 0.02 / liter, given the plant capacity of 220 million liters / year, \$ 4.4 million / year.
Cost of GHG reduction	GHG reduction cost is US\$ 278 /ton CO_2
Lifetime	50 years

Sector	**Power Generation**
Technology Name	**Small hydro power**
Subsector GHG emissions	5,414 Gg CO_2 Equiv.
Background/Notes, Short description of the technology option	Small hydro power uses the flow of water to turn turbines connected to a generator for the production of electricity. Small hydro is divided into further categories depending on its size, such as mini- (less than 10 MW), micro-hydro (less than 100kW) and pico-hydro (less than 5kW). Generating costs for mini hydro, micro hydro, and pico hydro range as follows 5-12, 7-30, and 20-40 US$ cents/kWh respectively and corresponding investments range between 1600-3500 US$/kW.
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Liberia has experience in construction of hydropower plants with capacity of 60 kW. The Yandohun micro-hydro, implemented by RREA and financed by the World Bank, involved the rehabilitation of 60 kW to serve 240 households and was commissioned in May 2013. It is the country's first community-owned power system. The Mein River Hydropower Project in Suakoko District, financed by USAID through the Liberia Energy Sector Support Project (LESSP), and the Nimba County project, supported by UNIDO and aiming to install multipurpose mini-hydro infrastructure, are still at the feasibility stage.
Implementation barriers	• May conflict with water use for other needs. • Must be designed to avoid environmental issues related to water use/diversion. • Social conflicts related to land use and transmission right of way have to be resolved
Reduction in GHG emissions	Replacement of diesel engine power generators , wood and charcoal fuels will result in a significant decrease in GHG emissions
Impact Statements – How this option impacts the country development priorities	Increase country energy security
Country **social** development priorities	• Facilitating irrigation and drainage, improving productivity and enhancing product quality. • Improving quality of health service, education and freshwater supply in the area. • Reduced fossil fuel-based power generation and reduced dependency on fuel import costs • Improving women's access to energy and reducing their work on fuel wood collection • Encouraging productive energy use in rural areas
Country **economic** development priorities -economic benefits	• Less costly economically than diesel and HFO thermal generation. • Good financial returns if risks mitigated

	• Providing jobs through construction and operation of the hydropower plant to local population. • Promoting and creating new economic activities and enhancing income in areas that are supplied with electricity. http://climatetechwiki.org/technology/smallhydro
Country **environmental** development priorities	• Small-scale hydropower produces no carbon dioxide during operation, thus significantly contributing to GHG emission reduction efforts. • Reduced air pollution • In contrast to large-scale hydropower plants, small-scale plants barely alter the river flow, hence they have few effects on the environment. • Decrease the use of wood, charcoal and fossil fuels
Costs	
Capital costs	Cost estimate compiled by the African Development Bank (AfDB) for a range of capital costs for small hydro projects in various African countries is US$ 5,060/kW – US$12,000/kW with an average of US$ 7,600/kW.
Operational and Maintenance costs	O & M cost is estimated at about 1.5% of capital cost per annum
Cost of GHG reduction	The total savings would be approximately 1,344,120 tCO_2 equivalent
Lifetime	30 years,

Sector	**Electricity Power Supply**
Technology Name	**Methane Capture from Landfills**
Subsector GHG emissions	1586 kt of CO_2 equivalent
Background/Notes, Short description of the technology option	Municipal Solid Waste (MSW) is waste generated by commercial and household sources that is collected and either recycled, incinerated, or disposed of in MSW landfills. Landfill gas (LFG) is created as solid waste decomposes in a landfill. Methane capture from landfills entails the recovery and use of landfill gas (LFG) as an energy resource. This gas consists of about 50 percent methane (the primary component of natural gas), about 50 percent carbon dioxide (CO2), and a small amount of non–methane organic compounds (USEPA, 2015). LFG is created as solid waste decomposes in a landfill. Solid Waste Management in Liberia is the responsibility of local authorities. In Monrovia, the MSW are managed Monrovia City Corporation (MCC). The waste disposal method practiced in Liberia is open dumping and swampland reclamation. There is a complete absence of engineered landfills. Instead, there are many dumpsites available in proximity to major communities posing threat to humans' health, wetland ecosystems, and water resources. By gas, the largest contribution of GHG in Liberia came from methane (CH4), which contributed 51.6% of the total national GHG emissions.There is potential for methane gas capture in municipal landfill in cities like

	Monrovia and other cities in the country. The captured methane gas can be used for electricity generation. The Monrovia City Corporation (MCC) owns the Whein Town landfill and is responsible for its environmental, health and safety performance. LFG capture is currently not occurring at the site. It is estimated that the landfill receives approximately 350 tons per day of municipal waste. However, the biogenic materials (paper, wood, textiles, and vegetable) are 64% of total MSW or about 172,000 tons, based on the waste composition in Liberia. The electrical energy from the biogenic portion of the MSW in Liberia's major urban areas, via thermo-chemical conversion, is estimated at 52 GWh per year (Climate Tech Wiki, 2011).
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	LFG capture projects aim at preventing emissions of methane and other pollutants from landfills. LFG is extracted from landfills using a series of wells and a blower/flare (or vacuum) system. This system directs the collected gas to a central point where it can be processed and treated depending upon the ultimate use for the gas. From this point, the gas can be flared, used to generate electricity, replace fossil fuels in industrial and manufacturing operations, or upgraded to pipeline–quality gas where the gas may be used directly or processed into an alternative vehicle fuel.
Implementation barriers	• Lack of legislation to enforce landfill gas extraction • Unfavourable financial performance: As shown by several CDM projects in the field of LFG capture and use (see cdm.unfccc.int), the financial performance of such projects is generally insufficient to attract enough investment funding from financial institutes (i.e. the project is unattractive compared to the interest rates provided by local banks). In the case of the CDM, projects are financially supported through the sale of carbon credits based on the avoidance of methane emissions. • There could be a lack of social acceptability, for example, when landfills are a source of live for nearby communities.
Reduction in GHG emissions	936,353 tCO_2 equivalent emission reductions
Impact Statements – How this option impacts the country development priorities	
Country **social** development priorities	• New businesses are created around the landfill gas project site • Provides sustainable energy supply • Improves livelihood of local population • Improved groundwater quality as the management of the site could relatively easily be combined with leachate collection and disposal action

Country **economic** development priorities -economic benefits	• Waste management is a business opportunity with potential for job creation • Poverty reduction • Boosts the economy • Better protection of the local environment as well as support for local businesses regarding benefits of composting, recycling and reprocessing schemes • Capacity building on sustainable waste management practices within MCC
Country **environmental** development priorities	• Reduction in self-ignited random fires • Reduced health risk from infectious and respiratory diseases • It directly reduces air pollution by offsetting the use of non-renewable resources • Reduce greenhouse gases that contribute to global climate change • Improve local air quality
Costs	
Capital costs	The estimated capital required for a 40-acre collection system designed for 600 cubic feet per minute (cfm) of LFG (including a flare) is approximately $1,143,000, or $28,600 per acre (2013 dollars), assuming one well is installed per acre.
Operational and Maintenance costs	Typical annual operation and maintenance (O&M) costs for collection systems are estimated to be $191,000, or $4,800 per acre.
Cost of GHG reduction	936,353 tCO_2 equivalent emission reductions
Lifetime	10 years

Sector	**Conversion of Waste to Energy**
Technology Name	**Biogas digester**
Subsector GHG emissions	46 Gg CO_2 Equiv.
Background/Notes, Short description of the technology option	Biogas is the gaseous product of the anaerobic digestion process (decomposition in the absence of oxygen) using solid waste, organic waste, and other sources of biomass (www.climatewiki.org). Various types of microorganisms are involved in the process that finally produces biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2). The composition of biogas varies depending upon the origin of the anaerobic digestion process. Typical composition is CH_4 (50% to 70%), CO_2 (30% to 50%), and traces of gases such as H, CO, and N. The methane when oxidized (burned with air) releases thermal energy that can be used for heating and cooking or when burned in a gas engine can produce electricity or propel vehicles. Biogas can be compressed for storage and transportation and it can be purified to increase the methane

	content to achieve natural gas quality. However, this only makes sense on a large scale as the process is energy intensive. Methane has a very high global warming potential, which is 28 to 33 times higher than that of carbon dioxide. When burnt however, it becomes carbon dioxide. Since the organic matter can only release as much carbon (dioxide) as it previously took from the atmosphere, it is considered climate neutral and a form of renewable energy. This however, only applies if no more than 3 % to 4 % of the methane leaks from the closed system to the environment. Digesters and fermenters, that is where the biogas is produced in, are available in all sizes making the actual production of biogas scalable. Digesters come in many forms and sizes, which may range from 1 m^3 for a small household unit to some 10 m^3 for a typical farm plant and more than 1,000 m^3 for a large installation.
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Biogas capture and utilization presents an attractive opportunity for waste management in Liberia because it is a valuable renewable energy source that can be used to provide electricity while reducing methane emissions. Biogas can be produced from nearly all kinds of biological materials deriving from the primary agricultural sectors and from various industrial and domestic organic waste streams. This technology could be particularly effective in handling rubber wastewater, which is otherwise dumped in rivers, creating serious pollution problems. The green byproduct from biogas digesters are rich in nutrients and could be reapplied to rubber plantations. Another waste management problem with environmental and human health implications in Liberia that could be tackled with biomass technology is the disposal of Municipal Solid Waste (MSW). Municipal Solid Waste (MSW) production for different regions of Liberia in 2014 was estimated as 269,626 tons/year with Monrovia producing 75% of the estimated waste. This lead to a projected energy production of 16,645 MWh/year. The use of waste as an energy source provides two important benefits: environmentally safe waste management and disposal, as well as clean electric power generation. Waste-to-energy combustion reduces the volume of trash by about 90%, decreasing the amount of land required for garbage disposal by 90%.
Implementation barriers	• Lack of technical capacity for construction and maintenance. • Inadequate and intermittent government support • High investment costs for the digester, tubes, gas stove, and pots. • Inadequate supply of water and feedstock • Lack of awareness about the technology, its associated benefits • Poor reliability and performance of the designs and construction • Behavioral, cultural, and social acceptance in some rural communities associated with the handling of animal and human waste.
Reduction in GHG emissions	A single, small scale bio-digester reduces between 3 and 5 tCO_2-eq./year
Impact Statements – How this option impacts the country development priorities	
Country social	• Women are spared the burden of gathering firewood • Provides better lighting

development priorities	• Improved health conditions by reduced indoor smoke and household air pollution (HAP) especially for women and children
Country economic development priorities -economic benefits	• Income and employment generation • Buying(fossil) fuel resources (e.g. kerosene, LPG, charcoal or fuel wood) is no longer needed • Biogas digesters greatly reduce the amount of time that women and children need to spend collecting wood, creating more time for women to work in productive enterprise and for children to study
Country environmental development priorities	• Replaces use of firewood for cooking in urban and rural areas • Reduced greenhouse gas emissions • Improved sanitation • The release of methane is avoided thus contributing to climate mitigation. A single, small scale biodigester reduces between 3 and 5 tCO2-eq./year • Reduced deforestation
Other considerations and priorities such as market potential	• Biogas faces intense competition with other fuel substitutes available in the market
Costs	
Capital costs	• Household biogas digesters have high upfront investment costs, in the range of US$ 500 to US$ 1,500. Levelised cost of cooking assuming 30-year lifespan is US$ 82, US$ 79, and US$ 77 for no discount rate, 5% discount rate and 10% discount rate respectively.
Operational and Maintenance costs	Annual operating cost is US$ 50 compare to LPG stove, traditional charcoal stove and electric stove which are US$ 220, US$ 260, and US$ 300 respectively.
Cost of GHG reduction	Unknown
Lifetime	30 years

Sector	**Renewable Energy**
Technology Name	**Solar Dryers**
Subsector GHG emissions	
Background/Notes, Short description of the technology option	The solar dryer is a relatively simple concept. The basic principles employed in a solar dryer are: • Converting light to heat: Any black on the inside of a solar dryer will improve the effectiveness of turning light into heat. • Trapping heat: Isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days. • Moving the heat to the food: Both the natural convection dryer

	and the forced convection dryer use the convection of the heated air to move the heat to the food. There are a variety of solar dryer designs. Principally, solar dryers can be categorized into three groups: a) natural convection dryers, which are solar dryers that use the natural vertical convection that occurs when air is heated and b) forced convection dryers, in which the convection is forced over the food through the use of a fan and c) tunnel dryers (JIN, 2006).
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	Solar drying involves the removal of moisture from produce so as to provide a product that can be safely stored for longer periods. The solar drying method uses indirect solar radiation. The principle of the solar drying technique is to collect solar energy by heating-up the air volume in solar collectors and conduct the hot air from the collector to an attached enclosure. Solar dryer technology can be utilized in small-scale food processing industries for producing hygienic, high-quality food products. It will also promote renewable energy sources as income-generating units, apart from saving the world from the ill effects of climate change. There is potential for applying solar dryers to dry cereals such as maize, wheat and rice after harvesting.
Implementation barriers	• Intermittent weather conditions • Durability of the dryer • Several indirect solar dryers have limited applications due to their unreliable performance and high investment cost relative to their production capacity
Reduction in GHG emissions	One dryer can dry 4 kg/day. If used 250 days/year it will dry one tons, and save 3.24 tons of CO_2, if it replaces electric drying.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	• Improve food security through allowing the longer storage of food after drying • Drying food reduces its volume. Therefore, in combination to longer storage times, the food is also more easily transported after drying which potentially opens up additional markets to the producer of the food.
Country economic development priorities -economic benefits	• Saves fuel and electricity cost • Creates livelihood for one person for each dryer • Provides good income for the women. • Country will save on foreign exchange used to import fossil fuel
Country environmental development priorities	• If solar drying replaces drying by electricity or fossil fuel, it reduces CO_2 emissions. • Save tons of produce going to waste • Help in mitigating global warming through the use low-carbon technologies
Costs	
Capital costs	Forced convection dryers have higher initial costs and since the fan

	needs to be purchased and operated. The initial cost of a one ton per day dryer is in the region of £1500-2000.
Operational and Maintenance costs	Forced convection dryers have higher operational costs. Operational costs of the natural convection technology are limited to labor costs.
Cost of GHG reduction	Unknown
Lifetime	7 years

Sector	**Energy Supply**
Technology Name	**Improved clean cook stove**
Subsector GHG emissions	N/A
Background/Notes, Short description of the technology option	A good cooking stove is defined as one that meets technical, scientific and safety standards, and has high combustion quality, technical efficiency, minimal smoke emission, ergonomics and structural stability. Replacement of inefficient wood stoves with efficient ones 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 so that it can reduce a number of accidents. It burns wood more effectively, so the amount of dangerous particles that might be released is reduced. Since about 1.5 billion people in the world use traditional stoves for cooking and heating, efforts to improve the efficiency of cooking and heating stoves have been increasingly popular in the developing world. Improved stoves come in different forms and sizes (Climate Tech Wiki, 2006).
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the	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. In Liberia, more efficient cookstoves are being promoted on the market but with limited patronage because of costs. According to Liberia's INDC, in 2004 it was estimated that over 95% of the population relied on firewood and charcoal for cooking and heating needs. In 2009 it was also estimated that 70% of

country environment.	the urban population use charcoal for cooking as compared to 5% of the rural population; 91% of the rural population use firewood for cooking as compared to 21% of the urban population.
Implementation barriers	• Continual supply, availability and quality of biomass. • Lack of local availability of high performance devices • Lack of local expertise or know-how or skills
Reduction in GHG emissions	Estimated reduction of GHG emissions over the 10 year period is 2.9 million tons of CO_2.
Impact Statements – How this option impacts the country development priorities	
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 -economic benefits	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.
Costs	
Capital costs	The cost of an efficient wood stove varies according to design features and materials used. It ranges within $150-180. Since more than 100,000 families use inefficient stoves, cost of implementation of efficient ones can be $15 million - $18 million over 10 years. Lifetime of quality stoves exceeds 10 years.
Operational and Maintenance costs	None
Cost of GHG reduction	A total of 9.07 million tons of GHG emission will be saved by 2030 compared to the reference year 2000.
Lifetime	10 years

Sector	Waste
Technology Name	**Briquette Production**
Subsector GHG emissions	N/A
Background/Notes, Short description of the technology option	Urban and rural households in low income countries rely on traditional biomass fuels such as charcoal and firewood for cooking and heating purposes, which has an adverse effect on forest resources and on people's health. A major reason for people to continue these as main sources of fuel for cooking is lack of affordable and reliable alternative sources of energy. Briquettes present a great opportunity to replace traditional biomass fuels for domestic and institutional cooking and industrial heating processes. Briquette production is becoming predominant in most developing countries since it serves as a substitute for charcoal and other fuel commodities. It also has an advantage by reducing deforestation which will eventually reduce greenhouse effects. It is also a means of providing clean environment since most waste will be used as resource for making these briquettes.
Implementation assumptions, How the technology will be implemented and diffused across the subsector? Explain if the technology could have some improvements in the country environment.	The transformation of organic wastes such as municipal solid waste, market waste and agricultural residues into briquettes, using simple and low-cost technology, has the potential to enhance sustainable development while raising the living standards of the poor in developing countries. Briquettes can be burned in the same ordinary wood stoves without loss of efficiency. Although several biomass-based energy projects have been undertaken in Liberia with various degrees of success, briquette businesses are not common in Liberia. However, there is a huge untapped market for briquettes in Liberia. In addition to solving the sanitation problem in the country, briquettes production also contributes to providing a clean environment and the ability for afforestation in order to reduce greenhouse gas emissions. In Liberia a company called Green Gold is piloting the commercial production of briquettes on the outskirts of Monrovia with its 'Fayacoal' brand by supplementing the bio-char with discarded charcoal dust salvaged from urban trading sites.
Implementation barriers	• High cost of briquettes as compare to charcoal and firewood. • Lack of consistency in quality of briquettes produced • Prevailing poor reinforcement of regulations against the indiscriminate cutting down of trees for fuelwood. • Lack of access to finance • Lack of sufficient marketing and distribution strategies • High transportation cost and high moisture content of raw materials that required more drying increased production costs.
Reduction in GHG emissions	78 kg CO_2 equivalent per MWh
Impact Statements – How this option impacts the country development priorities	
Country **social**	• Improve livelihoods for both youth and women in the communities

development priorities	• Provide employment and livelihood for impoverished, marginalized and vulnerable individuals
Country **economic** development priorities -economic benefits	• Employment generation • Save an equivalent volume of trees that would otherwise be cut down for charcoal
Country **environmental** development priorities	• Reduces deforestation • Reduce greenhouse gas emissions • Reduces the volume of solid waste • Reduces the use of fossil-base fuel to produce electricity • Uses locally available resources such as municipal solid waste and wood waste
Costs	
Capital costs	High capital cost for initial setup and maintenance, about $698,964
Operational and Maintenance costs	$ 0.242/kg of briquette
Cost of GHG reduction	Carbon emission savings of about 6.1 tons of carbon dioxide (CO_2) per ton of briquettes
Lifetime	14.5 years

Annex II: List of stakeholders involved and their contacts

Name	Institution
1. Emmett K-Max Paye	Initiative for Youth and Children Advancement (I-IYOCA)
2. Emmanuel Peters	Environmental Protection Agency (EPA)
3. Victor P. Jones	Liberia Refugee Repatriation Resettlement Commission (LRRRC)
4. Kadallah K. Karneh	Ministry of Post and Telecommunications (MOPT)
5. Yvette W. Zelee	Ministry of Public Works (MPW)
6. Mathias S. Nimley	Forestry Development Authority (FDA)
7. Ralph B. Quiah	National Investment Commission (NIC)
8. Patricia J.V Tarlue	Environmental Protection Agency (EPA)
9. Arthur Becker	Environmental Protection Agency (EPA)
10. John Y. Hena	University of Liberia (UL)
11. George Sweegage	Liberia Marketing Association (LMA)
12. Lucy Gregersen	UDP
13. Amos Y. Bartu, Jr.	Liberia Petroleum Refining Company (LPRC)
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15. Aloysius Chieh	Paynesville City Corporation (PCC)
16. Morris Dougba	Green Gold
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18. Claudius D. Dahn	DOPP
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20. Danise L. Dennis	Environmental Protection Agency (EPA)
21. Todd Ngara	UDP
22. Gwendolyn B.H. Dahn	Ministry of Education (MoE)
23. Oretha Y. Dorley	Environmental Protection Agency (EPA)
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25. Claude D. Edwin	Environmental Protection Agency (EPA)
26. Helen Senyon-Howard	Ministry of Commerce and Industry (MoCI)
27. James Kollie	Ministry of Transport (MoT)
28. Rebecca M. Oberly	Environmental Protection Agency (EPA)
29. Vera Watson	Environmental Protection Agency (EPA)
30. Amos Gbeyanyon Yloe	Ministry of Transport (MoT)
31. Sennay Carlor, III	Monrovia City Corporation (MCC)
32. Stephen B. Lavalah	Liberia Maritime Authority (LIMA)
33. Bannel Dennis	Liberia Institute of Statistics & Geo-Information Services (LISGIS)
34. Teddy P. Taylor	Youth Climate Change Initiative (YCCI)
35. Lawdo Nimley Thomas	Ministry of Gender, Children and Social Protection(MGCSP)
36. Atriana N. Sirleaf	Ministry of Internal Affairs (MIA)

Sectoral Working Group on Energy

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