THE GOVERNMENT OF THE REPUBLIC OF MALAWI

TECHNOLOGY NEEDS ASSESSMENT FOR CLIMATE CHANGE MITIGATION ENERGY SECTOR

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Ministry of Natural Resources,
Energy and Mining

MALAWI TECHNOLOGY NEEDS ASSESSMENT REPORT FOR CLIMATE CHANGE MITIGATION IN THE ENERGY SECTOR

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FOREWORD

Climate change remains one of the major threats to Malawi's development and people's livelihoods. Over the last few decades, the country has experienced an increase in magnitude and occurrence of climate related disasters such as floods and droughts almost in all districts including cities of Lilongwe and Blantyre. In order to tackle such climate change threats in a systematic manner, the National Climate Change Management Policy (NCCMP) was formulated. The Policy got approved and adopted by the Government of Malawi in 2016. The NCCMP guides the integration and mainstreaming of climate change management in development planning and implementation by all stakeholders at local, district and national levels. The policy further creates an enabling policy and legal framework for a pragmatic, coordinated and harmonized approach to climate change management.

The Government of Malawi is aware of the importance of technology in managing impacts of climate change. Technology Needs Assessment (TNA), an initiative that originated from the fourteenth Conference of Parties (COP 14) to the United Nations Framework Convention on Climate Change (UNFCCC), is a country-driven set of activities directed mainly at the identification, selection and implementation of climate change mitigation and adaptation technologies. Also, the TNA tracks the evolving needs of developing countries for new equipment, techniques, practical knowledge and skills. In Malawi, the TNA is aligned with National Climate Change Management Policy under priority area 3.4: Research, Technology Development and Transfer, and Systematic Observation. Under this priority area, the Policy highlights the role and contribution of technology and its transfer in the management of climate change. The TNA therefore provides a link between National Climate Change Management Policy and other policies and strategies to achieve Malawi's overarching development plan presented in the Malawi Growth and Development Strategy III. Due to the crossing cutting nature of climate change and its related impacts on national developmental sectors, the TNA also provides a framework for implementation of national sectoral priorities, strategies and plans which are related to climate change.

The process of developing Technology Needs Assessment Report for Malawi in the adaptation (water and agriculture) and mitigation (energy and forestry) sectors involved stakeholder participation, ensuring gender inclusion at very stage. The implementation of the prioritised climate technologies in the TNA reports will require a collaborative approach of all stakeholders including government, Non-Governmental Organisations (NGOs), civil society, Faith Based Organisations (FBOs), the private sector and academia. It is my sincere hope that the TNA Report will serve as a shop list of climate change technologies which are key for climate resilient building of the economy and livelihoods of Malawians while ensuring reduction in greenhouse gases.

Patrick C.R. Matanda
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(i). Mrs. Shamiso Najira
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(iii). Mr. Ben Yassin
(iv). Mr. Evans Njewa
(v). Mr. Patrick Mkwapatira
(vi). Mrs. Hannah Siamme and
(vii). Mr. Lyson Kampira (from National Commission of Science and Technology of Malawi).

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LIST OF ABBREVIATION AND ACRONYMS

AFOLU	Agriculture Forestry and Other Land Use
BARREM	Barrier Removal to Renewable Energy in Malawi
Berl	Bio Energy Resources Limited
BEST	Biomass Energy Strategy
CH_4	Methane
CO_2	Carbon dioxide
COP	Congress of Parties
CTCN	The Climate Technology Centre & Network
EAD	Environmental Affairs Department
EGENCO	Electricity generation Company Malawi Limited
ESCOM	Electricity Supply Corporation of Malawi Limited
ETHCO	Ethanol Company Limited
GDP	Growth Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GOM	Government of Malawi
INC	Initial National Communication
INDC	Intended Nationally Determined Contribution
MBS	Malawi Bureau of Standards
MCA	Multi-criteria analysis
MGDS	Malawi Growth and Development Strategy
MEGA	Mulanje Electricity Generation Agency
MERA	Malawi Energy Regulatory Authority
MIRTDC	Malawi Industrial Research and Technology Development Centre
MREAP	Malawi Renewable Energy Acceleration Programme
N_20	Nitrous Oxide
NAMA	Nationally Appropriate Mitigation Actions
NAPA	National Adaptation Programme of Action
NSREP	National Sustainable and Renewable Energy Programme
NCST	National Commission for Science and Technology
NSCCC	National Steering Committee on Climate Change
NTCCC	National Technical Committee on Climate Change
PAESP	Promotion of Alternative Energy Sources in Malawi
SADC	Southern Africa Development Community
SDG	Sustainable Development Goal
SEforALL	Sustainable energy for all
SNC	Second national Communication
TCRET	Test & Training Centre for Renewable Energy Technologies
TNA	Technology Needs Assessment

TNC	Third National Communication
UNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention to Combat Deforestation
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development programme
UNEP DTU partnership	United Nations Environment Programme - Technical University of Denmark partnership
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
WASHTED	Water Sanitation Health and Technology Development, a centre at University of Malawi

EXECUTIVE SUMMARY

Climate change, which is attributed to atmospheric accumulation of human-induced greenhouse gases, is a threat to Malawi and the world at large. The United Nations Framework Convention on Climate Change (UNFCCC) was established to commit and encourage countries to reduce emissions to prevent rise in temperatures that would interfere with natural climate systems. Countries have set ambitious targets to reduce emissions and developed countries support low income developing countries to adapt to the negative impacts of climate change. Although the Convention gives leeway to developing countries to put sustainable development first over efforts to reduce GHG emissions, the countries are encourage to develop plans and take action to mitigate climate change. Innovative use of technologies (such as renewable energy, low carbon fuels and energy efficient systems) would enable developing countries achieve development while participating in mitigation efforts. However, there is need to ensure that appropriate institutional frameworks and resources are in place at national level in order to achieve development and mitigation objectives.

According to the UNEP DTU Technology Needs Assessment Guidebook, a Technology Needs Assessment (TNA) for a country is defined as "participatory activities leading to the identification, selection and implementation of climate technologies in order to reduce greenhouse gas and/or vulnerability to climate change". The TNA process should be gender inclusive and be bottom-up, encompassing all relevant stakeholders to ensure acceptability of its outputs such as the Technology Needs Assessment Report. The TNA process must also be aligned to existing national plans and strategies in order to ensure their relevance to national development, which would highly lead to the likelihood of TNA being implemented successful. In general, the TNA, as a process, has three objectives, given as follows:

(i). to identify an prioritize mitigation technologies for selected sectors/sub-sectors,

(ii). to identify, analyze and address the barriers hindering the deployment and diffusion of the prioritized technologies, including enabling the framework for the said technologies, and

(iii). based on the inputs obtained from the two previous steps, to draw up Technology Action Plans with suggested actions presented in the form of project ideas.

This report presents output of the first objective: the production of Technology Needs Assessment (TNA) Report for Malawi in the energy sector, in which the mitigation technologies are identified and prioritized. The process for coming up with the TNA report has been a stakeholder participatory one, being informed by the methodology described in the "*A guidebook for countries conducting a Technology Needs Assessment and Action Plan*" developed by the UNEP DTU Partnership. The process started with the prioritization of the sectors for mitigation, which resulted in the selection of Energy and Forestry sectors. Thereafter, the institutional arrangement for conducting the TNA was instituted. The national consultants were then recruited to assist the National Team guided by the scope of the work .

The TNA process begun with the review of government strategic documents, including policies, reports and strategies where climate change mitigation options and/or technologies in the energy sector are presented. The process aimed to identify mitigation technologies that are aligned with the aspirations of the Government of Malawi in managing impacts of climate change in the energy sector. The process of identifying mitigation technologies also involved consultations with energy experts. A total of eleven technologies were identified. Technology fact sheets were developed on the identified mitigation technologies, using consultant's expert judgment, literature review and feedback from national stakeholders. The Climate Technology Centre and Network (CTCN) online resource centre and technology fact sheets from past participating countries of the TNA project were also referred and consulted on specifications for the identified technologies. CTCN is the operating arm of the UNFCCC Technology Mechanism hosted by the UN Environment Programme and the UN Industrial Development Organization (UNIDO).

The process of selecting identified climate technologies was a participatory one, making sure that gender was taken into account at every step. Technology selection was achieved using multi-criteria analysis (MCA). The MCA process involved expert working group establishing the evaluation criteria, weighting of the criteria and scoring the technologies against the criteria set. The criteria were grouped into costs and benefits of the climate technology for mitigation. The costs included the sub criteria of capital costs, and operating and maintenance of the technology hardware. The benefits included economic, social, and environmental and climate related (potential for greenhouse gas reduction) benefits. After evaluation, the top six prioritized technologies are listed as follows, in the order of prioritization.

1. Liquefied Petroleum Gas (LPG) for cooking
2. Biofuel as vehicular fuel
3. Biomass Gasification
4. Lake Malawi hydrokinetic electric power
5. Solar PV
6. Improved charcoal production kilns

CHAPTER ONE

INTRODUCTION

1.1 Background about Technology Needs Assessment Project

Malawi, and the rest of the world, is facing challenge of managing climate change that arises due to accumulation of greenhouse gases (GHGs) in the atmosphere. It is proven that the GHGs are mainly contributed through human activities, the chief of them being combustion of fossil fuel for energy generation (IPCC, 2014). Through the United Nations Framework Convention on Climate Change (UNFCCC), the world aims to stabilize atmospheric GHG concentrations to a level that would prevent dangerous anthropogenic interference with the global climate system (UNFCCC, 2019). As it is now, this requires substantial reduction in GHG emissions while at the same time adapting to eventual impacts of climate change. Under UNFCCC arrangements, developing countries like Malawi are encouraged to take part in efforts to reduce the emissions because these efforts support national sustainable development goals. Technology plays a great role in reducing GHG emissions. According to the Kenya Climate Innovation Center, climate change solutions lie in the technological innovations and creativity (Kenya Climate Innovation Centre, 2018). Technologies involving use of energy efficiency and conservation, renewable energy, nuclear energy, switch to low carbon fuels, and carbon capture and storage are among the common types employed in reducing GHG emissions in the energy sector. However, technologies need resources and institutional framework, to be developed and maintained.

The importance of technology in relation to global climate change response is revealed through international commitments made at Conference of Parties (COP) of the UNFCCC meetings (Haselip, et al., 2019). In relation to enhancing technology development and transfer to developing countries, in 2010, the COP established the Technology Mechanism that consists of two bodies: the Executive Committee and the Climate Technology Centre and Network (CTCN). The Executive Committee is the policy making body, while the CTNC is the implementing body, accelerating developing and transfer of technologies through provision of technical assistance upon request, creation of access to information and knowledge, and fostering collaboration among climate technology stakeholders (UNFCCC, n.d.). The CTCN has focal points in each country. The focal points act as National Designated Entities responsible for development and transfer of climate technologies, among others. In Malawi, it is the National Commission for Science and Technology (NCST, n.d.).

The Paris Agreement of 2015[1] Article 10, places importance of technology development and transfer in implementing climate mitigation and adaptation actions (UNFCCC, 2015). Article 10

[1] The Paris Agreement of 2015 aims to strengthen response to keep global temperature rise well below 2 degrees Celsius above pre-industrial levels and to increase the ability of countries to deal with impacts of climate change as well as making the finance flows consistent with low carbon and climate resilient pathway.

also calls for the support to developing countries for "strengthening cooperative action on technology development and transfer at different stages of the technology cycle, with a view to achieving a balance between support for mitigation and adaptation". The Paris Agreement established the Technology Framework to "provide overarching guidance to the work of the Technology Mechanism in promoting and facilitating enhanced action on technology development and transfer in order to support the implementation of this Agreement". The new Technology Framework has been worked upon by COP in 2018 to guide how best to facilitate technology transfer to developing countries, thus to guide the Technology Mechanism. The New Technology Framework places more emphasis on TNAs and on the TNAs' roles in promoting and facilitating enhanced actions on technology development and transfer.

The UNFCCC, through the process of Technology Needs Assessment (TNA), is supporting some developing countries to come up with sound climate mitigation technologies that could accelerate national development. Malawi is among the countries that are supported through the Global TNA Project phase III, which is funded by Global Environment Facility (GEF) and implemented by UNEP in partnership with the Technical University of Denmark (UNEP DTU Partnership). In reference to climate change, Intergovernmental Panel on Climate Change (IPCC) defines technology as "piece of equipment, technique, practical knowledge or skills for performing a particular activity". The IPCC envelops climate technology to include three components: hardware, software and orgware.

According to Technology Needs Assessment Guidebook (Haselip, et al., 2019), a Technology Needs Assessment for a country is defined as "participatory activities leading to the identification, selection and implementation of climate technologies in order to reduce greenhouse gas and/or vulnerability to climate change. It stresses that the assessment process should be gender inclusive and be bottom-up, including all relevant stakeholders to ensure acceptability and use of the identified and prioritized technologies. The TNA process must be aligned to existing national plans and strategies in order to maximize their relevance and increase their likelihood of being implemented successful (Haselip, et al., 2019). The TNA process has three objectives, given as follows:

(i). to identify an prioritize mitigation technologies for selected sectors/sub-sectors,

(ii). to identify, analyze and address the barriers hindering the deployment and diffusion of the prioritized technologies, including enabling the framework for the said technologies,

(iii). based on the inputs obtained from the two previous steps, to draw up Technology Action Plans with suggested actions presented in the form of project ideas.

1.2 National Context and Existing national policies about climate change mitigation and development priorities

As described above, the Technology Needs Assessment is conducted within a country's development priorities to ensure realization of the aim of sustainable development. The technology needs must therefore be derived from ongoing policies, programmes and projects, long-term vision documents as well as strategies for climate change mitigation and adaptation that are already in place. For Malawi, the TNA was conducted in the national context and existing national policies and strategies in climate change management as presented in the following sub-sections:

1.2.1 National Context

Malawi is a landlocked country in Africa bordering Tanzania to the north and north east, Mozambique to the east, south and south-west, and Zambia to the west. It has a total area of 118,484 km^2, of which 20 % is covered by water bodies (WorldAtlas, n.d.). According to the national census of 2018, Malawi's population was at 17.56 million, growing at an annual rate of 2.9%; with 85% of its people living in the rural area (NSO, 2019). Malawi is one of most densely populated countries in the SADC region.

From the GHG inventories presented in the Initial and Second National Communications to UNFCCC, Malawi is a net GHG emitter, though small in absolute terms. The country is vulnerable to impacts of climate change that hamper socio- economic development. For example, in 2015, floods affected 15 out of 28 districts in Malawi, about 1.1 million people were affected, 230,000 were displaced, 176 were killed and 172 were reported missing (GOM, 2015). The total cost of loss and damage that the Government of Malawi incurred during these severe floods was estimated to be US$335 million, and the recovery and reconstruction costs stood at US$494 million (GOM, 2015). Malawi has low adaptive capacity to climate change and the Intended Nationally Determined Contribution report of 2015 showed that most of the key socio-economic sectors were vulnerable to impacts of climate change and climate variability.

The majority of the population depends on rain-fed subsistence agriculture for their livelihood. About 90% of the population use traditional biomass (firewood and charcoal) for energy (GOM, 2018), which is unsustainably supplied, causing both climate and environmental consequences. The national electrification access level was estimated at 10% (JICA Malawi Office, 2018). The electricity sector is dominated by hydroelectric power (98%) that is generated from run-of-river power stations that are installed along the Shire River (GOM, 2018). The Shire River is the only outlet of Lake Malawi. The lake is thus modelled as a natural reservoir for generation of electricity down the Shire River.

The key climate related challenges linked to energy are the shortage and unreliability of electricity supply. The installed capacity is 361MW against an estimated demand of over

700MW (GOM, 2018). The generation of power at full capacity is challenged by reduced flow in the Shire River as a result of droughts in the catchment area of Lake Malawi. The level of Lake Malawi shows a decreasing trend. Reduced flow contributes significantly to some of the installed power not being available especially toward the end of dry season (September, October and November), severely causing power shortages. Power shortages have negatively affected productivity of the manufacturing sector and quality of other services at various levels. Noting this problem, the Malawi Government has in its Integrated Resource Plan (GOM, 2017), plans to generate power from diversified sources, which includes exploitation of renewables (such as solar PV and wind) for electricity generation into the grid. The International Energy Agency is projecting a worldwide increase in affordability for renewable energy, especially solar PV and wind, which may positively impact increasing renewable energy in the Malawi's energy mix (IEA, 2018).

The other challenge that the country faces is the decrease of forest cover due to deforestation and forest degradation. The forest cover was 47% in 1975, 36% in 2005 (Mauambeta, et al., 2010) and 33% in 2015 (FAO, 2015). Human activities are the major cause of deforestation and forest degradation, such as expansion of farming land and other land uses, extensive biomass harvesting for household fuel and tobacco curing, selective tree felling for timber and curios, and tree debarking for herbal medicine and bee keeping. Deforestation and forest degradation are exacerbated by population pressure, poverty and limitations in alternative livelihoods. The consequences for deforestation are costly for Malawi, such as loss of biodiversity and reduction in ecosystem services that provide income and other social benefits (like energy, food and medicine) to the people (Ngwira & Wanatabe, 2019). A typical example of the impact of deforestation and forest degradation is the reduction in the capacity to arrest soil erosion and capacity to enhance water infiltration in the catchment area of the Shire River. This has contributed to increased levels of flash floods and amounts of silts in the river during the rainy season, which affects hydropower generation (JICA Malawi Office, 2018).

1.2.2 Existing national policies about climate change mitigation and development priorities

Climate change is a global problem. Thus, national policies and strategies on climate change management must be in tandem with regional and international policies. The management actions in the form of reducing GHG emissions (mitigation) are not only linked to lowering impacts of climate change but also linked to sustainable development. Thus, mitigation policies and strategies must be in tandem with development priorities at national, regional and international levels. Malawi signed the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro, Brazil in June 1992 during the United Nations Conference on Environment and Development (UNCED). The UNFCCC was then ratified by Malawi in April 1994. As a Party to the UNFCCC, Malawi has undertaken a number of studies and published reports in the areas of climate change mitigation and adaptation.

(i). Initial National Communication (INC) in 2003;

(ii). Technology Transfer and Needs Assessment Report in 2003;
(iii). National Adaptation Programme of Action NAPA in 2006 (revised in 2015);
(iv). Second National Communication (SNC) in 2009;
(v). Nationally Appropriate Mitigation Actions (NAMA) in 2015; and
(vi). Intended Nationally Determined Contributions (INDC) in 2015
(vii). Third National Communication (TNC) is being developed, and expected to be completed by end of 2019.
(viii). First Biennial Update Report is being developed, to be completed by the end of 2019

Malawi is a member of the Sustainable Energy for All (SEforALL), which is an international organization working with leaders in government, the private sector and civil society to drive further, faster action toward achievement of Sustainable Development Goal (SDG) 7, which calls for universal access to sustainable energy by 2030, and the Paris Agreement, which calls for reducing greenhouse gas emissions to limit climate warming to below 2° Celsius (SEforALL, n.d.). In this respect, the Government of Malawi (GoM) has developed the present SEforALL Action Agenda that acts as an energy sector-wide vision spanning the period 2015 to 2030 to achieve the aspiration of SDG 7 (GOM, n.d.). The Action Agenda was developed taking into account existing plans, programs and strategies, while embracing SEforALL guidelines. Among others, the SEforAll Action Agenda for Malawi aims to increase national electricity access to 31.6% by 2030, renewable energy output to 83% and renewable energy consumption to 23% in 2030.

Malawi signed the Paris Agreement of UNFCCC in 2016, which is aimed at keeping the increase in global average temperature to well below 2° C above pre-industrial levels; and to pursue efforts to limit the increase to 1.5°C, recognizing that 1.5°C would substantially reduce the risks and impacts of global climate change (UNFCCC, 2016). The Paris Agreement mandates Malawi to determine, plan, and regularly report on the contribution that the country undertakes to mitigate climate change. This Technology Needs Assessment report provided a useful vehicle for Malawi to engage in mitigation activities in line with the Paris Agreement of 2016.

Malawi and the rest of the United Nations Member countries adopted the Sustainable Development Goals (SDGs), in 2015, which aim to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. At a continental level, Malawi subscribes to the Agenda 2063 of the African Union where among others, Africa aspires to be prosperous through inclusive growth and sustainable development, which among others wants Africa's unique natural endowments, its environment and ecosystems, including its wildlife and wild lands to be healthy, valued and protected, with climate resilient economies and communities (African Union, 2013).

The Malawi Government's overarching development policy document, the Malawi Growth and Development Strategy (MGDS) III has been framed to reflect these international policies to which the country subscribes to. It aims to "*move Malawi to a prosperous, competitive and resilient nation*" while addressing challenges such as climate change impacts and environmental degradation (GOM, 2017). In the MGDS III, just like the predecessors (MGDS I and II), the Malawi Government prioritizes climate change management such as mitigation and adaptation, under the Key Priority Area of "Agriculture, Water Development and Climate Change"

The Malawi Government, with support from CTCN through the Council for Scientific and Industrial Research (CSIR), developed the Incubator Programme of the Climate Technology Centre and Network (CTCN). The Incubator Programme is a capacity-building programme that is aimed at facilitating the implementation of Malawi's Nationally Determined Contributions (NDCs) through the identification and support for technology interventions to help reduce GHGs. The programme provides support to Least Developed Countries (LDCs) to increase and strengthen institutional capacities for NDC implementation. The Programme helps LDCs bring together key national stakeholders around the NDE to identify and prioritise specific technology actions for NDC implementation through the development of a technology roadmap. Through stakeholder consultations, the Malawi Government selected solar PV and conservation farming as priority technologies to work with the CTCN to reach the targets, included in Malawi's NDCs.

In addition to international instruments and national development strategy, the following sections present the national sectoral policies and strategies for climate change management in the energy sector.

1.2.2.1 National Climate Change Management Policy

The Government of Malawi developed the National Climate Change Management (NCCM) Policy in 2016 (GOM, 2016) to act as a key instrument for managing climate change in the country and to acts as a guide for integrating climate change into development planning and implementation by all stakeholders at local, district and national levels in order to foster the country's socio-economic growth and subsequently sustainable development. The overall goal of the Policy is to promote climate change adaptation, mitigation, technology transfer and capacity building for sustainable livelihoods through Green Economy measures for Malawi.

The NCCM Policy affirms Government's commitment to fully addressing climate change issues in order to reduce the vulnerability of its people, ecosystems and socio-economic development to the effects of climate change through adaptation and mitigation, technology transfer and capacity building. Translating this Policy into action will build Malawi's resilience to overcome the challenges of climate change and embrace the opportunities that are available to enable the country lay a solid foundation for a sustainable and prosperous Malawi. The policy further demonstrates the commitment of Malawi Government to meeting its international obligations towards addressing the challenges of climate change, such as the Sustainable Development Goal 13 as well as the Paris Agreement of 2016.

1.2.2.2 National Energy Policy

The Government of Malawi is committed to addressing the challenges facing the energy sector while managing environment and climate change. The Government published its National Energy Policy (NEP) in 2003 to enhance holistic utilisation of diverse energy resources to meet various needs. Following the publication of the NEP, a number of Energy Acts were published in the area of electrification, rural electrification, and petroleum and energy governance. Malawi Growth and Development Strategy (MGDS) III, Sustainable Energy for All (SEforAll) initiative and the Sustainable Development Goal (SDG) 7 provide the basis for actions in the energy sector. The National Energy the policy was revised in 2018. The overall goal of the revised NEP (2018) is "*to provide a guiding framework for increased access to affordable, reliable, sustainable, efficient and modern energy for all sectors and every person in the country*"

The 2018 revised National Energy Policy emphasizes the importance of private sector participation in the sector and provides an environment conducive for such participation, be it in the form of direct investment, Public Private Partnerships (PPPs), Independent Power Producers (IPPs) and other participation vehicles. The Policy emphasizes sustainable and clean energy which is accessible to all. Energy efficiency is another priority area of this Policy, which also recognizes the importance of security of energy supply systems. Mitigating environmental, social, safety and health impacts of energy production and utilization is a key part of the policy. All this will be done under a robust, investor-friendly and consumer sensitive regulatory regime.

In order to ensure implementation of the Policy, the Government of Malawi has developed several plans and strategies, such as the Integrated Resource Plan, which is a policy implementation tool to guide and facilitate investments in the energy sector. Furthermore, the Malawi Government has developed the Independent Power Producers (IPP) Procurement framework to guide the participation of private sector investors to complement government efforts in the power sector development in the form of Independent Power Producers (GOM, 2017). The Government, through development partners has come up with the Malawi Renewable Energy Strategy (MRES), to revolutionize the renewable energy sector, with the vision on achieving universal access to renewable electricity and a sustainable bioenergy sector (GOM, 2017) MRES presents a vision for renewables in the country up to 2030, working towards achieving the policy objectives of the NEP as well as being in line with the UN's SGDs 7 through the SE4All Action agenda. The strategy aims to promote among others, minigrids as well as off-grid renewable energy power system investment to be significantly led by the private sector.

1.2.2.3 National Charcoal Strategy

The other strategy that supports implementation of energy policy is the National Charcoal Strategy (GOM, 2017). The strategy also supports the implementation of various global initiatives and goals, including the UN Sustainable Energy for All (SE4ALL) by 2030. It presents a multi-sectoral framework and approach, focused on pillars that define opportunities to incrementally address problems of charcoal production and demand in the near, medium and long term. The strategy is aligned with the Malawi Growth and Development Strategy III, and other national strategies and policies that promote broad objectives of reducing deforestation, forest degradation and dependence on solid biomass fuels, such as the National Forestry Policy. The National Charcoal Strategy has 7 pillars, including the promoting alternative household cooking fuels, promoting adoption of fuel-efficient cookstove technologies, promoting sustainable wood production and regulating sustainable charcoal production.

1.2.2.4 The Malawi Integrated Resource Plan

Malawi Government, through the Ministry of Energy Environment and Natural Resources has produced a master plan in the energy sector, the Malawi's Integrated Resource Plan (IRP). This plan looks at least-cost investment in generation, transmission and demand-side measures, covering the 20 year period 2017 to 2037 (GOM, 2017). According to IRP, Electricity Supply Corporation of Malawi (ESCOM) aims to supply electricity to close to 30% of the population by 2030, quadrupling current generation levels to around 1875 MW. To meet the growing demand, new generation capacity needs to be integrated into the grid on an average annual basis of 157 MW over the planning horizon (2017-2036). The IRP specifically mentions plans to add 650 MW of new installed capacity by 2032 – including 165 MW of solar, 60 MW of wind, 23 MW of hydro, 50 MW of fuel oil, 250MW of coal, and 100 MW of biomass. The likelihood of implementation of these plans largely depends on the vibrant participation of the private sector in the power sector. Therefore, this TNA report finds its relevance to the realization of the IRP.

1.2.2.5 Biomass Energy Strategy

To symmetrically respond to the challenges of deforestation resulting from unsustainable harvesting and use of biomass energy, the Malawi Government has come up with the Biomass Energy Strategy (BEST) in 2009 (GOM, 2009). The BEST is aimed at developing a rational and implementable approach to the management of Malawi's biomass energy sector through a combination of measures designed to improve the sustainability of biomass energy supply, raise end-user efficiencies and promote appropriate alternatives. The strategy is meant to ensure a sustainable supply of biomass energy (e.g. firewood and charcoal) and promote access to modern cooking fuels and efficient biomass combustion technologies by households and small enterprises. The strategy development process was led by the Department of Energy Affairs in cooperation with the Department of Forestry and all relevant stakeholders.

CHAPTER TWO

INSTITUTIONAL ARRANGEMENT FOR THE TNA AND THE STAKEHOLDER ENGAGEMENT IN MALAWI

2.1. Institutional Arrangement for conduction of TNA Project in Malawi

The TNA Report forms an important reference document for identification and promotion of climate technologies for reduction of GHGs and adjustment to actual or expected climate and its effects in a particular country. The institutional arrangement is therefore important, to make sure that there is provision for project oversight, to ensure delivery of the project outcomes and achievement of the project objectives and goals that have has been set up in Malawi. The institutional set up was guided by the following:

(i). The guidance notes on the institutional arrangement, presented in the UNEP DTU Partnership Guidebook for conducting TNA project (Haselip, et al., 2019), and

(ii). The existing institutional structures already in place in Malawi for managing and coordinating climate change activities.

In line with the guidance from the UNEP DTU Partnership Guidebook for conducting TNA Project, the national institutional arrangement considered the critical components a TNA institutional structure including National Steering Committee, National TNA Committee, TNA Coordinator, National Consultants and Sector working groups. The setup of the national institutional arrangement was proposed and adopted by stakeholders at the Project inception meeting is given in Figure 1.

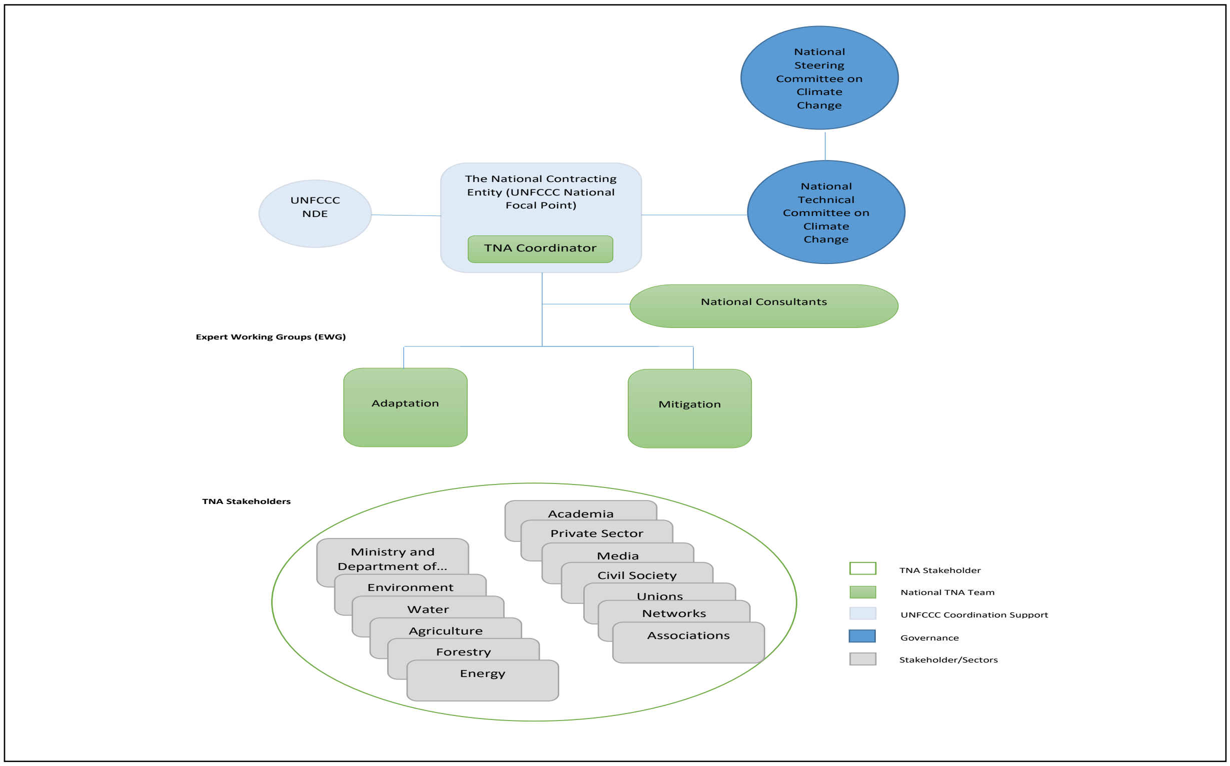

Figure 1: Malawi's institutional arrangement for managing the TNA project

Figure 1 also shows linkages between different elements of the TNA institutional arrangement in Malawi. The roles and responsibilities of each element are presented in the following sections:

2.1.1 National Steering Committee on Climate Change

The National Steering Committee on Climate Change (NSCCC) provides a high level guidance and political oversight and cross-sectoral coordination of TNA Process. It is the highest political level and it will provide a political acceptance of the deliverables of the TNA Project. NSCCC is chaired by the Ministry of Finance and Development Planning and its secretary is the Climate Change Secretariat in the Ministry of Natural Resources, Energy and Mining where the National Contracting Entity (UNFCCC Focal Point) is based. The NSCCC members include high level representatives from Government Ministries responsible for policy making related to the climate change initiatives.

2.1.2 National Technical Committee on Climate Change

National Technical Committee on Climate Change (NTCCC) provided technical oversight of the climate change management related projects, including TNA. It provides technical guidance to the NSCCC and the NTCCC is chaired by the Department of Climate Change and Meteorological Services. The National Climate Change Management Policy also provides room for strengthening membership of the committee by co-opting relevant stakeholders.

2.1.3 Secretariat for implementing the TNA project and TNA Coordinator

The Secretariat is the Environmental Affairs Department (UNFCCC National Focal Point), in the Ministry of Natural Resources, Energy and Mining is responsible for implementation of the TNA Project. The TNA coordinator, Mr. Christopher Manda, resides at the Secretariat. The main role of the Secretariat, through the TNA Coordinator, is to offer management support to the overall TNA process. This includes coordinating the TNA project stakeholders who constitute the Adaptation and Mitigation Expert Working Groups (EWGs) under the National Technical Committee on Climate Change, and to facilitate the working sessions of the EWGs. The Secretariat also liaises with the UNEP DTU Partnership (UDP) and the Regional Centre (Energy Research Centre of the University of Cape Town in the Republic of South Africa) to ensure that the TNA project and its deliverables are completed to the highest quality and standard.

2.1.4 Expert Working Groups

Expert Working Groups (EWGs) are stakeholder platforms through which the project is implemented. There are two EWGs each representing one priority theme of climate change management in Malawi and under the TNA project, one on mitigation and the other on adaptation. These EWG are provided for by the National Climate Change Management Policy and are established under the National Technical Committee on Climate Change. The membership of the EWG on mitigation priority sectors (Energy and Forestry) includes all the TNA stakeholders as indicated in Figure 1.

2.1.5 National TNA Consultants

National TNA consultants are experts on climate change mitigation and adaptation priority sectors responsible for supporting the TNA process in Malawi. The National Consultants selection went through a transparent and national procurement process guided by the Public Procurement and Disposal of Asset Authority (PPDA). After contracting in June 2019, the National Consultant made an inception report presentation to EAD and its management on 6th July 2019. This was done to ensure the National consultant is given proper guidance on the expected roles in the TNA process in Malawi. Dr Suzgo Kaunda, national consultant for mitigation priority sectors (Energy and Forestry) is responsible for the following:

(i). identifying and prioritizing technologies for the energy and forestry sectors through a participatory process with the broad involvement of relevant stakeholders and experts and the development of the TNA report;

(ii). leading the process of barrier analysis and development of an enabling framework for the prioritized technologies and development of the BAEF report; and

(iii). development of a technology action plan and awareness materials on the outputs of the TNA process in Malawi such as policy briefs.

Additionally, the National Consultant was responsible for capacitating the Mitigation Expert Working Group (EWG) members on the Multi Criteria Analysis (MCA) process. This was key in the prioritization of climate technologies in the mitigation adaptation sectors and for the members own knowledge.

2.2 Stakeholder engagement

TNA process is a stakeholder-driven approach. Stakeholder engagement is key to the TNA process. It cements legitimacy and ownership of the process and its related outputs. Stakeholders are different in nature and the importance of stakeholders in the actualization of the TNA goals qualifies the significance of stakeholder engagement process. Stakeholder engagement was guided by the "*Identification and Engagement of Stakeholders in the TNA Process"* guidebook by the UNEP DTU Partnership (Rogat, 2015). In order to ensure that all the stakeholders were identified in the TNA process, stakeholder analysis grid approach development by Hovland (Hovland, 2005) was employed by EAD through the TNA Coordinator and National Consultant. This was compared and aligned to the proposed membership set out in the Mitigation Expert Working group terms of references. Additional stakeholders to the Mitigation EWG membership included Ministry responsible for Local Governments/Councils, utility companies and media which were co-opted to form part of the identification and prioritization of technologies. Stakeholders were engaged in the TNA process including project inception, NTCCC and climate technologies prioritization meeting.

2.2.1 TNA Inception Meeting

Stakeholder engagement was initiated at the inception mission of the TNA project meeting held at Sunbird Lilongwe Hotel on 6th November 2018 where the stakeholders were introduced and briefed of the TNA project, its processes, outputs and timelines. The Appendix 1 provides a list of stakeholders who attend the meeting. This was followed by a meeting of the potential national consultants who would be recruited to support the TNA process.

Figure 2 Group photo of Participants of the TNA Project Inception Meeting (*Photo credit:* Chris Manda)

2.2.2 TNA Project presented to NTCCC

On 15th November 2018, the TNA Project was introduced to the National Technical Committee on Climate Change (NTCCC) at its meeting held at Golden Peacock Hotel. A presentation was made by the TNA Coordinator on the TNA process and outputs, implementation structure, status of implementation and way forward. Figure 3 provides a cross-section of stakeholders in attendance at the meeting.

Figure 3 Photo of members and stakeholders of the National Technical Committee on Climate Change attending the meeting (*Photo credit:* Chris Manda)

2.2.3 TNA Stakeholders' Meeting

The third meeting with stakeholders was conducted from 17 - 19th September 2019 at Matundu Cottage in Salima District. Both the Adaptation and Mitigation Experts Working Groups (EWGs) members and the co-opted stakeholders attended this meeting where consultant-identified climate technologies were presented to stakeholders for prioritization. The meeting provided an opportunity for stakeholders to learn about multi-criteria (MCA), review and provide inputs to the identified technologies for each of the selected sectors for the TNA process. The stakeholders prioritized climate technologies using the MCA analysis tools. Some of the highlights of the stakeholder involvement during the prioritization meeting are presented in Figures 4 and 5.

Figure 4: Photo showing TNA consultant for adaptation facilitating the MCA process (*Photo credit:* Mathew Malata)

Figure 5: Photo of Expert Working Groups at a technology prioritization workshop (*Photo credit:* Mathew Malata)

2.3 Gender Inclusiveness in the TNA process

The 2016 Paris Agreement clearly identifies the importance of gender equality in management of climate change. There are a number of entry points within the Paris Agreement for gender responsive climate action. For example, in mitigation there is scope to better reflect on how technologies would impact on gender issues in energy actions and in forest and natural resource management. In the case of the TNA process, gender inclusiveness makes the process complete and relevance of its implementation by all stakeholders is well understood. To ensure gender consideration in the TNA process, the consultants and EWGs were guided by the UNEP DTU Guidance document (De Groot, 2018) on gender responsiveness when conducting TNAs on gender responsiveness when conducting TNAs.

This TNA process was designed to include women at all stages, including project inception, NTCCC and climate technologies prioritisation meetings. However, the representation of men still dominated those of women at every stage of the process, which calls for more work to be done to ensure equal representation in future TNAs. The energy and forestry sectors are generally male dominated and thus, continued mainstreaming of gender inclusiveness policies and strategies at ministry and department levels should be encouraged and supported. For example, the representation of women at the 17-19th September 2019 (technology prioritisation) and the 6th November 2019 stakeholder workshops was 16% and 36% respectively.

CHAPTER THREE

TECHNOLOGY PRIORITIZATION IN ENERGY SECTOR

3.1 GHG emissions of energy sector

The energy sector is one of the significant sectoral sources of Greenhouse gas (GHG) emissions in Malawi. This has been revealed in both of the two National Communications that Malawi has published. The Initial National Communication (INC) reported that in 1994, the GHG emissions from the energy sector contributed 7798.34 Gg of CO_2 equivalent, representing 27% of the total national GHG emissions of 29,229.64 Gg of CO_2 equivalent (GOM, 2002). This sectoral emission was second to the emissions from the Land Use Change and Forestry sector, which emitted 17517.37 Gg of CO2, representing almost 60% of the total GHG emissions in 1994. Also in the Second National Communication (SNC), the contribution of the energy sector to national GHG emissions came second to Agriculture, Forestry and other Land Use (AFOLU) (GOM, 2011). For the period 1995 to 2000, the sector emitted a total of 4658.58 Gg (representing almost 20% of the total emissions in that period) and was second to AFOLU, which contributed 55% of the total emissions. The emissions from the INC are higher than those from SNC. This is largely due to emissions from carbon mono-oxide, which were significant in INC, not being part of the inventory in the SNC.

The GHG Inventory for the energy sector of Malawi from 2001 to 2017, as developed in the Third National Communication for Malawi (GoM, 2019), using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2: Energy Sector) (IPCC, 2006), is presented in Table 1. The inventory covers direct GHGs in the sector, namely: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Other GHGs have not been included due to their lack of default emission factors in the 2006 IPCC Methodology. As it can be seen from the table, energy emissions steadily increased from 1159.72 Gg CO_2 equivalents in 2001 to 1739.1Gg CO_2 equivalent in 2017. This represents an increase of almost 50% during the reporting period. The total emissions during the period is 24819.88 Gg of CO_2 equivalent, representing an annual average energy emission of 1431.60 Gg of CO2 equivalent

Table 1: Annual GHG emissions from energy sector by gases from 2001 to 2017 **(GoM, 2019)**

Inventory year	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO2	TOTAL
	(Gg CO_2 equivalent)	(Gg CO_2 equivalent)	(Gg CO_2 equivalent)		(Gg CO_2 equivalent)	(Gg CO_2 equivalent)	(Gg CO2 equivalent)	(Gg CO2 equivalent)
2001	670.75	389.83	99.14	NE	NE	NE	NE	1159.72
2002	713.27	396.07	100.56	NE	NE	NE	NE	1209.9
2003	777.79	400.94	102.35	NE	NE	NE	NE	1281.08
2004	796.91	402.78	103.86	NE	NE	NE	NE	1303.55

2005	801.1	409.81	104.97	NE	NE	NE	NE	1315.88
2006	835.44	416.99	106.63	NE	NE	NE	NE	1359.06
2007	872.25	421.4	108.67	NE	NE	NE	NE	1402.32
2008	981.17	426.37	111.58	NE	NE	NE	NE	1519.12
2009	998.01	432.32	113.46	NE	NE	NE	NE	1543.79
2010	939.02	436.63	113.99	NE	NE	NE	NE	1489.64
2011	975.1	446.83	115.99	NE	NE	NE	NE	1537.92
2012	1028.6	458.21	118.19	NE	NE	NE	NE	1605
2013	1076.22	466.33	120.64	NE	NE	NE	NE	1663.19
2014	983.63	478.96	120.79	NE	NE	NE	NE	1583.38
2015	909.33	468.23	122.95	NE	NE	NE	NE	1500.51
2016	1010.44	469.83	126.45	NE	NE	NE	NE	1606.72
2017	1132.6	478	129.03	NE	NE	NE	NE	1739.1
Totals	15501.63	7399.53	1919.25	NE	NE	NE	NE	24819.88
Annual averages	911.83	435.27	112.90	NE	NE	NE	NE	1431.60
Percentage of total	62%	30%	8%	NE	NE	NE	NE	100%

NE = Occur but not estimated

In terms of share of energy emissions by type of GHG, as presented in Table 1, CO_2 dominates the energy emissions, contributing a total of 15501.63 Gg CO_2 during the period, representing 62% of the total energy emissions. Over the same period, the CO_2 emissions rose from 670.75 Gg CO_2 in 2001 to 1132.6 Gg CO_2 in 2017, representing an annual average CO_2 emission of 911.83 Gg CO_2 and an increase of 69%. CH_4 emissions came second, at a total emission of 7399.53 Gg (representing 30% of total energy emissions) with 389.83 and 478 Gg CO_2 equivalent being emitted in 2001 and 2017 respectively, representing an emission increase of 22.6%. N_2O came last, emitting a total 1919.25 Gg of CO_2 equivalent, representing only 8% of the total energy emissions. In 2017, the N_2O emissions were 129.03 Gg of CO_2 equivalent, up from 99.14 Gg CO_2 equivalent in 2001, representing an emission increase of 30%. CO_2 was emitted from combustion of fossil fuel (coal and petroleum) whereas most of the CH_4 and N_2O, from energy-based combustion of firewood and charcoal. The CH_4 emissions from fugitive emissions as a result of coal mining and handling also contributed a significant proportion of CH_4 emissions.

Referring to Table 2, it can be seen that in terms of energy emissions by category, Transport contributed the largest energy emissions 11019.96 Gg of CO_2 equivalent, representing a share of 45% of the total emissions. The Transport category is seconded by the Other Sectors category (Residential), which emits 8541.68 CO_2 equivalent representing a share of 35%. The Manufacturing Industries and Construction category contributed 16% of the total emissions, at a total category emission of 4067.822 Gg of CO_2 equivalent. The Energy Industry and Fugitive emissions from fuels contributed negligible amounts of energy emissions, emitting a total of 850.67 and 337.19 Gg of CO_2 equivalent respectively.

Table 2: Total GHG energy emissions by categories and type of GHG during the period (2001 to 2017) **(GoM, 2019)**

Main Category	Category	CO_2 (Gg of CO_2 equivalent)	CH_4 (Gg of CO_2 equivalent)	N_2O (Gg of CO_2 equivalent)	Total emissions (Gg of CO_2 equivalent)	Percentage contribution of each category to total GHG emissions
[1.A] Combustion Activities	Energy Industries	53.04	268.7	528.93	850.67	**3%**
	Manufacturing Industry and Construction	4050.02	1.902	15.9	4067.822	**16%**
	Transport	10806.56	48.928	164.47	11019.958	**45%**
	Other Sector (Residential)	551.69	6779.52	1210.47	8541.68	**35%**
	Non -specified	0	0	0	0	**0**
[1.B] Fugitive emissions from fuels	Solid fuels (coal mining and handling - underground mines)	36.958	300.235	0	337.193	**1%**
[1.C] Carbon dioxide	Transport of Carbon dioxide	0	0	0	0	0
	[1.C.2] Injection and Storage	0	0	0	0	
[1] Energy		15498.27	7399.285	1919.77	24817.323	
Percentage contribution of each GHG to the total energy emission		**62%**	**30%**	**8%**	**100%**	

The transport category emissions are from mobile combustion, dominated by road transportation, seconded by civil aviation and finally waterborne navigation. As already stated, the transport category dominates the consumption of petroleum imports of diesel, petrol, avgas and jet-kerosene. In terms GHG emissions by fuel sources, petroleum is the largest source, seconded by coal and biomass. Of course, the CO_2 emissions from biomass fuel are reported in Agriculture

Forestry and Other Land Use (AFOLU) sector. The Residential emissions are dominated by CH_4 that is emitted from combustion of biomass energy. The emissions from the energy industry are negligible because most of the electricity is generated from hydropower, which is largely a non-emitting source. Also, insignificant amounts of electricity are generated from fossil fuel, for peak power supply only. Despite Malawi having significant technically proven coal reserves, their exploitation levels are relatively small. There are interventions to diversify power generation that include installation of thermal power plants. For example, a construction of the first phase, 300 MW coal fired plant at Kam'mwamba in Neno is committed by the Government of Malawi. This will significantly increase GHG emission from the energy industry category.

Assuming business as usual scenario, with the current trend of GHG in the energy sector, from 2020 to 2040 is presented in the Figure 6. The emissions are expected to increase once the planned thermal power plants are

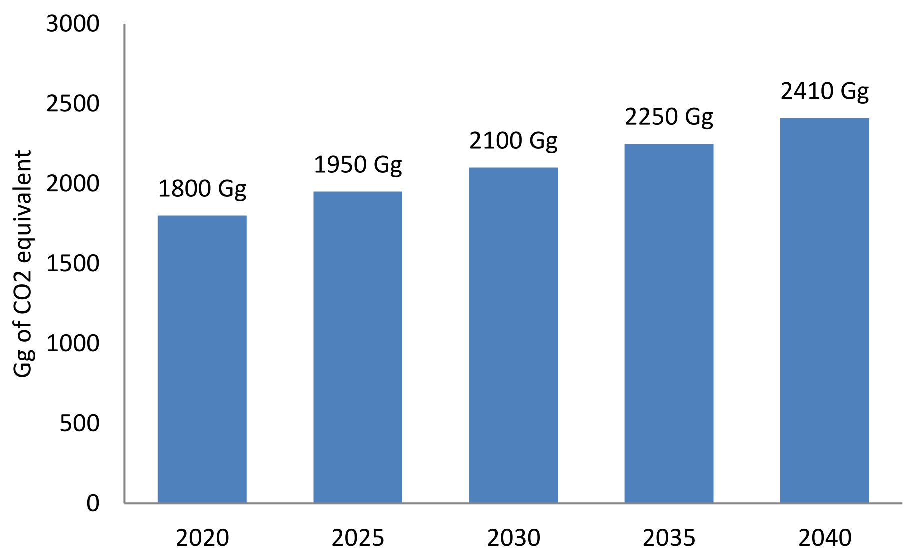

Figure 6: Project GHG emissions in the energy sector from 2020 to 2040
Source: (GoM, 2019)

3.2 Existing mitigation technologies of energy sector

Technologies for reducing GHG emissions can be categorized into whether the energy sources are renewable, the technology switches from use of heavy carbon to low carbon or renewable, the technology employs a energy conversion process that is efficient and conservation of energy. As a response to climate change and environmental management, and clean energy provision, the Malawi Government and development partners have promoted technologies that reduce GHG emissions. In this TNA process, the consultant conducted desk research as well as expert consultation on the existing mitigation technologies in Malawi. In the desk research process, information was collected from government of Malawi documents such as Intended National Designated Contribution (INDC), the revised National Energy Policy of 2018 (GOM, 2018), National Forestry Policy, the National Climate Change Management Policy of 2016 (GOM, 2016), Malawi's Nationally Appropriate Mitigation Actions (GOM, 2015), Biomass Energy Strategy, Malawi Renewable Energy Strategy (GOM, 2017), and National Charcoal Strategy.

3.2.1 Electricity generation technologies

Grid based electricity is generated by the Electricity Generation Company (EGENCO). The main technology used by EGENCO is hydropower generation using run-of-river power stations that are cascaded in the Shire River. Currently, EGENCO operates four hydro power stations namely: Nkula, Tedzani, Kapichira and Wovwe, with a total installed capacity of 351 MW (EGENCO, 2018). Large scale storage hydropower projects have been known to emit significant amounts of methane (a GHG with global warming potential of around 21), for example in Malaysia (Chow, et al., 2018). In general, run-of-river are environmentally friendly because they are not associated with significant damming of water for generation of electricity.

With the unbundling of the national power utility company, EGENCO sells generated power to the Electricity Supply Corporation of Malawi (ESCOM). ESCOM is responsible for supply and distribution of the generated electricity to customers. ESCOM is finding challenges to supply electricity according to the demand. According to electricity demand forecast, the maximum demand (base load) will reach 719 MW by 2020, 1,873 MW by 2030 and 4,620 MW by 2040 (GOM, 2017). The peak demand is also forecasted to be 982 MW by 2020, 2591 MW by 2030 and 6946 by 2040. The energy intensity, measured as the ratio of electricity consumption to real GDP is predicted to increase by a factor of 3 times over the 20-year period to 2037 (GOM, 2017). The projected demand versus what is currently installed implies that that there must be meaningful development in the electricity sector to meet the demand. The Malawi Government through EGENCO has plans to develop further hydropower from the identified potential sites to increase the installed electricity generation capacity, so as to meet the increasing demand for electricity. These are presented in the Integrated Resource Planning (IPR) for the Energy Sector, as follows: Tedzani IV, Chasombo, Chizuma, Hamilton Falls, Kapichira III, Kholombidzo, Fufu (with two options of the dam placement – higher or lower), Lower Songwe, Mbongozi and Mpatamanga (GOM, 2017).

Apart from large scale hydropower technology for generating on-grid electricity, Malawi has micro and small hydropower projects. These hydropower technologies supply off-grid power to grid isolated communities, such as the Bondo Microhydropower Project run by Mulanje Energy Generation Agency (MEGA, 2018), Kavuzi Microhydropower Station (GOM, 2018), and Lujeri microhydropower scheme in Mulanje district (Kachaje, et al., 2016). However, most of these installed microhydropower schemes are not in their functional state. Some of them were abandoned due to ESCOM grid reaching the community, because the electricity from microhydropower stations was judged to be inferior to community consumers. The country, especially in the northern region, has several technically proven microhydropower sites. Currently, one of such sites is being developed at Usingine in Nkhatabay, in which the consultant of this TNA is one of the engineers.

The IPR also plans to generate grid-based electricity from renewable energy sources, which are modeled as clusters where three generic power plants represent renewable technologies, namely: Generic Biomass, Generic Solar and Generic Wind. Further, the IPR plans a number of demand-side energy management measures, with solar hot water heating programme becoming the preferred measure. Currently, Electricity Supply Corporation of Malawi (ESCOM) and the Malawi Government are promoting a number of energy saving technologies on the demand side of electricity consumption. One such technology is the promotion of energy efficient lighting, such as Compact Fluorescent Lamps (CFLs) and Light Emitting Diodes (LED) bulbs, against incandescent bulbs (Times News, 2016) in order to manage peak power demand. The efficient energy lighting project, launched in 2012, supported by the Government of Malawi, ESCOM and development partners, sparked real interest in energy savings among the consumers, whereby in the first phase of the programme, 1.3 million free CFL bulbs were exchanged with incandescent bulbs and some 700,000 CFL were sold at subsidized price, resulting into saving 17.1 MW of peak power (UNEP, 2012). ESCOM reported to have sold over 330 000 efficient bulbs in 2016, in addition to those that were handed out for free, saving 65 MW of peak demand during morning spikes, and 51 MW during the evening period (GOM, 2017). Government has removed the excise duty on CFLs while doubling the duty on incandescent bulbs. While the prices for CFLs have dropped, incidences of poor quality CFLs in the country hamper the efforts of popularization of this technology. However, absence of monitoring, verification and enforcement measures against poor quality efficient lighting technology in Malawi have contributed to proliferation of poor quality efficient energy lighting bulbs in Malawian markets.

The other technology that ESCOM has implemented to reduce energy consumption is the introduction of prepaid-meters, replacing postpaid ones. It has been proven that prepaid electricity consumption meters promote an energy saving attitude among consumers (Spence, et al., 2015; Bency, 2017). Energy saving attitudes impact positive occupant behaviours towards a sustainable lifestyle and being less wasteful of electricity are key solutions to climate change mitigation (Cam, 2012). Thus pre-paid meters are one of the viable climate change mitigation in the Malawian housing sector. ESCOM has also reported that prepared meters have increased its financial status (GOM, 2017).

Arguably the most common renewable energy electricity generation technology for decentralized applications in Malawi has been the solar PV for lighting. According to literature, the first recorded solar PV demonstration technology for community lighting was installed in 1997 at Makanjira in Mangochi District by the Malawi Industrial Research and Technology Development Centre (MIRTDC), with funding from the UNESCO. Prior to that, it is stated that there were other solar PV technologies installed, but were not recorded officially, and might have been at household level (UNDP, 2005).

Solar home system PV technologies are sold by various retailers in Malawi, and some are imported into the country by returning residents from abroad (for example Republic of South Africa). Interestingly, some oil companies like Total Malawi Limited, are involved in sale of solar PV technologies, like solar lamps and other solar home systems, which are available these solar available in their service stations across Malawi (Total Malawi Limited, 2019). There are many solar technicians certified by the Malawi Energy Regulatory Authority (MERA), who provide solar PV installation services. The Government of Malawi has been involved in the promotion of renewable and clean energy technologies for so long. In 1999, The Government together with UNDP carried out a National Sustainable Renewable Energy Programme (NASREP) with support from UNDP (Gobede, 2011). The NASREP was a national energy programme whose objective was to increase the sustainable use of, reliance on and access to energy in Malawi, focusing on the country's underutilised renewable energy resources in order to provide a viable and sustainable contribution to the country's energy mix. The Barrier Removal to Renewable Energy in Malawi (BARREM) project implemented from 2002 to 2007 was the output of the NASREP (Banks & Gondwe, 2007).

Before BARREM Project it is reported that there were about 500 solar PV installed systems in Malawi used for telecommunications, pumping and lighting installations (UNDP and GEF, 2000). The increased usage of solar PV technologies in the country is attributed to the BARREM, which among others promoted uptake of renewable energy through creating enabling environment. Through the BARREM Project, demonstrational solar PV systems were installed in various places across the country. Apart from solar PV for lighting, solar technologies such as the solar PV for running a refrigerator, solar PV system for powering the draft fans used in tobacco flue cured farming were also demonstrated.

Also, the BARREM Project supported the Mzuzu University to establish a Test & Training Centre for Renewable Energy Technologies (TCRET), eventually developed a degree in renewable energy. The Government of Malawi also implemented the Promotion of Alternative Energy Sources Programme in Malawi (PAESP) in 2007 to demonstrate applicability of renewable energy technologies such as solar PV and wind power technologies. Under the PAESP, six solar PV-wind mini-grid technologies were installed throughout the country, 2 in each of the 3 regions (Gobede, 2011). These solar-wind minigrid systems are known as "solar villages' in Malawi. The provide electricity to a community without grid electricity for business and domestic applications.

Currently, apart from individual households putting up solar PV systems as back-up power source, there are several organizations that support communities in rural electrification for schools, health centres and agricultural (water pumping and irrigation). Other tertiary education and research institutions like University of Malawi - The Polytechnic, Lilongwe University of Agriculture and Natural Resources, and Chitedze Agricultural Research Institutions are involved in research and technology development on solar PV technologies. Apart from Government based interventions in promotion of solar PV, organisations are involved in installation of solar PV for rural energy interventions, such as the Malawi Renewable Energy Acceleration Programme (MREAP), funded by the Scottish Government through Strathclyde University and University of Malawi - The Polytechnic's Centre for Water Sanitation Health and Technology Development (WASHTED). MREAP has been involved in the design and installation of solar PV technologies for rural schools and health centres in Chikwawa District (Tembo, et al., n.d.).

The Government of Malawi with support from development partners has demonstrated 'large scale' street lighting technologies using solar PV, for example at Government Headquarters at Capital Hill and in Zomba City (Malawi News Agency, 2017). Another 'large scale' solar PV technology, financed by the Japanese Government, is the one installed at Kamuzu International Airport, to installed capacity of 830 kW, which is fed into the ESCOM grid (Embassy of Japan in Malawi, 2013). Figures 6 and 7 show solar PV panels for a solar home system, and for a large scale power generation system, respectively.

Figure 7: A photo of a man on a rooftop working on a solar PV of a solar home system

Figure 8: A cross-section of solar PV panels as part of a large system for generating electricity

The current challenge is to increase uptake of the solar PV technology for generation of electricity to feed into the grid, absence of private sector involvement in grid-based renewable electricity supply being one of the reasons. This scenario would change with the coming in of the revised Energy Policy of 2018 and The Independent Power Producer (IPP) Framework for Malawi (GOM, 2017) that create a favorable environment for private sector engagement. Already, as in 2019, there have been a number of IPPs that have expressed interest to generate electricity to sell to the grid (ESCOM). These include, the JCM Matswani Solar Corp Limited that plans to install a 60 MW solar PV system in Salima, and the Environmental Social Assessment has been done

The other challenge is erosion of consumer confidence in off-grid electricity supply from renewable energies due to their limitations in power application as well as proliferation of poor quality RETs products on the market (Times News, 2018). The other challenge is that most of the products of RETs are imported into the country, residing the capacity f the country to grow technologically through research and development in renewable energy technologies. There is a need to start manufacturing RETs, for example, solar PV, water and wind turbines in Malawi.

3.2.2 Thermal energy technologies

The Malawi Population and Housing Census of 2018 has revealed that the majority of households still use firewood as the main source (77 %), followed by charcoal (18%) and electricity (2%) (NSO, 2019). This translates to 95% of the population using biomass for cooking. The majority of charcoal is used as a cooking fuel in urban areas, where around 15% of the population resides, while in the rural areas it is firewood that dominates. The technologies used for production of charcoal from wood fuel are inefficient, implying that more forest has to be cut to produce a unit quantity of charcoal. Also, the majority of households still use the inefficient 3-stone open fire stove for cooking, which again results in the stove consuming more firewood to cook one unit quantity of food. Alternative fuels for cooking and heating that are clean and affordable are limited. The thrust of the technology behind cooking using the biomass stove is on reducing energy losses, which could be achieved using insulation. In addition to insulation and correct design of the stove, the practice/behaviour, fuel management (e.g cutting firewood into smaller pieces) and conditions of cooking determine the amount of energy losses.

The overdependence on firewood and charcoal as thermal energy, coupled with inefficient conversion technologies, have contributed to deforestation. Government of Malawi and development partners have carried programmes and projects, in which technologies have been developed and/or imported and demonstrated, to reduce deforestation on the side of biomass energy supply. These include a clay firewood cooking stove, locally called *Chitetezo Mbaula* (refer to Figure 9), which was promoted by The Government through NASREP and the Programme for Basic Energy and Conservation (ProBEC) in Mulanje, Thyolo and Ntcheu. Currently, the Government and non-governmental organizations are still promoting the clay firewood cooking stoves in some parts of the Malawi. In ideal cooking conditions and practice, a Chitetezo Mbaula could save up to 60% of firewood compared to the traditional 3 stone open fire (Malinski, 2008). However, this clay firewood cooking stove technology has not been diffused to all parts of the country, in the way the Charcoal Ceramic Jiko (technology originated from Kenya, refer to Figure 10) has been popularized in Malawi. The Charcoal Ceramic Jiko Stove is similar in design to the clay firewood study except that the Ceramic Jiko has a grate. The Ceramic Jiko stove is manufactured by local tinsmiths in both rural and urban areas of Malawi; the lining could be made from only clay (to reduce cost), though some local manufacturers mix clay with cement to make the lining strong. It is reported that Ceramic Jiko stove technology has been so much disseminated in Malawi, such that efforts to disseminate it would not have significant effects.

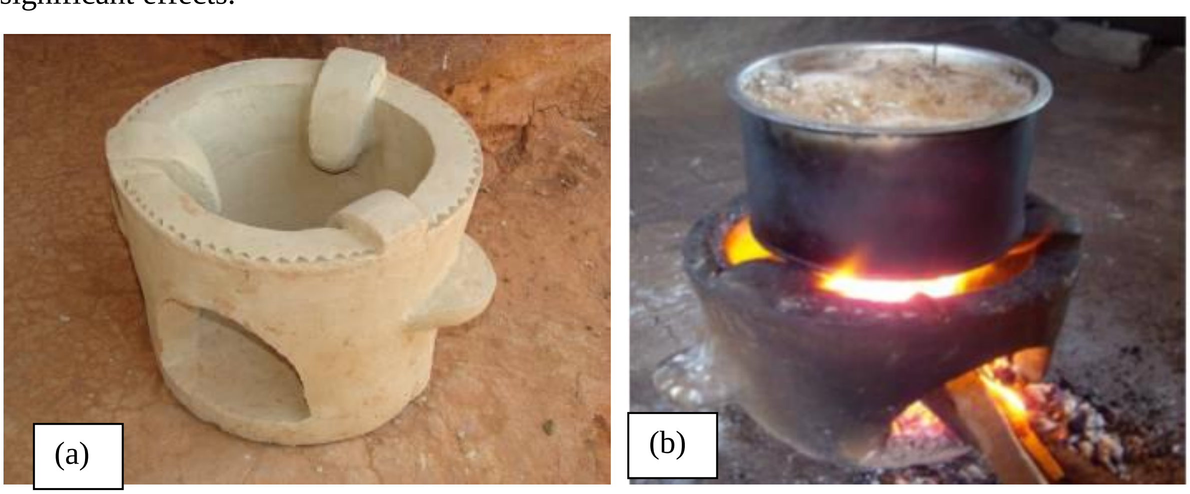

Figure 9: (a) Clay firewood cooking stove (Barry etal., 2009) (b) Clay firewood cooking stove in operation (GTZ, 2008)

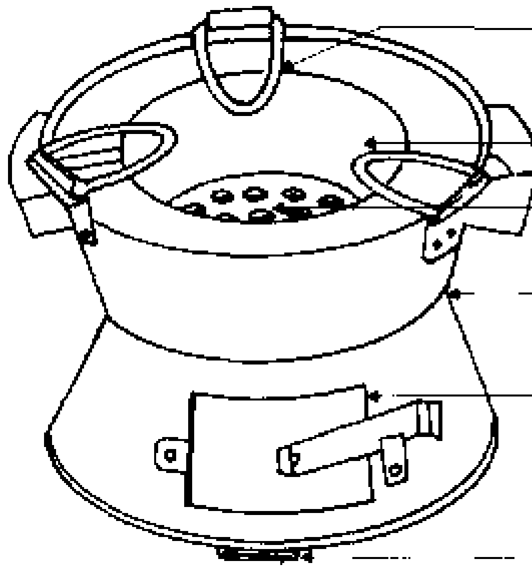

Figure 10: Clay firewood cooking stove (*Chitetezo Mbaula*) (Malinski, 2008)

The other firewood cooking stove technology existing in Malawi is the rocket stove. This stove could be produced for the household and institution (refer to Figure 11 for an institutional type of rocket stove) applications. In Malawi, the stove was promoted by the Government of Malawi and ProBEC, where a Malawian company (Ken Steel Engineering) is involved in the manufacturing the institutional types for supply in primary schools and other organizations. The rocket type of stoves are not popular compared to clay firewood cooking stove due to high cost and deviation from traditional cooking practices

Figure 11: Institutional Rocket Stove by Ken Steel Engineering in Malawi (GTZ, 2006)

The biomass-gasification technology is available, but at experimental stage. Probably the first prototype was constructed by the Malawi Industrial Research and Technology Development (MIRTDC). Lately, the Jesuit (of Roman Catholics) has produced a micro gasifier stove that is incorporated with a thermal electrical conversion system, producing electricity while providing heat for cooking and heating. Since the organic feed stock for biomass gasification is widely available, for example crop waste, the gasification technology provides a significant potential for clean energy generation in Malawi. The biogas production technology, mainly using cow dung as substrate, has been developed and installed in the country for both household and institutional applications. However, most of the installed biogas systems are not functional. Production of biogas from municipal waste and human soil (pit latrines) would be a viable technology in Malawi.

Liquified Petroleum Gas (LPG) gas stoves are available, sold by Afrox Gas Limited but only in urban areas. There is a negative perception about the use of LPG cooking, in that the cylinder would explode when cooking. It is viewed as an expensive cooking option, only acceptable to richer households.

3.2.3 Transport fuel technologies

As reported in the INC and SNC for Malawi, the Malawian energy sector non-biogenic GHG emissions are dominated by emissions from use of petroleum (petrol and diesel) in the road transportation category. One of the mitigation options that the country has identified is the increased usage of biofuels in the transport category. While the primary aim is of energy security, the current blending of petrol with ethanol at a blending ratio of 80:20, is taken as one of the existing climate change mitigation technologies. Also, the country, through the National Commission on Science and Technology (NCST), from 2010, has experimented on the 100% fuel-powered vehicles (refer to Figure 11) and the results were positive (NCST, 2010). The project was implemented in collaboration with Lilongwe Technical College, Ethanol Company Limited, Malawi Energy Regulatory Authority, Plant and Vehicle Hire Organisation and Malawi Bureau of Standards. Ethanol used in the blending with petrol is produced from sugarcane molasses by two companies: Ethanol Company Limited (ETHCO) based in Dwangwa, Nkhotakota District and Presscane Limited based in Nchalo, Chikwawa. Both of these companies get the molasses from Illovo Sugar factor in Dwangwa and Nchalo respectively. The limitations in molasses to produce adequate quantity fuel grade ethanol hamper the take-off of this project (The Times, 2017). Therefore, there is opportunity for biofuel production in Malawi. The use of ethanol reduces emissions of greenhouse gases, carbon monoxide (CO), hydrocarbons (HC), sulphur dioxide (SO2) and particulate matter and ethanol is generally less toxic to handle than petroleum fuels.

Figure 12: Photo of ethanol vehicle that was experimented on by the NCST (https://www.ncst.mw/?page_id=245)

Use of biodiesel replacing fossil fuel diesel has been experimented at Malawi universities, as part of their academic work. Production of biodiesel from Jatropha circus, to be used on commercial basis, has been promoted by Government of Malawi through a company called Bio Energy Resources Limited (BERL). BERL worked with the Malawi Energy Regulatory Authority on production licensing and pricing and with the Malawi Bureau of Standards on product quality (Wakeford, 2013). BERL had a vision of creating a private sector driven sustainable bio fuels business in Malawi with a sustainable non food crop supported by small scale farmers. However, as of 2019, the company has not started producing biodiesel.

3.3 Decision Context

The energy sector is one of the important economic sectors of Malawi. As it has been elaborated in Chapter One, Section 2, biomass energy, which is sourced unsustainably and in poorly processed form, dominates the energy supply sector (around 90%) in Malawi. The consequences of this dominance are the environmental degradation and increase in GHG emissions through reduction of the forest cover (GHG sink). These consequences contribute to the causes of slow national development. Further, Malawi faces shortages of modern sources of power such as electricity (access rate being only 10%) that limits economic activities. Cognizant of these, the revised Energy Policy of 2018 (refer to section 1.2.2) is aimed at reducing the contribution of biomass in the energy mix by promoting development and use of modern energy sources, as well as encouraging participation of the private sector in the power business.

Secondly, the Climate Change Management Policy of 2016 (refer to section 1.2.2) places emphasis on promoting climate change adaptation, mitigation, technology transfer and capacity building for sustainable livelihoods through Green Economy measures for Malawi. Through the development of the Nationally Appropriate Mitigation Actions (NAMA), the Government has strategized on mitigation options that will spur national development resulting in the reduction of greenhouse gas (GHG) emissions and enhanced sink capacity (GOM, 2015).

Thirdly, Malawi has developed several strategies and plans to solve challenges in the energy sector (Section 1.2). These strategies are all supported by the overarching Government of Malawi development policy document, The Malawi Growth and Development Strategy III where climate change management is part of the key priority area "Agriculture, Water Development and Climate Change". In MGDS III (2017-2022), a number of climate change strategies have been planned to address the effects of climate change in all the sectors of the economy. One of such strategies is to promote research, technology development and transfer in climate change (GOM, 2017).

Finally, the overarching planning document in the energy sector of Malawi, the Integrated Resource Planning plans to diversify power sources to include generation of power from coal (e.g the 300 MW, Kammwamba Coal Fired Station, 120 MW The Pamodzi in Salima, and The Salima Generic Coal utilising coal from northern region of Malawi), this pursuing the path of non-green electricity generation, which would increase GHG emissions from the energy sector. This calls for the development and use of the clean energy technologies.

3.4 Process of identifying climate change mitigation technologies

The process of identification of climate change mitigation technologies in the energy sector was guided by requirements that the identified technologies must be supported by the Government of Malawi's strategic documents such as policies and strategies. The identification used desk research as well as expert consultation. In the desk research process, information was collected from Government of Malawi policy documents and strategies (refer to Section 1.2.2) such as Intended National Designated Contribution (INDC), the revised National Energy Policy of 2018 (GOM, 2018), National Forestry Policy, the National Climate Change Management Policy of 2016 (GOM, 2016), Malawi's Nationally Appropriate Mitigation Actions (GOM, 2015), Biomass Energy Strategy, Malawi Renewable Energy Strategy (GOM, 2017), National Charcoal Strategy. The Incubator Programme of the Climate Technology Centre and Network (CTCN) for Malawi also provided useful literature on identification of technologies for climate change mitigation in the energy sector.

Technology facts on each of the identified technology were written down, again, with information being sourced from literature and seeking of expert opinion. The facts included details on how the technology works, advantages and disadvantages, recommendations on how to overcome the disadvantages associated with the technology, how much the technology cost, its benefits and sustainability. The Technology Facts Sheets are attached in the Appendix

Initially the consultant identifies 16 technologies. The identified technologies were reviewed and initially reduced to 11 at an Expert Working Group meeting that took place in Salima from 17th – 19th September 2019. The 11 technologies were then prioritized. The mitigation technologies that were reviewed and adopted for prioritization were selected using participatory multi-criteria analysis (MCA) tools in the agriculture sector are described in Table 3.

Table 3: Description of the identified mitigation technologies in the Energy Sector

Technology	**Description of the Technology**
Biofuel as vehicular fuel	Biofuels are fuels produced directly or indirectly from organic material including plant materials and animal waste. Biofuel used in the transport sector could be fuel grade ethanol and biodiesel from energy crops such as sugar cane and Jatropha respectively. Currently, biofuels (only ethanol) provide 4% of transport energy in Malawi. Fuel grade Ethanol is blended with petrol at blending ratios of 20:80. Higher blending rations are technically possible. The use of ethanol and biodiesel in conventional internal combustion engines could results in substantial reduction in GHG emissions due to fossil fuel substitution enhance outdoor air quality through reduced unburned hydrocarbons, carbon monoxide and particulate associated with combustion of diesel and petrol. Further, biofuel has capacity to create jobs and improve the national economy.
Biogas	Biogas is produced through the digestion of organic matter by anaerobic bacteria in an oxygen-free surrounding. During the anaerobic digestion, the fuel, methane gas (CH_4) is produced as by-product of their digestion process. The biogas could be packaged as a cooking fuel away from production site through bottling (after removing CO_2 in the gas). This is another business venture associated with this technology. In Malawi, most of the organic matter (substrate) into the digester is cattle

	dung, for household biogas systems. The convenient potential/target would the dairy farming, where biogas plants are installed as part of the diary business, providing energy for use at the farm. Where the substrate is from waste, biogas technology is a viable waste management technology. It is possible to develop an institutional scale biogas using municipal waste water treatment plants, for example, the water treatment plant in Zingwagwa Township in Blantyre City. Replacement of fossil fuels and traditional solid biomass by clean fuels like biogas for cooking, lighting and electricity generation help in curtailing GHG emissions. Also, biogas would contribute to waste management in Malawi. The slurry (digested organic matter) is fertilizer, which could contribute to food national food security.
Biomass briquette	Turning organic waste matter into carbonized fuels (e.g biomass briquettes) is one of the most promising solutions to energy challenges in Malawi, as well as one of the waste management options. Biomass briquettes are a biofuel substitute to coal, firewood and charcoal. Briquettes may be used to heat industrial boilers in order to produce electricity from steam in large-scale production. In addition, briquettes may also be co-fired with coal in order to create the heat supplied to the boiler. Biomass briquettes are produced from agricultural waste and are a replacement for fossils fuels such as oil or coal and can be used to heat boiler in manufacturing plants. In Malawi, briquettes are sold as fuel in urban areas, but in limited cases supported by projects. In terms of resources, the country has significant potential for briquettes production (office paper waste, agricultural wastes and forestry products e.g saw dust). Collection of solid waste for briquettes would create jobs, in case of commercial level of briquetting business. Socially, cooking using briquettes improves indoor air quality, positively impacting on health, especially of women and girls. Since the carbonized fuels (like briquettes) are packaged and of high energy value per unit volume, there is stimulation into stimulate waste collection. Environmentally, briquetting from organic waste is one of the viable ways of waste management.
Energy conservation and efficiency for industry and buildings	Industries and buildings are without doubt significant energy consumers in Malawi. In industry, energy is consumed to do work such as driving electrical motors, production of steam in boilers either for process steam or production of electricity or both. The other industrial energy consuming systems include cooling/heating systems and lighting system. Usually, energy consumed is a result of primary energy transformation, which might be from fossil fuel based. Also, in buildings, energy consumption come from use of energy consuming appliances especially in high-income households and institutions, to power energy consuming appliances such as water geysers, cooking stoves, lighting, cooling/heating, entertainment and security facets. Energy used in buildings is still dominated by biomass, and electricity to some extent. Often times, diesel generators are operated to

	provide electricity for use in households during peak times. There is therefore, energy savings potential if energy conservation measures/and practices are incorporated and that energy is consumed efficiently. These fall under the concept of energy management, which is defined at the judicious way of utilising energy so as to reduce energy input without compromising on the product/service quality and remaining competitive on the market. The options considered for energy savings in industry and buildings particularly leading to CO_2 emission reductions include the following: (i). use of renewables for heating, cooling and electricity, (ii). improvements to the building envelope, including materials, natural ventilation and daylighting, (iii). improvements in building services, including heating, mechanical ventilation and air-conditioning, (iv). maintenance of industrial equipment and buildings, (v). systems optimisation and re-commissioning works, and (vi). retrofitting energy saving solution e,g smart meters The saved fossil fuel due to application of energy efficiency and conservation measures directly contributes to GHG reduction. The energy conservation and efficiency would also reduce energy cost and thus make industry products or services competitive on market.
Improved charcoal production kilns	Charcoal is the form of biomass energy is favoured in urban areas because cooking does not produce smoke, and it has a high value of energy density and it can be bought in packages, unlike firewood. Cooking with charcoal is relatively fast and associated with improved social status, compared with firewood. In Malawi, the charcoal market is wide spread, creating a market for several people. A charcoal licensing system is in place, but in practice, the bulk of charcoal production is undertaken without official licensing. Charcoal is one of the most important reasons for deforestation. In Malawi, charcoal is primarily produced in forested areas, especially in districts surrounding urban centres. Wood is harvested from these areas through clear felling, selective cutting or from purposely grown plantations. The harvested wood is converted into charcoal in a batch-type process. Traditionally, earth or mound carbonisation kilns with relatively low efficiencies (around 15%). The benefits of promotion of improved - charcoal production kilns include economic benefits including continued charcoal trade that is generated from efficient and sustainable process. Social benefits include positive health impacts due to charcoal being associated with clean cooking. Efficient kilns will translate into forest cover saving. The saved trees contributes to making

	the country greener positively impacting the air quality, soil erosion management and supporting bio-diversity. Also, saved forest contributes to GHG emission reduction.
Efficient firewood cookstoves	The technology of efficient biomass firewood stove, like any other efficient cook stoves; depends on having an efficient combustion process and minimization of heat losses. The efficiency of the stove does not depend on combustion efficiency only: all elements of the cooking system, preparation of fuel, which includes the cookstove, cooking vessel (e.g. pot), user cooking practice, and kitchen design, come into play. Unlike charcoal stoves, the design of the firewood cooking stove must accommodate firewood, which must be cut into relatively small pieces and the combustion chamber part of the stove must be large compared to charcoal stove. The stove comprises the support structure, the combustion chamber and the pot-stand, all in one unit. The design must let in access air for complete combustion and that there should be proper. Safety features are also important design parameter. The cost aspects of the efficient design should be affordable so that the majority of Malawians are able to purchase. The efficient cookstove should also have elements that make could make it more convenient to be used for cooking. Further, for the efficient cookstove to be promoted widely, the materials to manufacture the must be available locally. Examples of demonstrated efficient firewood cookstove include clay cookstove, known as Chitetezo Mbaula. There is potential to popularize the improve firewood cookstove such as the Chitetezo Mbaula. Firewood is used by the majority of Malawians for cooking, and thus used to promotion of efficient firewood cookstove has great impact to reduce deforestation than other types of stoves. The benefits of promoting efficient cookstoves in Malawi include the following: generation employment for rural communities. Socially, efficient stove reduce indoor air pollution and improve health. Environmentally, efficient cooking stove reduce demand for fuel wood hence one of means of halting forest degradation. The saved forest from use of efficient cookstove translates to reduction of GHG emissions through enhancing carbon sink.
Lake Malawi hydrokinetic electric power	From science, hydropower can be generated using head (potential energy) or on flow velocity (kinetic energy). The conventional hydropower generation uses head. However, there is enormous potential from harnessing hydropower from flowing water sources such as rivers, lakes and oceans. Hydropower extracted due to water velocity (kinetic energy) is called hydrokinetic power, its potential is given by the following governing equation. $$P = \frac{1}{2} C_p \rho A V^3$$

	Where P is the mechanical power generated by the turbine, C_p is the power factor, ρ is the density of water, A is the area of the rotor blades, V is the fluid velocity. The power coefficient is a measure of how much the turbine can harness the mechanical power from the available hydraulic power. Since water is denser than air, hydrokinetic power technology represents a highly-concentrated and clean energy resource compared to wind turbine. Enormous electricity could be produced from hydrokinetic power extracted from Lake Malawi. From science, due to boundary layer phenomenon, the velocity of water flow increases from the lake bed with height until reaching the maximum velocity, and then it decreases unto to the water surface. It is thus, possible to place a turbine at a position of maximum water flow velocity to harness maximum hydrokinetic power. The technology has potential to increase the electricity generating capacity, which will provide adequate power for economic activities. The excess electricity generated could be sold outside Malawi. The electricity generated will help to reduce power shortages, increasing the social aspects of Malawians such as health and education The technology will increase of share renewable energy in the energy supply sector. This will have a positive impact on the environment. This is the renewable energy generation technology. Thus, if the power generated replaces fossil fuel based power, the mitigation potential is very high
Liquefied Petroleum Gas for cooking	Liquefied petroleum gas (LPG) is a mixture of propane and butane, which are gases that become liquid under pressure and can then be stored in pressurised containers. LPG is manufactured during the refining of crude oil (40%) or from natural gas during extraction (60%).The proportion of each gas varies depending on the source. LPG has a high energy per unit volume and is convenient to use for thermal application. Its calorific value per unit volume is about 2.5 times larger than that of natural gas (methane). It is Apart from cooking, LPG could also be used for as a vehicular fuel, and in heating, refrigeration and air conditioning systems. The gas has low carbon content compared to coal and its use is thus connected to climate change mitigation. As a cooking fuel, LPG is seen by the International Energy Agency (IEA) as one of the plausible main means for moving away from unsustainable use of biomass for cooking. The Malawi Government also identified it as one way of reducing deforestation. However, there are challenges for populisation of this technology in Malawi. Through a study to assess the market potential of LPG cooking fuel by Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) Project, the scope for LPG for cooking is seems to be concentrated mostly among the middle and high income groups in urban areas. Further, the study found out that for those that cook using LPG, the gas is only used as a back-up fuel. The relatively

	high gas price and the equipment (stove and cylinder) cost make the technology available only to some segments of the households and institutions. There is need for awareness on LPG as a cooking fuel as well as improvement in the gas distribution networks in the country.
Solar PV	Solar photovoltaic (PV) cells convert sunlight directly into electricity. Currently, crystalline silicon (c-Si) and the thin-film (TF) technologies dominate the global PV market. In a c-Si PV system slices (wafers) of solar-grade (high purity) silicon are made into cells that are assembled into modules and electrically connected. TF PV technology consists of thin layers of semiconducting material deposited onto relatively inexpensive, large-size substrates such as glass, polymer or metal. The solar PV systems are modular in structure, and thus, they can be built to meet almost any electric power need, small or large. The technical requirements for the installation of solar PV vary greatly depending on the size of the system and kind of technology used. Small off-grid systems in remote/rural areas using solar home systems (SHSs) could be bought in off-the-shelve and installed with relatively little local expertise. The solar PV systems require relatively minimal maintenance, which involve cleaning of the solar panel to ensure efficiencies are maintained. Installation of SHSs has been increased in the country. Most of the SHSs are undocumented, and are mostly used for lighting and phone charging. The installation of large scale solar PV for electricity generation either as mini-grid or grid based is limited. The latter technology could greatly improve the contribution of renewables in electricity generation mix for the country, thus greater potential for climate change mitigation. Malawi has instituted the Malawi Energy Regulatory Authority (MERA) that provides regulatory requirements for energy such as solar PV electricity generation. According to MERA, grid connected systems require an appropriate license or permit to export to the grid along with the necessary metering equipment, connected by a professional, to ensure that the level of export to the grid is measured for any subsequent compensation. Larger installations obviously require appropriate planning permissions that would accompany any moderate to large infrastructure project. Also, the Malawi Bureau of Standards has developed standards on solar PV systems, however there are challenges on enforcement of the standards as evidenced by proliferation of poor quality solar products.
Biomass Gasification	Biomass gasifiers are energy systems that generate combustible gas (syngas) from solid biomass (any solid carbonaceous material) through series of thermo-chemical processes. The advantage of biomass gasification is that using the syngas is potentially more efficient than direct combustion of the original biomass because syngas can be combusted at higher

	temperatures or even in fuel cells so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher. The syngas could be used in fuel cells and internal combustion engine. The gasifiers could be for industrial scale or households scale. The latter are commonly called biomass micro-gasifier to be used for household cooking. It is possible to incorporate a thermal-electric converter to the biomass gasifier to generate electricity together with heat. Micro-gasifier stoves are currently the cleanest burning option to burn solid biomass in a cook stove. Compared to solid biomass burning improved cookstoves, gasifiers have advantages, including the following: (i). cleaner burning of solid biomass. (ii). more efficient due to more complete combustion, (iii). uses a wide variety of small-size biomass residues (no need for wood pieces or charcoal), (iv). easy lighting allows for cooking to commence within minutes, much faster compared to lighting charcoal. The technology is relatively new to Malawi: being at experimental stage at universities and research institutions (e.g Chitedze Agricultural Research Institution) and at Jesuit Centre for Ecology and Development in Lilongwe. Economically, promotion of biomass gasification technology would create jobs created through local artisans in production of biomass gasifiers. Also, the technology creates market for sale of fuel e.g. biomass briquettes for production of gas and char. Socially, clean cooking using gas from the biomass gasifier enhances quality heath among the women and girls. Environmentally, saved trees from substitution with firewood and charcoal enhances ecosystem through tree conservation. The electricity for lighting and phone charging improves household quality of life. The technology has high potential of enhancing carbon sink through forest that is saved and minimization of GHG emission from the biomass sector e.g methane.
Ethanol Cook stove	Cooking using ethanol/alcohol as fuel is practiced in many countries. The equipment required for ethanol cook stoves is similar to existing kerosene stoves. The technology can be applied in households, institutions (*e.g.* schools) and industries where it is used for boiler heating. An ethanol stove for cooking has to fulfill certain criteria. It has to ensure that the ethanol is burnt stable, i.e. in a way that it will not explode, and the flame has to reach certain heat levels (blue flame) to ensure that the energy is used efficiently. There are cookers that burn liquid ethanol directly, which is quite risky. The ethanol cook stove could use indirect combustion, transferring the liquid ethanol into a gas stadium, and hybrids between the two. Also, gelfuel, a jelly produced from ethanol, is a more user-friendly way of burning ethanol, but has not yet gained wide acceptance in Malawi, probably due to the high price of both fuel and stoves and the bad quality of gelfuel stoves available

	in the market. A study in peri-urban Malawi to evaluate the ethanol stove against an improved ceramic charcoal stove, revealed that the ethanol stove was potentially appropriate for use but suffered from manufacturing problems, with further work required on safety, performance and emissions. However, the stove can be made appropriate with achievable development. The study recommended the stove to be made both affordable and accessible to users. Also the ethanol market would need some marked changes to reduce price, increase available volumes and develop alternative feed-stocks. The benefits of promoting ethanol cookstove are as follows: Economically, creation of jobs for stove manufacturers as well as from ethanol sales. Socially, there is improved heath resulting from reduced/prevention emissions and particulate matter as a result of switching from cooking using firewood and charcoal. Environmentally, ethanol cooking stoves have minimal air pollution problems. Switching from firewood and charcoal to cooking using ethanol saves trees, enhancing air quality, ecosystem management and reduction in environmental degradation. The greenhouse gas emission reduction contribution from ethanol cookstoves depends on the feedstock used for the ethanol, the distance from feedstock location to ethanol production, and fuel it replaces. If it replaces firewood and charcoal that are harvested from forest unsustainably; the mitigation potential of use of ethanol stove is high.

3.5 Prioritization of technology options

The technology prioritization is a stakeholder participatory process and employed the multi-criteria analysis (MCA) approach. In order to refresh the knowledge of the expert working group on the MCA process, TNA consultants organized a one-day training (first day of the technology prioritisation workshop) for them. Each step of the MCA process was thoroughly discussed and using practical examples. An UNEP-DTU excel-based template for calculation purposes was also introduced and thoroughly discussed with the members. It was noted that the MCA process generated interest and nearly all participants actively participated in the discussions. After the training, expert working group members used a stepwise approach of MCA in the prioritization of the identified mitigation technologies for the energy sector, as presented in the following sub-sections.

3.5.1 Identification of evaluation criteria

The MCA approach is about making a decision on the technology to be picked based on several factors. In this assignment, the factors were cost-benefit, environment and climate change. Thus, the prioritization process requires firstly having an evaluation criteria in place. The TNA is a participatory process: expert working group members were involved to come up with the evaluation criteria (refer to Table 4), after reviewing the generic list of criteria available in the

TNA Guidebook for evaluating mitigation technologies (Haselip, et al., 2019). The criteria were organized under costs and benefits in order to facilitate the scoring process. Costs were broken down into capital costs and operating costs of the technology. The benefits were categorized into economic, social, environmental, and climate related. The economic benefits were sub-categorized into job creation and poverty reduction; the social benefits were sub-categorized into poverty reduction and gender equality; while the reduction of deforestation and reduction of GHG emission potential were chosen as environmental and climate change related benefits respectively. Each of the technologies was assessed against these criteria.

The members also involved in coming up with the relative weightings and scores.

Table 4: Evaluation criteria used in the MCA prioritization process.

Criteria category	**Criteria and description**	**Sub-criteria**
COSTS	1. *Capital costs*. Cost of setting up the technology – often incurred during start-up phase	1. Capital costs
	2. *Operating and maintenance costs* – costs of maintenance and implementation of the technology;	2. Operating and maintenance costs
BENEFITS	3. *Economic benefits* – the ability of the technology to improve local economy; catalyze private investment; and create jobs;	3. Job creation
		4. Ability to spur private investment
	4. *Social benefits* – ability of the technology to reduce poverty and inequity between social classes; improve health of the people; and preserve cultural heritage;	5. Poverty reduction
		6. Gender equality
	5. *Environmental benefits* – ability of the technology to protect the environment and/or biodiversity;	7. Reduction of deforestation
	6. *Climate related benefits* – ability of the technology to reduce vulnerability and build climate resilience, and reduce GHG - as a co-benefit.	8. GHG emission reduction potential

After the establishment of evaluation criteria, the Consultant presented the technology factsheets for all the 11 identified mitigation technologies in the energy sector and the soft copy version was made available to the expert group members for use in the prioritization process. These fact sheets are presented in Appendix 3. The identified technologies were then evaluated against these evaluation criteria. It was the consequences of the identified technologies that were been assessed and not the technologies themselves – and this required thorough thought about the consequences of each of the technologies. The consequences of the technologies were with regards to costs of the technology (minimizing the costs) and maximizing the benefits.

3.5.2 Scoring the technologies

The energy experts from the Expert Working Group members were assembled in one room to score the technologies against the criteria established. Scoring of the technologies was done by the expert working group, using interval scale method. In establishing an interval scale for a criterion, the participants defined the levels of performance corresponding to any two reference points on the scale, 0 and 100. The score of 0 was associated with the performance level of the technology in the currently considered set of technologies which performs the least and 100 with that which performs best. Table 5 provides the score descriptions used in the current assignment. The advantage of use of interval scale was that differences in scores among technology options have consistency within each criterion.

Table 5: Descriptions of the scores used in the MCA process.

SCORE	General description
0	Information on technology does not apply to a particular criteria
1 - 20	Extremely weak performance, strongly unfavorable;
21 - 40	Poor performance, major improvement needed;
41 - 60	An acceptable or above level;
61 - 80	Very favorable performance, but still needs improvement;
81 - 100	Clearly outstanding performance which is way above normal.

The technologies were scored on each of the criteria presented in Table 4. The resultant scores are given in a performance matrix table (refer to Table 6). The scores in the matrix table (refer to Table 5) show perceived relative contribution of each criterion towards the choice of priority adaptation technologies. They show the importance of each criterion in the face of the panel of Expert Working Group.

Table 6: Performance matrix for evaluating the climate change identified mitigation technologies.

Technology	Costs		Benefits					
			Economic		Social		Environmental	Climate related
	Capital Cost	O& M	Job creation	Private Investment	Poverty Reduction	Gender equality	Reduce Deforestation	Reduce GHGs
Biomass Gasification	70	60	70	65	70	100	100	60
Solar PV	50	60	100	80	100	0	0	80
Biogas	60	60	20	50	20	100	80	40
Biofuel as vehicular fuel.	90	80	100	70	100	100	70	50
Energy efficiency and conservation measures in industries and buildings	35	50	10	5	10	0	50	20
Liquefied Petroleum Gas (LPG) for cooking	100	65	100	20	100	100	80	80
Improved charcoal production kilns	40	60	30	70	30	100	80	70
Biomass Briquettes	30	80	15	90	15	0	20	50
Ethanol Cookstoves	70	90	10	45	10	0	80	80
Efficient firewood cookstoves	20	20	40	50	40	0	10	50
Lake Malawi hydrokinetic electric power	0	70	100	100	100	0	50	100

After scoring the technologies against the criteria (Performance Matrix), weighted scores (normalised scores) were assigned to each of the criteria to express the relative importance of each criterion with respect to the other criteria. The weighting scores were derived from the relative importance the panelists attached to each criterion with respective to the others in achieving the desired outcome. The sum of the normalized scores was set to be equal to 1 or 100%. Table 7 provides the normalized (weighted) scores determined by the panelists of the expert working group.

Table 7: Evaluation criteria used in the MCA prioritization process.

Criteria category	**Sub-criteria**	**Weighting coefficients (%)**
COSTS	Capital costs	20
	Operating and maintenance costs	5
BENEFITS	Job creation	15
	Ability to spur private investment	10
	Poverty reduction	15
	Gender equality	5
	Reduction of deforestation	10
	GHG emission reduction potential	20
Total		100

The weighting coefficient for each criterion (refer to Table 7) was multiplied by its corresponding scores presented in Table 6. The resulting weighted scores were summed up for each technology option to derive an overall score value. The aggregation of the weighted scores was conducted using the MCA calculator. The results of the aggregation of the weighted are given in Table 8.

Table 8: Scoring matrix for evaluating the climate change identified mitigation technologies.

Technology	Costs		Benefits						Total score	Technology rank
			Economic		Social		Environmental	Climate related		
	Capital Cost	O& M	Job creation	Private Investment	Poverty Reduction	Gender equality	Reduce Deforestation	Reduce GHGs		
Biomass Gasification	1400	300	1050	650	1050	500	1000	1200	7150	3
Solar PV	1000	300	1500	800	1500	0	0	1600	6700	5
Biogas	1200	300	300	500	300	500	800	800	4700	8
Biofuel as vehicular fuel.	1800	400	1500	700	1500	500	700	1000	8100	2
Promotion of energy efficiency and conservation measures in industries and Institutional buildings	700	250	150	50	150	0	500	400	2200	11
Liquefied Petroleum Gas (LPG) for cooking	2000	325	1500	200	1500	500	800	1600	8425	1
Improved charcoal production kilns	800	300	450	700	450	500	800	1400	5400	6
Biomass Briquette	600	400	225	900	225	0	200	1000	3550	9
Ethanol Cookstove	1400	450	150	450	150	0	800	1600	5000	7
Efficient firewood cookstoves	400	100	600	500	600	0	100	1000	3300	10
Lake Malawi hydrokinetic electric power	0	350	1500	1000	1500	0	500	2000	6850	4
Criterion weight	20	5	15	10	15	5	10	20	100	

3.5.3 Results of technology prioritization

Table 9 below shows the results of the technology prioritization following the MCA process. The table presents the top 6 priority mitigation technologies in the energy sector with "*Liquefied Petroleum Gas (LPG) for cooking*" topping the list, followed by "*Biofuel as vehicular fuel*". The third priority technology prioritized by the expert working group is "*Biomass Gasification*". These priority technologies will be taken to stage two of the TNA process which will involve analyzing barriers to, and enabling framework for, their diffusion.

Table 9: Prioritized mitigation technologies in energy sector

Rank	Technology	Total score
1	Liquefied Petroleum Gas (LPG) for cooking	8425
2	Biofuel as vehicular fuel.	8100
3	Biomass Gasification	7150
4	Lake Malawi hydrokinetic electric power	6850
5	Solar PV technology	6700
6	Improved charcoal production kilns	5400

As it can be seen from the results of the prioritized technologies, half of the technologies in the top six are thermal based energy technologies for cooking and heating. It could be that the stakeholders viewed these could significantly off-set the overdependence of traditional biomass energy consumption for domestic and institutional applications, resulting in creation of employment, empowering women, improvement in human health, and reducing the GHG emissions from saved trees. This could have been influenced by the presence of the policy makers in the expert working group members that carried out the priorization process.

It is also interesting to note that solar PV technology is not rated among the top three, despite the technology being recommended in most of the strategic energy and climate change mitigation documents. Selection of biofuel for vehicular fuel is an important one because the country does not have oil refining industries and the transport sector supports economic activities and the country has suffered economically from lack of petroleum products (petrol and diesel). Promotion of biofuel would opportunities for farmers to engage into commercial cash crop, that would offer alternatives to tobacco farming.

CHAPTER FOUR

CONCLUSION

The process for developing the TNA report for Malawi has been a stakeholder participatory process, being informed by the methodology described in the "*A guidebook for countries conducting a Technology Needs Assessment and Action Plan*" developed by the UNEP DTU Partnership. The process started with the prioritization of the sectors for mitigation, which identified the Energy and Forestry sectors. The institutional arrangement for conduction of the TNA in Malawi was instituted, and consultants recruited. The Consultants were briefed about the scope of work. Firstly, the consultant reviewed strategic documents, including policies and strategies in which climate change mitigation options are highlighted, so that the TNA falls within the strategic position of the Government of Malawi. The Consultant then identified climate technologies for mitigation in the energy sector through document review, and reference to the CTCN website for technology specifics when coming up with technology factsheets for the identified technologies. A total of 11 technologies were identified, and their technology factsheets developed, customized to Malawi.

The process of optimizing the identified technologies followed the stakeholder participation, while incorporating gender issues through every step of the technology prioritization process. The expert working group, using the multi-criteria analysis, prioritized the identified technology against criteria that was established by the expert working group that participated in the Technology Prioritization Seminar. The top six prioritized technologies are listed as follows, in the order of prioritization.

1. Liquefied Petroleum Gas (LPG) for cooking
2. Biofuel as vehicular fuel.
3. Biomass Gasification
4. Lake Malawi hydrokinetic electric power technology
5. Solar PV
6. Improved charcoal production kilns

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APPENDICES

APPENDIX 1: TECHNOLOGY NEEDS ASSESSMENT (TNA) STAKEHOLDER WORKSHOP SUNBIRD LILONGWE HOTEL, MALAWI, 6TH NOVEMBER 2018.

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APPENDIX 3: TECHNOLOGY FACT SHEETS

Biomass Gasification Technology

Technology Characteristics	**Narrative description of the characteristic**
General information	Biomass Gasifies are energy systems that generate gas from solid biomass. There are some smaller versions (biomass micro-gasifier) are small enough to fit directly under a cook-pot (refer to Figure 1). It is possible to incorporate a thermal-electric converter to the biomass gasifier to generate electricity together with generation of heat. Micro-gasifier stoves are currently the cleanest burning option to burn solid biomass in a cook stove. The "gas burner" provides the convenience and efficiency similar to cooking on fossil gas with very little soot and other emissions. Advantages of Gasifier Stoves Compared to solid biomass burning improved cookstoves, gasifiers have several advantages, including the following: Cleaner burning of solid biomass (considerable reduction of soot, black carbon and indoor/outdoor air pollution). More efficient due to more complete combustion (less total biomass consumption). Uses a wide variety of small-size biomass residues (no need for wood pieces or charcoal). Easy lighting allows for cooking to commence within minutes, much faster compared to lighting charcoal. There are also advantages compared to stoves operated on alternative fuels like liquid fuels or solar: Solid biomass fuels are often available locally, easy to transport and easy to store after gathering. Creation of gas from dry biomass can be achieved with relatively simple inexpensive technology directly in the burner unit, which is portable and does not require piping or special burner-heads (in most cases). Performance similar to biogas (but not dependent on water and bio-digester) and approaching the convenience of fossil gases. Furthermore, pyrolytic micro-gasifiers can create charcoal, which may be used in a charcoal stove, further processed into charcoal briquettes or used to improve soil productivity as biochar. Disadvantages and Challenges of Gasifier Stoves Users may encounter some challenges when using gasifier cookstoves: Micro-gasifiers need small-sized fuel. They are only useful if fuel is available in the right size. Firewood in the form of large logs or sticks is not suited and needs other types of improved stoves. Most micro-gasifiers are batch-loaded and cannot be refueled during use. Thus, cooking times are pre-determined by the size of the fuel container. The heat output of most micro-gasifiers is not easy to regulate unless the stove is operated with a fan for forced convection. In this case the power

	of the fan can be regulated. Micro-gasifiers burn the biomass in two stages: first the gas-generator produces the wood gas, which is a thick whitish ‘smoke’ or fume. This “smoke” is burnt by the gas-burner, which is thus basically a ‘smoke-burner’. If the gas-burner operates well then there is no problem. However, should the flame of the gas-burner extinguish (e.g. blown out by gusty wind), the gas-generator will continue producing wood gas, which will not be burnt and then escape as thick white smoke from the stove. Status of Gasifiers in Malawi There no history of use of biomass gasifier in Malawi. There has been some level of technology development; there has been is some activity in the country's universities and research organisations. The Jesuit Centre for Ecology and Development (JCED), has produced a modern gasifier cook stoves that uses briquettes, in collaboration with Lilongwe University of Agriculture and Natural Resources. The technology has been developed into a usable prototype, using briquettes from tobacco stalks as biomass energy input, but the technology is yet to be popularized in the country. The community in tobacco making communication will be empowered to make briquettes to feed in the gasifier. Other crop waste such as cotton stalks are also planned for production of briquettes. Other wastes for production of briquettes such as saw dusts and non woody-waste are planned to be used. The developed JCED Gasifier cookstove (refer to Figure 2) is reported that it could take upto 3 hours cooking or other heating purposes, and does not produce smoke. The excess heat generated by the gasifier can be harvested by a thermo electric generator and converts it to electric energy that charges a battery to light a house for about 6 hours, or more if less than 3 light bulbs are used. When not in cooking, a solar panel can be used to charge the battery. Thus, JCED Gasifier has multiple benefits to the project beneficiaries – clean, safe and efficient cooking and heating energy source, including the converted electric energy for lighting the house and charging mobile phones.
Physical component/innovative technique	Biomass gasifiers generate gas from pyrolysis process. The gasifier can separate gas generation from gas combustion in space and time. In a reactor (gas generator) that is optimized for heat-dependent drying and pyrolysis, solid biomass is first converted into gases and vapors. These are guided into a combustion zone (gas burner) where they are burnt with a surplus of oxygen from a secondary air inlet. Figures 3 and 4 show the steps and details of the gasification processes. In a conventional fire, the heat is controlled by regulating the fuel supply: the more fuel is added, the more heat is generate, provided sufficient air is available for the combustion. If the thermal electric converter is incorporated the heat generated from combustion process is also used to generate electricity. In contrast to this, gasifiers control and optimize both processes separately to achieve efficient and clean utilization of the fuel, as follows: regulating the heat that is reaching the solid biomass to optimize the drying

	and pyrolysis process controlling the supply of air and regulating the availability of oxygen for optimizing the subsequent steps of wood gas combustion and char gasification. More air to the ‘gas-generator’ produces more gas that can be combusted in the ‘gas-burner’. The regulation, however, is a bit tricky and one of the challenges is to find a better solution to this.
Feasibility of technology and operational necessities	The technology is mature and feasible. It does not require operational necessities, apart from feeding in of biomass briquettes into the gasifier and and removal of char.
Institutional framework for adoption and diffusion	Not available, but the Department of Energy Affairs, in the section of alternative energy, could provide institutional framework for adoption and diffusion
Cost	The investment cost is relatively high compared to improved firewood cookstove of charcoal stoves.
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	The job created through local artisans in production of micro-gasifiers Also, the technology creates market for sale of fuel e.g. biomass briquettes for production of gas and char.
Social	Clean cooking using gas from the biomass gasifier enhances quality heath among the women and girls
Environment	Saved trees from substitution with firewood and charcoal enhances ecosystem through tree conservation. Use of biomass stove enhances air quality The electricity for lighting and phone charging improves household quality of life Briquettes from biomass waste is a useful way of waste management, making the environment clean
GHG mitigation potential	The technology has high potential of enhancing carbon sink through forest that is saved and minimization of GHG emission from the biomass sector e.g methane
Applicability* of the technology in Malawi (short, medium and long term)	The technology is mature and thus, it can be applied in a short term
Size (household and large-scale)	The technology can be applied at both household and large-scale levels

*On Applicability of the technology

Applicability of technology is define as follows: short term is the technology that is proven to be liable and is commercially ready in similar market

Medium term refers to the technology that is in pre commercial in a similar market

Long term refers the technology that is still under research and Technology phase

Figures


Figure 1: A Simple biomass gasifier cookstove

Figure 2: Gasifier stove that can also produce electricity, manufactured by Jesuit Centre for Ecology and Development (JCED) in Malawi

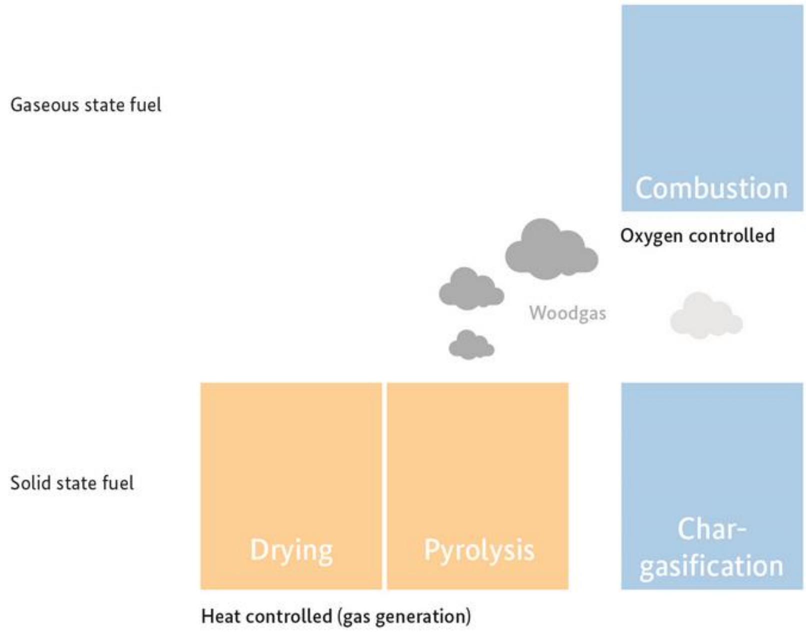

Figure 3: Processes of biomass gasification

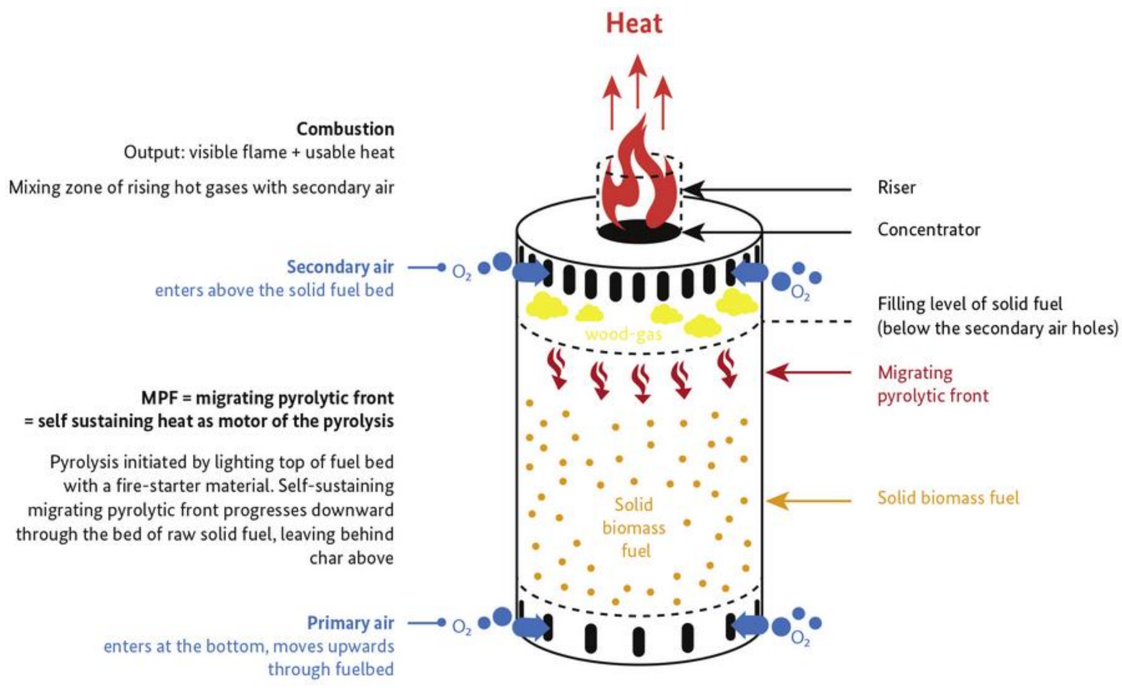

Figure 4: Details processes of biomass gasification

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Solar PV technology

Technology Characteristics	Narrative description of the characteristic
General information	Solar PV has enormous energy potential in Malawi. The energy policy, renewable energy strategy, NAMA and many other strategic documents lists solar PV technology as one of the viable options for clean energy supply and climate change mitigation. A key driver is the fact that, due to a steep learning curve and increased competition, worldwide, rapid cost reductions of Solar PV systems have been experienced over recent decades. It has energy payback periods ranging from 2 to 5 years for good to moderate locations and lifecycle GHG emissions in the order of 30 to 70 gCO2e/kWh depending on panel type, solar resource, manufacturing method and installation size. This compares to emission factors for coal fired plants of more than 900 gCO2e/kWh and for gas fired power stations of more than 400 gCO2e/kWh, showing the large potential for solar PV to contribute to reductions in carbon emissions from the electricity sector. The Solar PV technology generates electricity due to the "photovoltaic effect". The Photovoltaic effect can be briefly summarised as sunlight striking a semiconductor and causing electrons to be excited due to energy in the sunlight (photons). The excited electrons become free of their atomic structure and, in moving away, they leave behind 'holes' of relative positive charge that can also migrate throughout the material. By placing two different semiconductors together in thin layers (or wafers) the free electrons and 'holes' can be separated at their interface/junction, creating a difference in charge, or voltage, across two materials. Sometimes, the term "p-n junction" is used which refers to the two different types of semiconductor used. A single such arrangement, or cell, creates only a modest voltage and current, but when arranged into larger arrays the cells can produce useful amounts of electricity which is known as solar PV electricity. On the basis of their manufacturing process, solar cells consist basically of three main components - the semiconductor, which absorbs light and converts it into electron-hole pairs, the semiconductor junction, which separates the electrons and holes, and the electrical contacts on the front and back of the cell that allow the current to flow to the external circuit. R&D and practical experience with photovoltaics have led to the development of three generations of solar cells. Figure 1 presents basic component of a solar PV system for a standalone energy system.
Physical component/innovative technique	The common PV technologies can be broadly categorised into two groups – crystalline silicon and thin film. Crystalline silicon technologies account for the majority of PV cell production, whereas thin film is newer, less efficient, but growing in popularity. *Crystalline silicon based solar cells* The first generation is represented by crystalline silicon (c-Si) modules, which may be single- (sc-Si) or multi-crystalline (mc-Si) depending on the manufacturing technique. They dominate the PV market with around 90% share. Improvements in efficiency have been mirrored by improvements in

	manufacturing techniques including thinner cells (lower material costs), larger wafers, increased automation and other factors that likewise contribute to the significant cost reductions seen in the past decades. Manufacturers are now striving to use less silver and other expensive materials (maybe replacing silver with copper), while maintaining or even extending the technical life of cells and modules. *Thin film solar cells* Second generation technologies, so called thin film (TF) solar cells are based on alternative materials such as cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), amorphous silicon and micromorphous silicon set as thin films. The layer that absorbs the sunlight is only a few micrometres thick and can be deposited onto relatively large smooth surfaces such as glass, metal or plastic. This PV type has the advantage of lower labour and energy intensity compared to crystalline silicon PV but a reduced efficiency in terms of electricity generation. Thin films of various sorts now represent only about 10% of the market, down from 16% in 2009. *Multi-junction cells* Multi-junction cells, also called Third Generation, involves superposing several cells in a stack. In the case of two cells, it will form a double junction, also called a tandem cell. They were originally developed for use in space and have multiple junctions typically using more exotic semiconductors such as gallium and indium compounds. These types of cells have already crossed the maximum theoretical efficiency of single junction solar cells, and many laboratories have reported lab scale solar cells reaching efficiencies in the excess of 40%. Third generation cells are typically considered in combination with solar concentrator systems as described below and are currently being commercialised in this context. The use of concentrators allows much smaller cells to be used which in turn reduces the cost associated with these more exotic materials. *Concentrated solar PV* Solar cells have been found to operate more efficiently under concentrated light which has led to the development of a range of approaches using mirrors or lenses to focus light on a specific point of the PV cell, called concentrator systems. Specially designed cells use heat sinks, or active cooling, to dissipate the large amount of heat that is generated. This type of concentrating configuration requires a sun tracking system using either single axis or double axis tracking to make sure that the mirrors/lenses are always pointing at the correct orientation. The concentrating photovoltaics (CPV), although growing significantly, represent less than 1%. *Off-grid and grid connected PV* There is an obvious yet important qualification to the discussion above on efficiency, which is that solar panels are limited to only produce electricity in periods of sunlight, either direct light or diffuse sunlight on overcast days. During the night they will not produce power. This means that solar cells, if used for remote/off-grid generation purposes, need to be implemented in conjunction with some kind of storage system such as a

	battery or as a hybrid system with some other type of generator. Where solar cells are grid connected this is less of a problem. They can be used during the day to reduce the local demand from the grid (or even to export back to the grid) and then at night, or during periods of low incident light, the grid can supply the necessary power. The former kind of application, as a remote or off-grid generator, is most commonly observed in developing countries and isolated areas, while grid-connected solar PV is more common in industrialised countries which have a wider reaching grid. Grid connected solar PV also can have differences in the approach used depending on the way in which customers purchase the electricity. If the solar array is distributed, for example over a larger number of residential houses, then the single installations are operated by the consumer directly. The advantage of this to the consumer is that the cost of electricity, that the consumer must compete with, is the distributed cost, i.e. the cost to purchase power at the location of demand which is normally significantly higher than the actual levelised production cost of electricity (that doesn't account for transmission/distribution charges/losses and profit margins along the value chain). Solar installations can also be large and centralised but this demands that the power is sold into the common grid at market prices and must compete directly with other technologies (bearing in mind any subsidies that might be applicable for solar generation). *Solar Home System (SHS)* Solar Home Systems are stand-alone PV systems that offer a cost-effective mode of supplying amenity power for lighting and appliances to remote off-grid households. In rural areas that are not connected to the grid SHS can be used to meet a household's energy demand fulfilling basic electric needs. Globally SHS provide power to hundreds of thousands of households in remote locations where electrification by the grid is not feasible. Bangladesh is currently (2015) the world's largest market for solar home systems, while in sub-Saharan Africa, Kenya leads
Feasibility of technology and operational necessities	Due to its position within the tropics, the energy potential for application of solar PV is high in Malawi. In order to actually design the system for the site, typically satellite data is used to determine the average yearly radiation level at a site for a number of reasons i) local ground based measurements are expensive and equipment must be cleaned to prevent soiling ii) satellites can provide up to 20 years of data for an average which is important given the large annual variation in solar irradiation levels and iii) the accuracy of satellite data is found to be good in correlation with ground based measurements. Based on these estimates of resource and the associated time-series/seasonal-variation it is possible to estimate the power that would be generated throughout a typical year. This allows the economics of a project to be determined and also allows other aspects of the system (for example battery size if it is an off-grid application) to be calculated. *Technical Requirements* The technical requirements for the installation of solar PV vary greatly depending on the size of the system and kind of technology used. Small

	off-grid systems in remote/rural areas using first generation technology, such as solar home systems, can be bought in what is effectively a 'kit' form and installed with relatively little local expertise. Maintenance is minimal and mainly requires the cleaning of the solar panel to ensure efficiencies are maintained. Alternately the installation of grid scale concentrating solar power with third generation technology is a highly specialised field, requiring detailed calculations for the plant layout, expected yield and economics of the project. The equipment, with the required tracking mechanisms, requires maintenance and upkeep, and the power output must be forecast for export.
Institutional framework for adoption and diffusion	Malawi has instituted the Malawi Energy Regulatory Authority that provide regulatory requirements for energy such as solar PV. Grid connected systems require an appropriate licence or permit to export to the grid along with the necessary metering equipment, connected by a professional, to ensure that the level of export to the grid is measured for any subsequent compensation. Larger installations obviously require the appropriate planning permissions that would accompany any moderate to large infrastructure project. Also, the Malawi Bureau of Standards has developed standards on solar PV systems, however there are challenges on the enforcement of those standards. The presence of Department of Energy Affairs, the Testing and Training Centre for Renewable Energy Technologies at Mzuzu University and other universities and research institutions in the country provide convenient institutional framework for adoption and diffusion of the PV technology
Cost	The cost of the solar PV system depends on the size of the system.
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	Solar PV provides alternative power that support economic activities
Social	Solar PV enhance quality education and heath through provision of clean power
Environment	Solar PV is the green power sources. It helps to reduce air quality if it replaces fossil fuel and unsustainable biomass energy
GHG mitigation potential	If the solar PV electricity displaces fossil fuel, it presents a huge potential for reducing GHG mission through fuel substitution
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in short term
Size (household and large-scale)	Both, at household and large scale

* On Applicability of the technology

- Applicability of technology is define as follows: short term is the technology that is proven to be liable and is commercially ready in similar market
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Figures

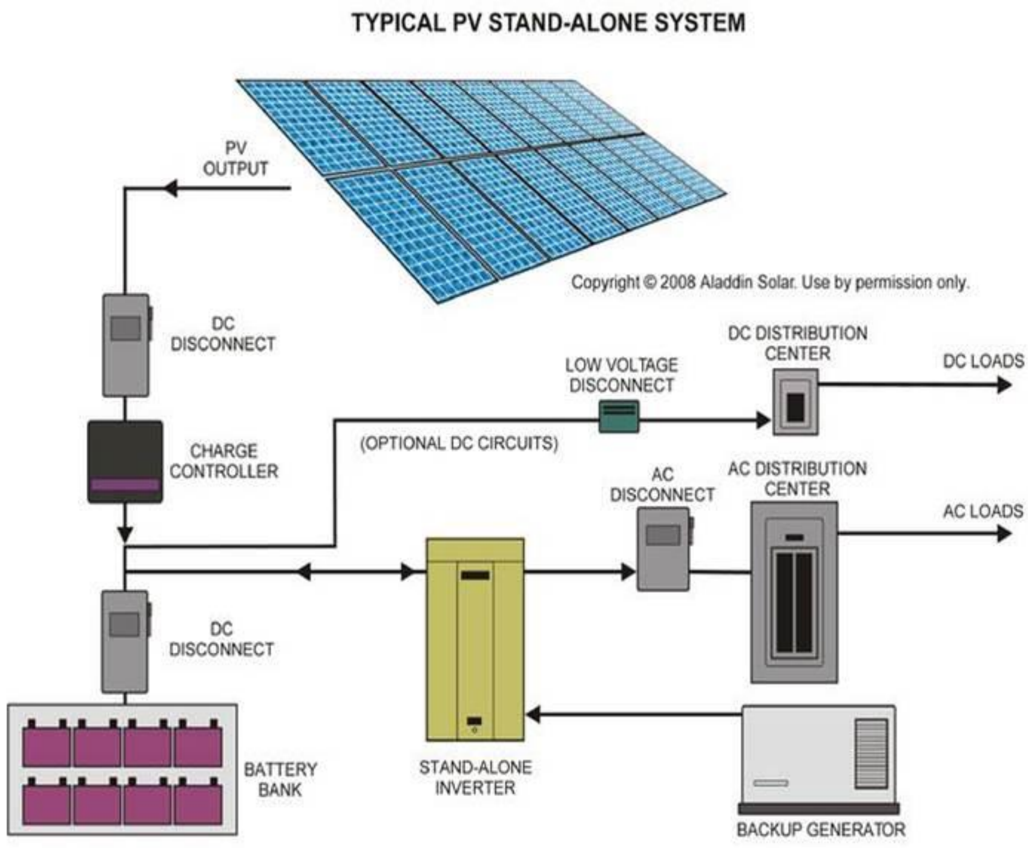

Figure 1: Typical solar PV standalone system arrangement

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Biogas technology

Technology Characteristics	Narrative description of the characteristic
General information	Biogas is produced through the digestion of organic matter by anaerobic bacteria in an oxygen-free surrounding. In Malawi, most of the feed material into the digester is cattle dung, for household biogas systems. During anaerobic digestion, methane gas (CH4) is produced by-product of their digestion process. Methane is a fuel and a typical biogas contains 60% methane. Table 1 shows typical composition of biogas. Biogas is about 20% lighter than air and has an ignition temperature in the range of 50°C to 750°C. It is odorless and colorless gas that burns with clear blue flame similar to that of LPG gas. The calorific value of 1m^3 is about 22 MJ if burns with 60% efficiency. The composition of gas varies with raw material used. Unlike in a compost heap, where the decomposition is shared by aerobic and anaerobic bacteria and the methane gas is released into the atmosphere, the gas can be collected in a closed biogas digester. Apart from cooking, the gas produced can be used for lighting. If the system is big enough, the biogas can be used to generate steam in a boiler for production of electricity. Further, if the biogas is cleaned to remove CO_2, and then bottled, then it can be an important fuel for cooking in urban areas of Malawi, packaged like LPG. Apart from being used for domestic thermal application (cooking and heating), biogas can be used in power generation devices for on-site (co)generation or it can be upgraded to natural gas standards for injection for use as transport fuel, and generation of electricity. Malawi has considerable potential for generation biogas from: animal waste (dung) and human waste (sewage). The immediate potential is from daily industry using cow dung. Also, after overcoming cultural challenges, the human waste forms significant potential, especially in cities. In fact, the Malawian Biomass Energy Strategy also showed that industrial wastes from the city of Blantyre could potentially produce 1.1 million m^3 of biogas per year - enough to run a 270 kW generator. A 270 kW generator running on biogas could replace the use of, for example, diesel. An estimate of the potential of displacing a 270 kW diesel generator by a 270 kW biogas generator gives a potential emissions reduction of 2,900 tCO_2 per year. Similar biogas plant could also be put up in other 3 cities (Lilongwe, Zomba and Mzuzu). Malawi has had programmes on developing biogas technology, done at indivivual household scale and as funded projects. The latter example is the Choma Biogas project design and installed by the Mzuzu University, with support from the Malawi British High Commission and Government of Malawi. Despite the technology being mature, it has not been popularised in the country. Further, most of the available of installed biogas plants are not functioning due to several barriers as follows: **Investment Barrier** Considering the typical biogas plants (e.g the fixed dome plant), the cost of each household biogas digester (8~16 m^3) ranges from US$500 to

	US$1,000 (K375,000.00 to K750,000.000). This is relatively on the higher side for most Malawian rural households have low disposable income and weak financial capacity. As a result, most of the few biogas digesters available in the country were built with funds from development partners rather than individual households or communities themselves. This has constrained the adoption, development and sustainability of biogas technology in Malawi, which builds a strong case for the promotion of low cost alternative biogas digester designs such as the Tubular Polyethylene Biogas Digester (Figure 4). In addition, the household must continue to pay a biogas digester maintenance cost. Also, current practice of deep-pit treatment method is by far considered the most attractive option for manure treatment given that it requires very limited additional investment and labour input. **Technical barriers** The biogas digesters have to be located in many cases in the remote rural areas, where farmers lack ready access to improved technologies and management methods. According to current experiences in Malawi, the performance of some digesters is unstable, with varying levels of gas production. Some of the installed plants have stopped functioning due to leakages and other technical problems. This is due to several technical reasons, such the limited capacity and experience among local personnel to design and install the biogas plants, limited resources for biogas service support, and insufficient farmer training and maintenance. Also, local knowledge and capacities for planning and process control are lacking in many places and resources required for operation and maintenance in the long run have often been ignored. Furthermore, maintenance and management of biogas digesters require adequate support services and trained staff. **Cultural barriers** Some sections of the country are not able to use gas from biogas plants that operate on human soil.
Physical component/innovative technique	The biogas technology, in this case is about a system that generates biogas from organic substrate (feed materials) which could be traditionally categorized into fixed dome (Figure 1) and floating drum(Figure 2) types of digesters. However, there are some designs of digesrets that The digester is an important part of the biogas plant since that is where the anaerobic reactions take place to produce methane. Refer to Figure 1, the captured gas is stored in the upper part of the digester tank (gas storage area), for a typical fixed dome type. The generation of biogas gradually increases the pressure in the stored area. When the volume of the captured gas is larger than the amount consumed, the pressure in the gas storage increase greatly and slurry will be pushed into the outlet chamber. If the amount of gas consumed exceeds gas availability, the slurry level drops and the fermented slurry flows back into a fermentation chamber. The placement of the digester tank (underground fermentation) keeps the temperature in the tank relatively stable ensuring that the slurry can be fermented at adequate temperatures throughout the year without requiring additional heating. The bottom of the digester inclines from the material-

	feeding inlet to the material-outlet, allowing free flow of the slurry. The digester is usually designed to allow the effluent to be removed without breaking the seal, taking the effluent liquid out through the outlet chamber. The mechanics of biogas generation is given in Figure 3.
Feasibility of technology and operational necessities	A typical biogas plant, as shown in the diagram in Figure 2, should comprise of following parts: (i). Digesting Chamber – a deep airtight circular pit, the digestion chamber is filled with organic solid waste mixed with water, fermentation (anaerobic decomposition) occurs and gas is produced and rises up within the chamber. (ii). Inlet Pipe – to be used to pour the raw material into base of digester. (iii). Outlet Pipe - meant to take out sullies from digester. (iv). Mixing Tank (Inlet) – to be used for preparing homogenous mixture of the raw material, usually an equal amounts of biomass and water to feed into digester. (v). Compensation & Removal Tank (Slurry Outlet) – solid (slurries) and liquid waste from digestion chamber. Slurries can be collected and treated to be used as fertilizer, being rich in nitrogen contents. (vi). Gas Accumulator - gas produced is collected in an accumulator that may be the floating drum or a concrete made dome over the digestion chamber. (vii). Gas Collection and Distribution - At the top of accumulator gas collection and distribution system is fixed, which is further channeled to the consumption unit. (viii). Each household should have two to three cows that they keep in a kraal overnight. This is to allow ease of collection of manure for ingesting into the biogas digester. A digester needs between 20 and 30 kg of manure daily to produce enough gas for a household to cook between 2 – 3 hours a day. (ix). The households should have a reliable source of water to operate a digester. The life span of a plant very much depends on the quality of the material used for its construction. Therefore, quality materials should be used, preferably locally available to reduce the cost. Typical construction of traditional biogas plants are listed as follows: (i). Cement – High quality branded cement, sealed bags, protected from moisture and contamination. (ii). Sand - Fine aggregates or sand, clean and free from coagulated lumps, impurities especially mud. Coarse and granular sand can be used for concreting work but fine sand better for plastering. (iii). Gravel - Stone crushed, hard, strong and clean, according to design. (iv). Water - Clean water, pH value not exceeding 7. (v). Bricks - Regular shaped, kiln burnt bricks, soaked before use. (vi). Stones - In case of stone masonry, clean, strong and good quality stones size as appropriate.

	(vii). Steel - as appropriate. (viii). Pipes and appliances – as appropriate. The generic steps required for the operation of biogas plant are as follows: (i). Feeding - Initially the digester should be fed optimum level with mixture of water and raw material at a ratio of 1:1. After 1-2 weeks of operation, continuous daily feeding is recommended. (ii). Seeding - Common practice involves seeding with an adequate population of both the acid-forming and methanogenic bacteria. Actively digesting sludge from a sewage plant constitutes ideal "seed" material. As a general guideline, the seed material should be twice the volume of the fresh manure slurry during the *start-up phase*, with a gradual decrease in amount added over a three-week period. If the digester accumulates volatile acids as a result of overloading, the situation can be remedied by reseeding, or by the addition of lime or other alkali. (iii). Stirring/Agitation - Stirring of digester contents is recommended at regular intervals may be manually in order to avoid formation of scum. (iv). Gas Collection - Gas can be collected from the drum through a non-return valve system. Preferably a water pipe is most suitable than gas pipe. Gas pipe should be regularly cleaned to remove moisture contents.
Institutional framework for adoption and diffusion	Department of Energy Affairs provided framework for adoption and diffuse of the biogas technology, as detailed in energy policy
Cost	The investment cost depends on the size of the plant and its type. Collection of feed materials (e.g dung) and operation of the plant also present a cost
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	Use of biogas will enable household to save fuel that could be purchases, this is translated into disposable income to be used for other activities Supply of substrate would create eemplyment
Social	(i). Social benefits are include enhanced human health (especially for women and girls) resulting from smoke-free and ash-free kitchen, so women and their children are no longer prone to respiratory infections; (ii). Enhanced empowerment of women and girls because they are spared the burden of gathering firewood; (iii). The nitrogen content in the slurry after anaerobic digestion enhances compared to untreated animal manure, thus can be used as organic fertilizer.
Environment	Biogas technology is one of the effective waste management technology, making the environment clean
GHG mitigation potential	Replacement of fossil fuels and untreated traditional solid biomass by clean fuel like biogas for cooking, lighting and electricity generation help in curtailing GHG emissions. Also, biogas fertilizer use in agricultural land

	would partly or fully offset the need for chemical fertilizers which itself have high energy demand during production, thus reducing GHG indirectly. Furthermore, biogas utilizes methane from waste, which would have been released to atmosphere contributing to GHG reduction directly.
Applicability* of the technology in Malawi (short, medium and long term)	Short term
Size (household and large-scale)	Household and large scale

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Figures

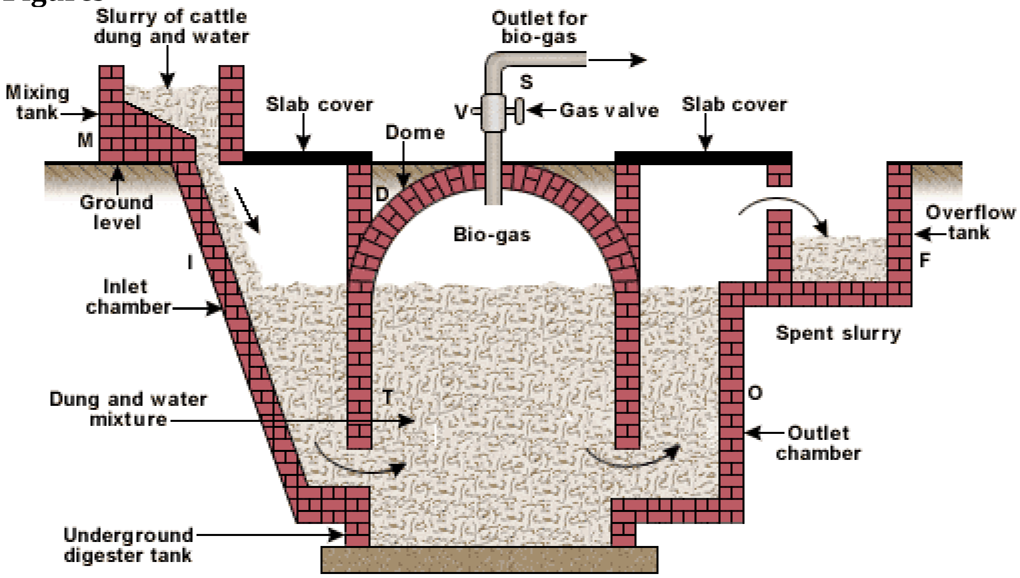

Figure 1: Biogas Digester (Fixed dome)

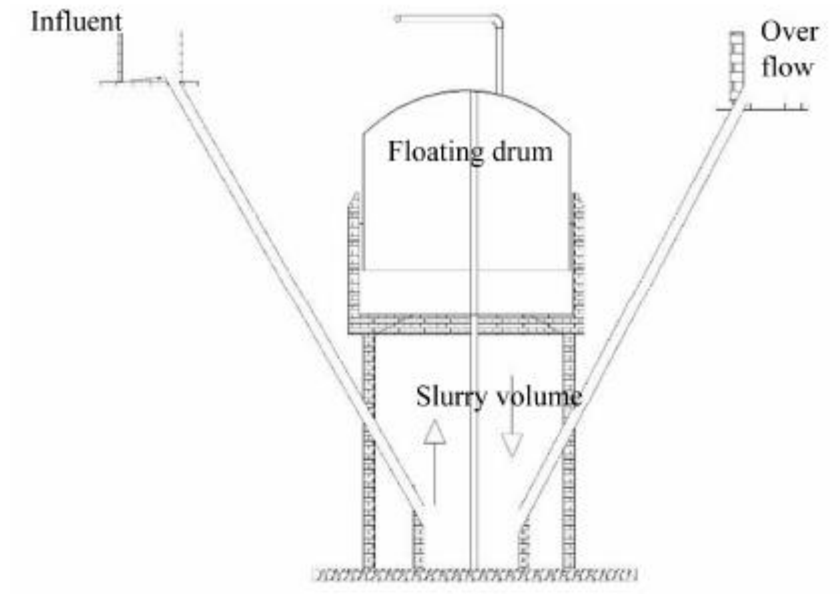

Figure 2: Floating drum digester

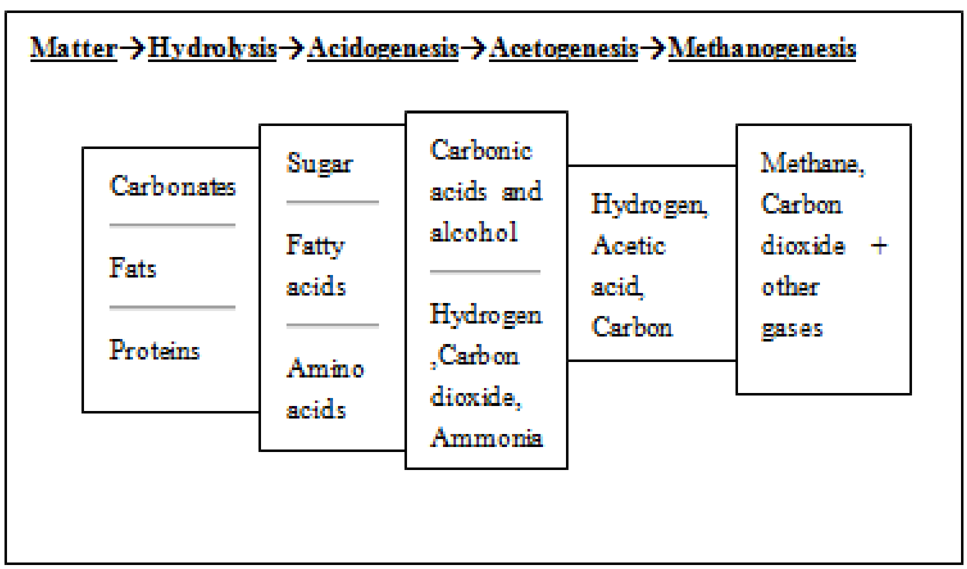

Figure 3: Biochemical stages during fermentation process

Scheme of the Biogas Supply Line:

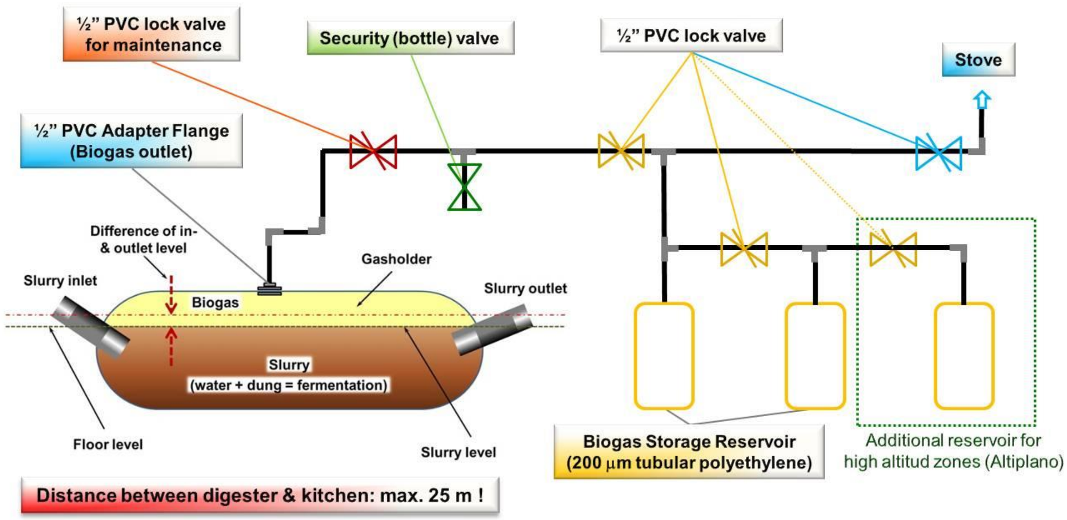

Figure 4: Typical specifications for a household biogas Tubular polyethylene biogas digester

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Biofuel for Internal Combustion Technology

Technology Characteristics	Narrative description of the characteristic
General information	In general, the increasing industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels (diesel and petrol). Petroleum-based fuels are obtained from limited reserves, in regions that are not geographically evenly distributed. Therefore, those countries not having these resources, like Malawi, face energy security challenges which are exacerbated by unstable international oil prices. The energy insecurity affects economic and social activities necessary or development of the country. Thus, it is necessary to for countries like Malawi to have alternative fuels which can be produced from local renewable energy resources, such as ethanol, biodiesel, vegetable oils. The 2018 Malawi Energy Policy encourages production and promotion of biofuels to make a significant contribution to transport energy sub-sector. Currently, biofuels provide 4% of transport energy in Malawi coming from locally-produced bio-ethanol and bio-diesel that is blended with petroleum fuels at blending ratios of 20:80 and 9:91 respectively. Currently, there are only two companies (Presscane in Chikwawa and Ethanol Company Limited (Ethco) in Dwangwa) producing bio-ethanol in the country, and it is being produced from sugarcane molasses. On the other hand, there is currently one company that is producing biodiesel, and it is being produced from jatropha. The ethanol production plants in Dwangwa Estate, which produce 15–20 million litres of bioethanol from sugarcane molasses, and the Nchalo Plant, which has a production capacity of 12 million litres per annum. The production of ethanol could increase as the third sugar producing industry has been established in Salima District, under the Government of Malawi Project, Greenbelt Initiative. The Salima Sugar Company output is jumped by 185 percent to 100 000 metric tonnes (Mt) in 2018 from last 35 000 Mt from 2017 (The Nation, 2018). Thus, a third ethanol plant could be established in Salima, increasing Malawi's potential for biofuel. As an example of biofuel, ethanol is a good alternative fuel because it is a renewable bio-based resource and is oxygenated, thereby providing the potential to reduce particulate emissions in compression-ignition engines. In this review, the properties and specifications of ethanol blended with diesel and gasoline fuel are also discussed. Special emphasis is placed on the factors critical to the potential commercial use of these blends. The effect of the fuel on engine performance and emissions (SI as well as compression ignition (CI) engines), and material compatibility is also considered. Biodiesel is methyl or ethyl ester of fatty acid made from virgin or used vegetable oils (both edible and non-edible) and animal fat. The main resources for biodiesel production can be non-edible oils obtained from plant species such as *Jatropha curcas* (Ratanjyot), *Pongamia pinnata* (Karanj), *Calophyllum inophyllum* (Nagchampa), *Hevca brasiliensis* (Rubber) etc. Biodiesel can be blended in any proportion with mineral diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition (diesel)

	engine, and essentially require very little or no engine modifications because biodiesel has properties similar to mineral diesel. It can be stored just like mineral diesel and hence does not require separate infrastructure. The use of biodiesel in conventional diesel engines results in substantial reduction in emission of unburned hydrocarbons, carbon monoxide and particulate. Biofuel research has shown that Jatropha Curcas is a potential source of biodiesel production, and income among poor farmers in Malawi. Currently, Jatropha Curcas is being grown in many districts but mainly along the Lake Shore and lower shire districts such as Nsanje, Chikhwawa, Mangochi, Salima, Nkhotakota, Nkhata-Bay and Karonga in Malawi (Nalivata et al., 2010). So far there are about 18 million trees of Jatropha Curcas that have been planted in the country and more companies are showing increasing interest to invest more in the sector (GoM, 2010). The Jatropha Curcas crop is grown as hedges by smallholder farmers hence cannot compete with other cash crops in the country. Although, there have been increasing investment decisions and increased rate of adoption of Jatropha Curcas production on small scale and commercial production, there is no information on driving factors behind adoption of Jatropha Curcas production by farmers. BERL concerned itself with the entire chain from production to marketing and distribution. Smallholder farmers grow jatropha as a small scale cash crop for intercropping and hedge purposes in mostly maize oriented subsistence farming communities. BERL arranged transport of jatropha to a BERL factory for processing into oils for blending with paraffin and for transport, as well as glycerin for soap. Press cake is routed into fertilizer and fermentation purposes. The BERL was designed to have a 4,500 tonne/year production capacity (Wakeford, 2013). Further, it is reported that BERL made some success in terms of its work in blending paraffin with jatropha oil for lighting purposes as part of the business model. This allowed the company to smartly ride the existing finely detailed distribution network for paraffin in Malawi. Replicating such a network would have taken much longer. Also, the company established connections and a good working relationship with the Malawian government, which greatly sped the process of having a national jatropha certification standard. However, without an innovative business model, a jatropha project was poised to have challenges. BERL designed to include sunflower as an alternative feedstock for production of biodiesel to compensate for the initial low yield of jatropha seeds. The project was projected reach the break-even in 2015 with new possibilities to be exploited beyond 2015. As reported by Mapemba and Grevulo (2013), promotion of biofuel crops (like jatropha) and adoption in Malawi among local farmers must focus on several factors including gender of household head (favoring female), plot size and level of education. They recommend Government to encourage participation of large scale commercial farmers and thus, allocate land accordingly. According to Malawi' revised Energy Policy (2018), the key challenges in

	biofuels industry include bioethanol has a lower calorific value making it a less efficient fuel relative to petrol or diesel – a disadvantage that is compensated for by its ability to enhance the octane rating of petrol. It also acts as an oxygenate in petrol engines, thereby contributing to abatement of pollution by eliminating production of carbon monoxide and other harmful gases. A more fundamental problem, however, is reliability of supply because of the current limited national bioethanol production capacity arising from insufficient supply of molasses. In addition, there is no nation-wide dedicated pump station infrastructure for handling bioethanol grades other than the existing blended petrol. While Malawi does not use staple food crops, notably maize and cassava, for production of bioethanol, it is important for the National Energy Policy to ensure that production of bioethanol does not threaten food security. Equally, that jatropha plants, as opposed to edible oilseeds such as sunflower or groundnuts, are currently being used to produce small quantities of biodiesel does not remove the potential risk that could arise from use of food crops for production of biofuels.
Physical component/innovative technique	Biofuels are obtained from energy crops (e.g sugar cane and jatropha), thus they compete with other land uses e.g for food production. Therefore, there is need for proper planning as promotion of biofuel is encouraged. Policy-makers need to evaluate trade-offs across the different socioeconomic and environmental impacts to guide decisions that affect sugarcane development plans. In Malawi, Jatropha production has minimal impact on food security and supports poverty alleviation initiatives (Gasparatos et al, 2016). The country was for the first time had an company called Bio Energy Resourced Ltd (BERL), to produce biodiesel from Jatropha but is yet to be materialize due to challenges. This company was premised to plant jatropha (usig association of small scale formers) and then uses it to produce crude oil and biodiesel. BERL is responsible for the whole production chain and for the marketing. Its aim is to create a responsible production chain which has no negative impact on the environment or on food production.
Feasibility of technology and operational necessities	Basing on the BERL Model, as a technology, promotion of biofuel for internal combustion activities include the following: (i). Purchasing sites for processing and growing units. (ii). Preliminary research, testing the pressing machinery. (iii). Purchasing and building storage capacity for the seeds. (iv). Setting up an ICT system. (v). Recruiting and training personnel. (vi). Setting up a logistics system for collection, storage and transport. (vii). Collecting, transporting and storing the seeds. (viii). Recording the harvest in an administrative system. (ix). Implementing and supervising the initial production. (x). Setting up a sales and distribution network. (xi). Contracting regional distributors and facilitating sales. (xii). Organising the marketing. (xiii). Organising awareness-raising campaigns among end-users.
Institutional framework for adoption and diffusion	The Department of Energy in the Ministry of Natural Resources Energy and Mining provides a framework for adoption and diffusion of the promotion of energy crops for biofuel production

Cost	The cost of implementation of the technology depends on the processes involved and size. However, it is encouraged to involve large scale companies to provide resources for producing biofuels in Malawi and the costs involved in it promotion would not be very much expensive for the Government and other donor communities to finance
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	(i). Establishment of biofuel industries will assist rural communities to be engaged in economic activities (ii). Development of biofuel initiatives will stabilise the Malawis's petroleum supply and diversify its fuel option, thus enhancing energy security needed for economic activities.
Social	(i). Poverty alleviation from engagement in biofuel production (could provide alternative to tobacco farming as a commercial crop) (ii). Increased usage of clean energy reduces local emissions, which improves the human health
Environment	Increase of clean energy improves the local air quality that is contaminated with fossil fuel based vehicular emissions
GHG mitigation potential	Biofuel from Japtroha Curcas and Sugar molasses offer a great potential for carbon emission reduction in mobile combustion through substitution from use of petrol and diesel for mobile combustion activities
Applicability* of the technology in Malawi (short, medium and long term)	Short
Size (household and large-scale)	Large scale

*On Applicability of the technology

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- Medium term refers to the technology that is in pre commercial in a similar market
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Promotion of Energy Efficiency and conservation in industries and Institutional buildings

Technology Characteristics	Narrative description of the characteristic
General information	Buildings are some of the energy consuming units, especially in high-income households and institutions, to power energy consuming appliances such as water geysers, cooking utensils, lighting, cooling/heating, entertainment and security facets. Included in the buiding category are: commercial offices, retail, warehouses (excluding industrial), hotels and catering, transport and communication (building-related energy use only), sport and leisure including libraries and theatres, education (schools and universities), health centres, hospitals, government and other buildings including churches, mosques and community centres. Within buildings energy saving can take place through refurbishment of existing property or by building new buildings which replace old buildings and/or which energy performance is better than that of existing buildings. The industry is also one of the energy consumers, where energy is consumed to do work such as driving electrical motors, production of steam in boilers either for process steam or production of electricity or both. The other industrial energy consuming systems include cooling/heating systems and lighting system. Usually, energy consumed is a result of primary energy transformation, which might be from fossil fuel based or from unsustainable sources. In this case, efficiency of energy utilisation and conversation is important to reduce primary energy demand to produce a unit product or service. Therefore, there is energy savings potential if technologies on energy efficiency and conservation in buildings are taken into consideration. These fall under the concept of energy management, which is defined at the judicious way of utilising energy so as to reduce energy input without compromising on the product/service quality and remaining competitive on the market The options considered for energy savings households and institutional buildings particularly leading to CO_2 emission reductions include the following: (vii). Use of renewables for heating, cooling and electricity; (viii). Improvements to the building envelope, including materials, natural ventilation and daylighting; and (ix). Improvements to building services, including heating, mechanical ventilation and air-conditioning When considering the sources of CO2 emissions from buildings, also so-called 'life cycle CO2 emissions' of building should be taken into consideration, such as the emissions related to production of building materials, as well as downstream waste disposal from construction and renovation of buildings. The main design considerations which should be taken into account in the buildings for energy efficiency measures include the following: • The orientation and form of the building to improve daylighting: Preferably, a building should face north since Malawi is in the southern hemisphere. Lighting controls such as occupancy sensors

have been shown to save significant electrical energy in commercial buildings. However, the success rate depends on having well-monitored building sites. Advanced control strategies that require a systems approach, such as daylighting and load shedding, were less successful. For strategies such as daylighting which require the electrical light levels to respond to the external daylight input to a room, a lighting control system is needed. However, since the manufacturers supply components rather than systems, these components do not necessarily work well when put together as a system. This could hold especially for dimming resulting in complaints at the poor performance. Similar problems are faced with advanced shading systems for controlling solar heat gain through building windows. Linking the lighting controls with building envelope controls is also a problem particularly for motorised blinds, louvers and the variable transmittance electrochromic windows. Such system improvement processes could benefit from involvement of the users of the building on commission.

- Warming and ventilation: Buildings can be designed to be naturally ventilated with considerations such as inlet and outlet aperture sizes for the air flow being important. Air conditioning using electrical energy is second only to lighting in terms of energy demand in buildings.
- Managing the effects of solar gain and the use of less energy intensive services equipment: For instance, improvements could be achieved in the field of humidity control.

Developing countries usually have a restricted energy supply and energy savings for space heating and cooling, lighting and hot water can free up supplies for other activities and improve security of energy supply as well as improve comfort in the home and provide economic savings on energy bills. The technologies involved are well known and tested and even simple changes can make a difference. There are however many possible approaches depending on the building, its orientation location, and usage so that solutions have to be considered in the context of each building, whether it is new build or refurbishment. Since the techniques and know how are available and in many cases not very sophisticated, technology transfer should be relatively simple and could be well supported by training courses.

The advanced commercial building design may not work well if monitoring and management systems are not in place. There are many barriers to the uptake of the technology for eco buildings of which the main ones are:

- Grid interconnection arrangements for all decentralised electricity generation including BCHP needs improvement.
- In buildings which are not occupied by the owner the benefits of the higher investment go to the tenants rather than the investor, which could be a disincentive for owners to invest in energy saving measures.
- Time pressures can mean that existing building design is the only

	option for the architect/design engineer in the time available. - Fee structures for professionals can work against innovation. - Innovation requires new collaboration between design professionals, the construction industry and occupiers of the building, which can be difficult to arrange. - Lack of strict building regulations. - Lack of training and awareness in architectural and engineering courses. - Environmental labelling and information on embedded carbon in materials is insufficient.
Physical component/innovative technique	
Feasibility of technology and operational necessities	Setting up an energy management programme, as a climate technology, involves application energy conservation practices and energy efficient technologies, in an innovative and systematic manner. Some of the energy conversion/consuming appliances will need to be replaced or retrofitted with new and efficient ones. The strategic approach to energy management programme in terms of key steps, applicable industrial and institutional categories, is presented as follows: (i). Establish top-level commitment to energy management programme. This is necessary so that programme is owned at the top level, to ensure its success. The top management will be in charge to make sure that the all employees are taking part in energy conservation measures and the energy commitments realised. (ii). Then the energy manager or person responsible for energy or energy coordinator, to communicate with top management and works directly for the energy management programme and coordinate its implementation. (iii). The next step is to carryout energy audit to understand issues concerning the energy system: energy consumptions patterns and energy efficiency and conservation opportunities. This could then be done on regular basis as part of energy management programme. Carrying out an energy audit requires expertise to collect and analyse historical information about energy input and output of an energy system as well as estimation for the future, this should include direct measurements of energy. After understanding the energy consumption pattern and state of energy consuming equipments, the full audit is conducted in which energy conservation opportunities are identified and improvement plan written. (iv). Plan and organise an energy management programme, guided by a policy statement, with clear set of target and implementation plan.

	(v). Establishment performance and monitoring system of the energy management programme At household level, the steps may not be as systematic as detailed above, but it is possible to conduct energy audit to identify areas of wastage and apply energy conservation measures as well as use of efficient energy consuming appliances.
Institutional framework for adoption and diffusion	Not available
Cost	The cost of putting up an energy management programme and its implementation will depend on several factors, such as availability of staff, nature of the programme and equipment.
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	(i). Reduction of energy cost for production of unit service and product. This would make contribute energy savings for households and reduction in unit market price of the service and product resulting into competitive advantage and growth of a industry (ii). Energy efficiency and conservation are some of the peak-power management options, which minimises power interruptions during peak hours, contributing to smooth operations of economic activities at all times.
Social	Energy efficiency and conservation contributes to having power at all times, and thus social activities like health, education and security are discharged without interruptions. This contributes towards social development of a country
Environment	The saved fossil fuel and forests contributes towards environmental management in the area of improvement in outdoor air quality
GHG mitigation potential	Especially in industry where heavy carbon fuel like coal is used, saved fossil fuel due to application of energy efficiency and conservation measures directly contribute to GHG reduction.
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in a short term
Size (household and large-scale)	The application could be at household and large-scale

*On Applicability of the technology

- Applicability of technology is define as follows: short term is the technology that is proven to be liable and is commercially ready in similar market
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Figures

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Promoting of Liquefied Petroleum Gas 9LPG) for household cooking

Technology Characteristics	Narrative description of the characteristic
General information	Liquefied petroleum gas (LPG) is a mixture of propane and butane, which are gases that become liquid under pressure and can then be stored in pressurised containers. LPG is manufactured during the refining of crude oil (40%) or from natural gas during extraction (60%).The proportion of each gas varies depending on the source. LPG has a high energy per unit volume and is convenient to use for thermal application. Its calorific value per unit volume is about 2.5 times larger than that of natural gas (methane). It is used for road transport, cooking, heating, refrigeration and air conditioning. It is a portable source of energy used for cooking and transport. The gas has low carbon content compared to coal and its use is thus connected to climate change mitigation. Status of the technology and its future market potential As a cooking fuel, LPG is seen by the IEA as the main means for moving away from unsustainable use of biomass for cooking: the target expressed in IEA (2006) is to reduce the use of biomass in cookstoves by 50% by stimulating 1.3 billion people to switch from biomass to LPG. Globally, the future market potential for LPG is thus huge, especially as a form of cooking energy. LPG price increases could make LPG-based cooking less accessible for the poor, particularly in the rural areas. The scope for LPG for cooking is therefore not clear in developing countries, but it seems that it will be concentrated on the middle and high income groups in urban areas. This was verified in Malawi through a study to assess the market potential of LPG cooking fuel by Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) project. The study found out that the gas is only taken as a back-up cooking fuel, and that the relatively high gas price and stove make the technology available only to a few rich urban household. It was also found that generally, there is lack of awareness of LPG as a cooking fuel, coupled with absence of gas distribution networks in the country. However, use of LGP for cooking is recommended in the revised Malawi Energy Policy of 2018, and one of its broad policy objectives is to "To ensure availability of LPG, biogas and natural gas in sufficient quantities at affordable prices for industrial and domestic use". The Policy recommends the need to look at ways of doing away with barriers to lower pricing and increased uptake of LPG and to identify potential partnerships to promote greater market penetration. As experienced from other countries like India, LPG is considered as fuel for wealth households because they choose it due to its being popular urban fuel, it is cleanliness during cooking and its being efficient. Thus perception plays a role in choice of LPG as cooking fuel in urban areas. The fuel switching occurs faster in urban areas than in rural areas, due to urban women having greater decision making status and availability of infrastructure among some of the reasons. Thus, in the Malawi case, it is sensible to focus popularization of LPG in urban areas. Although LPG is currently the most viable clean cooking fuel in most

	areas of the world, it is a non-renewable fossil fuel and therefore its long-term sustainability has been called into question. Malawi does not produce LPG and therefore, the LPG cooking would still be affected by the energy (petroleum products) insecurity.
Physical component/innovative technique	The typical composition of the LPG cooking system is made up of the stove itself, the gas cylinder, the piping system. Refer to Figure 1. The cylinder has a regulator that controls the flow of the gas. The gas flow to the stove can also be controlled by the stove itself. Generally the LPG cooking technology is well mature, and it presents a viable alternative to use of charcoal for cooking, but to the wealthier households. The incentives are required so that LPG becomes a fuel of choice for all households.
Feasibility of technology and operational necessities	The reliability of LPG cook stoves is generally considered high as the technology is mature and applied widely across the world. The same could be said about the supply chains for the LPG. IEA (2006) also points out that the gas supply infrastructure is becoming more complex and more investment is required, in particular to increase transport skills and reduce investment costs. For importers there needs to be local distribution infrastructure development both for the fuel and for new stoves and stove conversions. Where LPG has been used in developing countries, as in the examples in China and Brazil below, then the governments in each case have subsidised the price of the gas and/or the price of conversions to burn LPG. This could also be the same to Malawi. Although many developing countries already have access to LPG, the applicability of the technology to the rural poor is hampered by the required import facilities and distribution systems and complexities related to the poor quality of roads and relatively high per capita costs if the population density is low. The other main problem with LPG that they can be expensive relative to other fuels and thus less attractive for the poor. In addition, the prices of LPG could be more volatile than the price of other fuels and feedstock for cooking. These possible price impacts could negatively affect the affordability of the technology and LPG fuels, in particular to rural area households (IEA, 2006). However, LPG is not commonly found in rural areas where biomass use tends to be highest and where the health effects of smoke are also highest. Nonetheless, it is used amongst middle or high income groups in urban areas of developing countries. The high initial cost of purchasing appliances and cylinders, the relatively complex technology, irregularity of supply and risk of explosion mean that it is not widely used in the majority of poorer areas of developing countries (IEA, 2006). The LPG supply chain is not practical for the poor as cylinders are usually exchanged at filling stations. Since there are not many of these in rural areas and since transport is poor, access to LPG is very difficult.
Institutional framework for adoption and diffusion	Not available
Cost	The cost initial cost of the equipment is relatively high, compared to other stoves. The cost of LPG is also quite high

Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	If catering businesses (restaurants) switch from wood fuel to LPG, the saved time in cooking could result in increased sales.
Social	In Malawi, the main benefits of LPG cooking stove are in helping people to switch from unsustainable biomass use to a clean and safe cooking fuel. This provides enormous health benefits helping to avoid respiratory problems caused by smoke and other pollutants released by inefficient biomass burning in enclosed spaces. It also releases women and children from the drudgery of collecting firewood and health problems associated with carrying heavy bundles long distances
Environment	There are also benefits for the local ecology and biodiversity.
GHG mitigation potential	LPG cooking stove provide a 'clean' burn with almost complete combustion of the fuel so that there are only low pollutant emissions from NOx and very low particulate or other hydrocarbon emissions.
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in short term
Size (household and large-scale)	It could be applied at household and large scale

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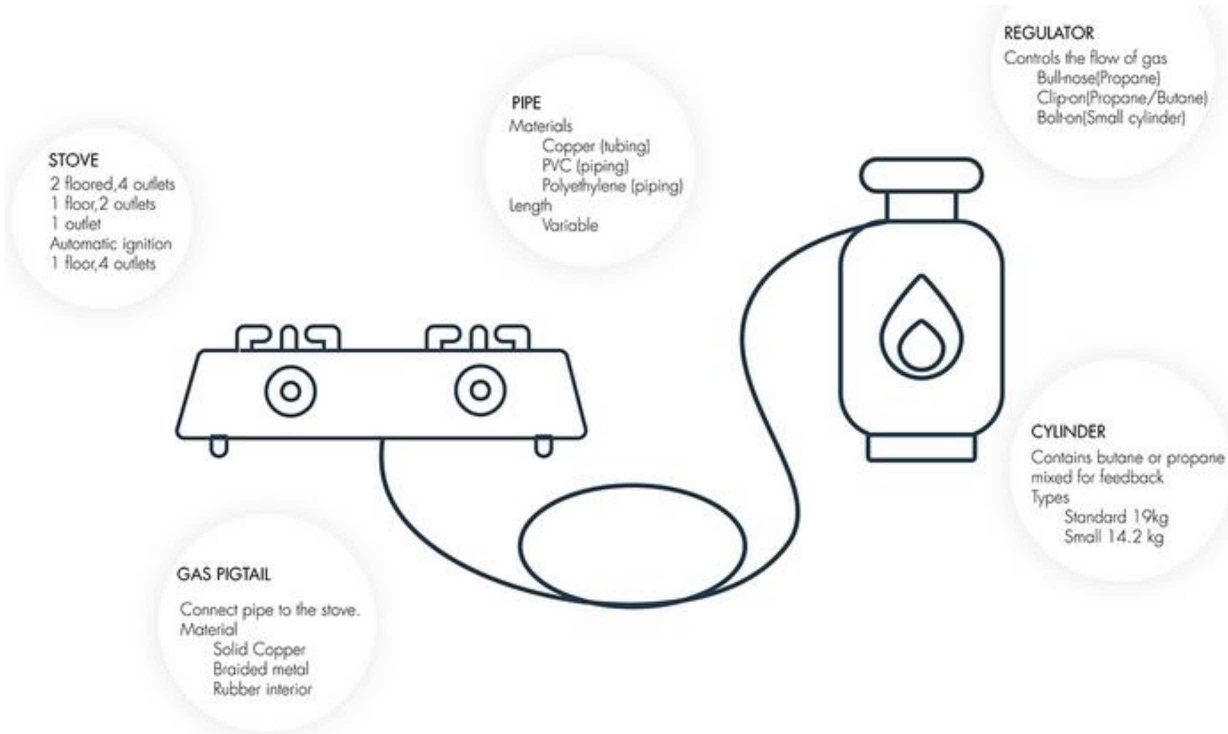
Figures



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Technology: Improved Charcoal kiln for charcoal production

Technology Characteristics	Narrative description of the characteristic
General information	In Malawi, charcoal is primarily produced in forested areas especially in districts surrounding urban centres. Wood is harvested from these areas through clear felling, selective cutting or from purposely grown plantations. The harvested wood is converted into charcoal in a batch-type process. Traditionally, earth or mound carbonisation kilns with relatively low efficiencies (around 15%), refer to Figure 1, are applied. Charcoal licensing system is in place, but in practice in cases, the bulk of charcoal production is undertaken without official licensing, and charcoal is transported and traded clandestinely. About 95 % of the Malawian rural population uses firewood as their only

	energy source. In the urban regions and in the peri-urban people are using charcoal as their primary energy source for cooking. Only about 35 % of the urban population is connected to the grid but due to the increasing cost and unavailability of electricity and some perceptions, some urban households cook using charcoal stove. The preference of charcoal above wood is mainly socio-cultural determined. Other differences between these two energy sources will be outlined later. According to John Vos and Martijn Vis (2010), the total demand for wood (both for fuelwood and charcoal) is estimated to be 2 kg per person per day, thus presently the Malawi population uses 13 million metric tons wood annually. Its advantages when used as a domestic fuel are that it: produces less smoke while burning, requires little or no preparation before actual use, has a higher energy content per unit mass, can be easily transported and stored, and reused when left over after cooking. However, in Malawi, charcoal is mostly produced from traditional earth kilns (mounds), refer to Figure 1, where the conversion efficiency (fresh wood to charcoal) is quite low. Therefore, if charcoal is produced efficiently, some of the forest will be saved, contributing to mitigation of climate change. Malawi has had a successful improved charcoal production programme, using the efficient technology of Beehive brick Charcoal kilns, which could be scaled down to be used by small scale charcoal producers. This was initiated by the Government of Malawi, with funding from World Bank in 1986. The charcoal was to be produced from sustainable wood from forest plantation, such as Viphya Plantations. The construction and operation of the kilns was done by the trained local labour and all the necessary inputs and materials were procured locally. However, due to economic reasons, the project was not successful. Factors that could affect commercial charcoal production and trade include: scarcity of wood for charcoal making; inadequacy or flaws in government regulations; lack of understanding of local wood fuel systems which often tend to adapt themselves to changing situations; informal nature of operations and the market; variations in the systems to match specific site conditions. The Malawi Energy Policy of 2018 and National Charcoal strategy favors production of charcoal from efficient charcoal production kilns, and from sustainable sources of wood. As stated in National Charcoal Strategy, issuance of a charcoal ban without provision of viable alternative fuels has not reduced illegal charcoal production or deforestation in Malawi. The commercial production of charcoal using improved kilns would face challenge from limitations to forest land access as well as diminishing source of wood. It is a fact that charcoal will still remain one of the major sources of cooking energy in urban and peri-urban areas of Malawi. Based upon this fact, the Government issued the first ever licence for sustainable charcoal production to a local company. Related to this the Department of Energy Affairs has constructed efficient charcoal production kilns in Mwanza and Neno Districts. Three types of kilns were constructed, Adams Retort,

	Casamance and Half Orange. Refer to Figure 2. Charcoal can also be produced from improved metal kilns. The main advantages of transportable metal kilns compared with the traditional earth pit or clamp method are: (i). Raw material and product are in a sealed container giving maximum control of air supply and gas flows during the carbonization process. (ii). Unskilled personnel can be trained quickly and easily to operate these units. (iii). Loss of supervision of the process is required compared to the constant attendance necessary with pits and clamps. (iv). All of the charcoal produced in the process can be recovered. With traditional methods (pits and mounds) some of the charcoal produced is lost in the ground and that which is recovered is often contaminated with earth and stones. (v). Transportable metal kilns, if designed to shed water from the cover, can be operated in areas of high rainfall, providing the site has adequate drainage. Traditional methods of charcoal production are difficult to operate in wet conditions. (vi). With maximum control of the process a wider variety of raw materials can be carbonised. These include softwood, scrubwood, coconut palm timber and coconut shells. (vii). The total production cycle using metal kilns takes two to three days. The disadvantages of using metal kilns compared with the traditional earth pit or clamp method are: (i). Initial capital to cover the cost of the manufacture of the kilns must be obtained. Basic mechanical workshop skills and equipment must be available and the steel used in the kiln construction often has to be imported. (ii). For ease of packing and maximum efficiency some care is needed in the preparation of the raw material. The wood must be cut and/or split to size and seasoned for a period of at least three weeks. (iii). Transportable metal kilns may prove difficult to move in very hilly terrain, although more gentle slopes can be easily traversed. (iv). The life span of metal kilns is only two to three years.
Physical component/innovative technique	According to GIZ HERA Cooking_Energy, the charcoal making process (carbonization) takes place in 4 stages, as follows: The carbonization process takes place in roughly 4 main stages. (i). Stage 1: drying (100-200 ^{0}C) Air-dry wood still contains 10-20 % water which has to be lowered before starting the process. Instead of using valuable wood in semi-industrial carbonisation units agricultural waste can be applied in this step. (ii). Stage 2: pre carbonisation stage (200-300 ^{0}C) Endothermic reactions take place resulting in the formation of pyroligneous liquids like methanol and acetic acid (wood vinegar). (iii). Stage 3: carbonisation (250-300 ^{0}C) In this stage, exothermic

	reactions take place; the bulk of the light tars and the pyroligneous acids are released. (iv). Stage 4: final carbonisation (300-500 ^{0}C); In this final exothermic reactions a product having a fixed carbon content of at least 75 % should be obtained. The recommended final temperature is about 500 ^{0}C. During the carbonization process the following liquids are released: pyroacids (in particular acetic acid), tars, water and heavy oils. Furthermore the following gasses are emitted: CO, CO2, methanol, NOx, N2O, methane and other hydrocarbons. Apart from the visible smoke special attention should be paid to the very small particles Particular Matter (PM2.5). To avoid health effects exposure of these noxious substances to the workers should be minimized. Properly constructed and operated brick kilns are without doubt one of the most effective methods of charcoal production.
Feasibility of technology and operational necessities	The production and distribution of charcoal consist of seven major stages: 1. Preparation of wood 2. Drying - reduction of moisture content 3. Pre-carbonization - reduction of volatiles content 4. Carbonization - further reduction of volatiles content 5. End of carbonization - increasing the carbon content 6. Cooling and stabilization of charcoal 7. Storing, packing, transport, distribution and sale The first stage consists of collection and preparation of wood, the principal raw material. For small-scale and informal charcoal makers, charcoal production is an off-peak activity that is carried out intermittently to bring in extra cash. Consequently, for them, preparation of the wood for charcoal production consists of simply stacking odd branches and sticks either cleared from farms or collected from nearby woodlands. Little time is invested in the preparation of the wood. The stacking may, however, assist in drying the wood which reduces moisture content thus facilitating the carbonization process. More sophisticated charcoal production systems entail additional wood reparation, such as debarking the wood to reduce the ash content of the charcoal produced. It is estimated that wood which is not debarked produces charcoal with an ash content of almost 30 per cent. Debarking reduces the ash content to between I and 5 per cent which improves the combustion characteristics of the charcoal. The second stage of charcoal production is carried out at temperatures ranging from 110 to 220 degrees Celsius. This stage consists mainly of reducing the water content by first removing the water stored in the wood pores then the water found in the cell walls of wood and finally chemically-bound water. The third stage takes place at higher temperatures of about 170 to 300 degrees and is often called the pre-carbonization stage. In this stage pyroligneous liquids in the form of methanol and acetic acids are expelled and a small amount of carbon monoxide and carbon dioxide is emitted (Fernandes, 1991).

	The fourth stage occurs at 200 to 300 degrees where a substantial proportion of the light tars and pyroligneous acids are produced. The end of this stage produces charcoal which is in essence the carbonized residue of wood (Fernandes, 1991). The fifth stage takes place at temperatures between 300 degrees and a maximum of about 500 degrees. This stage drives off the remaining volatiles and increases the carbon content of the charcoal. The sixth stage involves cooling of charcoal for at least 24 hours to enhance its stability and reduce the possibility of spontaneous combustion. The final seventh stage consists of removal of charcoal from the kiln, packing, transporting, bulk and retail sale to customers. The final stage is a vital component that affects the quality of the finally-delivered charcoal. Because of the fragility of charcoal, excessive handling and transporting over long distances can increase the amount of fines to about 40 per cent thus greatly reducing the value of the charcoal. Distribution in bags helps to limit the amount of fines produced in addition to providing a convenient measurable quantity for both retail and bulk sales. Efforts to improve charcoal production could largely focused on enhancing the efficiency of the combustion stages two to five through the design of new charcoal kilns. The improved charcoal kilns can be broadly classified into five categories, namely: (i). Improved earth kiln (Casamanance Kiln) (ii). Metal kilns (iii). Brick kiln (iv). Cement or masonry kiln (v). Retort kilns
Institutional framework for adoption and diffusion	The Department of Energy Affairs in the section of alternative energy would provide institutional framework for adoption and diffusion of the technology
Cost	The investment cost will depend of the type of improved charcoal kiln and size. The operation and maintenance costs might also be large, depending on the type and size.
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	The economic benefits include enhanced charcoal trade that is generated from efficient and sustainable process
Social	(i). Charcoal is associated with clean cooking and thus has positive health impacts (ii). Has no preparation like cutting and drying, and thus cooking is fast, releasing time for other productive use (iii). Generally charcoal has large energy value per unit volume, thus small version of stoves are used translating into cost savings and flexibility of use
Environment	The saved trees contributes to making the country greener positively

	impacting the air quality, soil erosion management and supporting bio-diversity
GHG mitigation potential	Saved forest (from production of charcoal) will thus contribute to CO_2 emission reduction and fuel saving.
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in short term
Size (household and large-scale)	The technology could be applicable to household and large scale

*On Applicability of the technology

- Applicability of technology is define as follows: short term is the technology that is proven to be liable and is commercially ready in similar market
- Medium term refers to the technology that is in pre commercial in a similar market
- Long term refers the technology that is still under research and Technology phase

Figures

Figure 2: One of the improved charcoal production earth kiln in Malawi (Casamanance Kiln)

Figure 2: Adam Ritord Charcoal Kiln


Figure 4: Half Orange Charcoal production Kiln

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Biomass Briquette Technology

Technology Characteristics	Narrative description of the characteristic
General information	Turning organic waste matter into carbonized fuels could be one of the most promising solution to energy challenges in Malawi and one of the waste management options. Since the carbonized fuels (like briquettes) are packaged and of high energy value per unit volume, there is stimulation into stimulate waste collection, which could be a viable business. In Malawi biomass is the main source of energy for the majority of the population. This is the case because of high poverty levels as well as low coverage of electricity and other alternative sources of energy (Yaron et al., 2010). With about 40% of Malawians living below the poverty levels, access to and use of electricity and other non-biomass forms of energy remains low (Kambewa and Chiwaula 2010). As such biomass briquette technology becomes the best-recommended technology for its efficiency to meet Malawi's rural population thermal energy need. The biomass briquette technology (Figure 1(a)) is supported by the activities, including the following: These are improved production of the briquettes from both agriculture wastes (maize straws, soya bean husks) and wood wastes (sawdust, wood chips), the promotion of sustainable village woodlot establishment and management, and promoting the production and use of fuel-efficient cooking stoves to make use of the briquettes Figure 1 (b)). In Malawi, both the Nationally Determined Contribution (NDC) and the NAMA have prioritized biomass briquettes technology to contribute to the country's mitigation and adaptation goals in the energy sector as compared to the conventional use of wood biomass through charcoal and firewood. Biomass briquettes are not new to Malawi, but they are relatively used by small percentage of Malawians, especially in urban areas. The main promoters of biomass briquettes in Malawi includes Government departments such as Energy Affairs, Environmental Affairs, Forestry, The academia such as Mzuzu University, LUANAR, and the University of Malawi; some non-governmental organizations such as Total Land Care (TLC), United Purpose (UP), World Vision, and others with support from the multilateral agencies such as World Bank, European Union, USAID, JICA, UKAID and NORAD. Department of Energy Affairs (DoEA) has been invloved in briquettes for exhibition and marketing purposes, under the BARREM Project. Further, Wild Life and Environmental Society of Malawi (WESMA) started a briquette production project at the National Sanctuary in Lilongwe, but is not available curently. The Malawi Industrial Research and Technology Development Centre (MIRTDC), in Blantyre,together with some other organizations, developed a new press which was ready for the market in 1999. The Wood Industry Corporation of Malawi (WICO) had also been invloved in briquetts production from several sawdust in Malawi. WICO is currently not operational, but there are several saw mills in Malawi. Basing on hugely unmet energy needs of cooking and heating in organ areas of Malawi, briquettes would find market in the country, especially in urban areas. Currently, the majority of the briquette producers in Malawi

	use waste paper as base material. Waste paper is not a huge potential of biomass waste currently as most communication are done online. Other raw materials, such as wood saw dust and crop residues could be used to increase production capacity in line with increased demand in the country. The briquettes burn could well using most common stoves in Malawi, including the commonly used ceramic Jiko charcoal stove (Figure 1b). While firewood is cheaper to use than other available fuels, the briquettes seem to be able to compete with the fuel costs for charcoal. Main barriers of popularizing the biomass briquettes technology in Malawi include the following: inadequate skills and capacity to produce briquette among the local communities,
Physical component/innovative technique	Biomass briquettes are a biofuel substitute to coal, firewood and charcoal. Briquettes may be used to heat industrial boilers in order to produce electricity from steam in large-scale production. In addition, briquettes may also be co-fired with coal in order to create the heat supplied to the boiler. Biomass briquettes are produced from agricultural waste and are a replacement for fossils fuels such as oil or coal and can be used to heat boiler in manufacturing plants. Biomass briquettes are a renewable source of energy thus is an option for climate mitigation. The extrusion production technology of briquettes is the process of extrusion screw wastes (straw, sunflower husks, buckwheat, etc.) or finely shredded wood waste (sawdust) under high pressure. Recently, there is an improvement in the briquette production through the development and propagation of non-conventional briquettes technology such as briquettes machine, briquettes plant, biomass briquettes plant for production of agro - residue briquettes to meet thermal energy requirement.
Feasibility of technology and operational necessities	The making of briquettes is divided in four main steps, as described in the manual *Fuel Briquettes:a Users Manual* (Legacy foundation, 2003). **1 Raw Material Collection** A lot of different ingredients can be used for briquette making. Burnable, fibre-rich material that is both available nearby and that can be taken free of charge is preferably selected. The manual labour required for the collection of material will then be the only related cost for getting hold of raw material. **2 Material Processing** To make briquettes the raw material should be pressed together, but before this, the material has to be prepared. The preparation is necessary to release and distribute the fibres in the material. This makes the materials more susceptible to bond when compressed in the presser. The organic matter, like agricultural residues, first needs to be chopped or pounded into smaller pieces in dry condition. Then it should be left to partially decompose in order to loosen up the structure of the material. How long time the decomposition takes varies and depends on the material and the climate. After the different materials have been decomposed properly they should be soaked in water and blended. This makes the fibres to randomly distribute in the sludgy matter that is created.

	If the briquettes are to be made out of waste paper the preparing process is different, and much easier. The paper must be soaked in water for about half a day, or more, and then it should be shredded and pounded into small pieces. When this is done the material is ready to be pressed into briquettes. The pounding of raw material, whenever it is necessary during the preparations, are the most laborious and time consuming phase in the production chain. The pounding is usually made using large mortars and pestles. **Pressing** For the material to be de-watered and to bond, it is necessary to submit it to pressure. The method of pressing will affect the final shape and burning characteristics of the briquette. A higher density gives the briquette a higher heat value, and makes the briquette burn more slowly. The most common type of the briquettes is the cylindrical shaped, often with a centre hole (doughnut shape). To press this type of briquette it is necessary to use a cylindrical mould, most commonly a perforated tube of PVC, placed in upright position. In the centre a metal piston can be placed which enables the making of a hollow shaped doughnut briquette. The tube is then filled with raw material. The raw material in the cylinder is then compressed by descending a disc or a solid cylinder that just fits in the PVC tube. Water, blended in the raw material, leaves the tube through the perforated holes during the compressing phase. When compressing the briquette, the compression of raw materials requires a non linear force to distance. There are different ways of applying the force for pressing cylindrical shaped briquettes. The pressing mechanisms include hand based and screw based (Figure 3). Hand- based are mainly for paper-based briquettes. The screw based could be used for industrial application, for example in production of briquettes for tobacco and ceramic brick curing
Institutional framework for adoption and diffusion	The Department of Energy Affairs under the section of alternative fuels offers institutional framework for adoption and diffusion of the technology
Cost	The cost of the technology depends on the type of the presser and size. The hand-based pressers for household application are less expensive compared to screw-based commercial/large-scale ones
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	Briquettes are sold as fuel in urban areas. Briquettes from organic solid waste are the sustainable way of waste beneficiation for economic development. Also, in the event that briquettes are cheaper than charcoal or any substituted energy that is expensive, the saved energy cost has a positive economic positive of the households. Collection of solid waste for briquettes would create jobs, in case of commercial level of briquetting business
Social	Cooking using briquettes improves indoor air quality, positively impacting on health, especially of women and girls
Environment	Briquetting from organic waste is the viable way of waste management.

GHG mitigation potential	Since biomass is harvested unsustainably for wood energy among others, the savings in fuel wood demand due to use of briquettes results in reducing carbon emissions. The potential for GHG mitigation is very high considering that the majority of Malawi relay on unsustainable biomass for energy supply
Applicability* of the technology in Malawi (short, medium and long term)	The technology could applied in a short term
Size (household and large-scale)	It could be applied at both household and large-scale basis

*On Applicability of the technology

- Applicability of technology is define as follows: short term is the technology that is proven to be liable and is commercially ready in similar market
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Figures ***Illustration 1: A typical biomass briquette made of compressed paper and sawdust.*** ***Illustration 1: A typical biomass briquette made of compressed paper and sawdust. Illustration 1: A typical biomass briquette made of compressed paper and sawdust.***

Figure1 (a) Biomass briquettes and (b) briquettes on stove

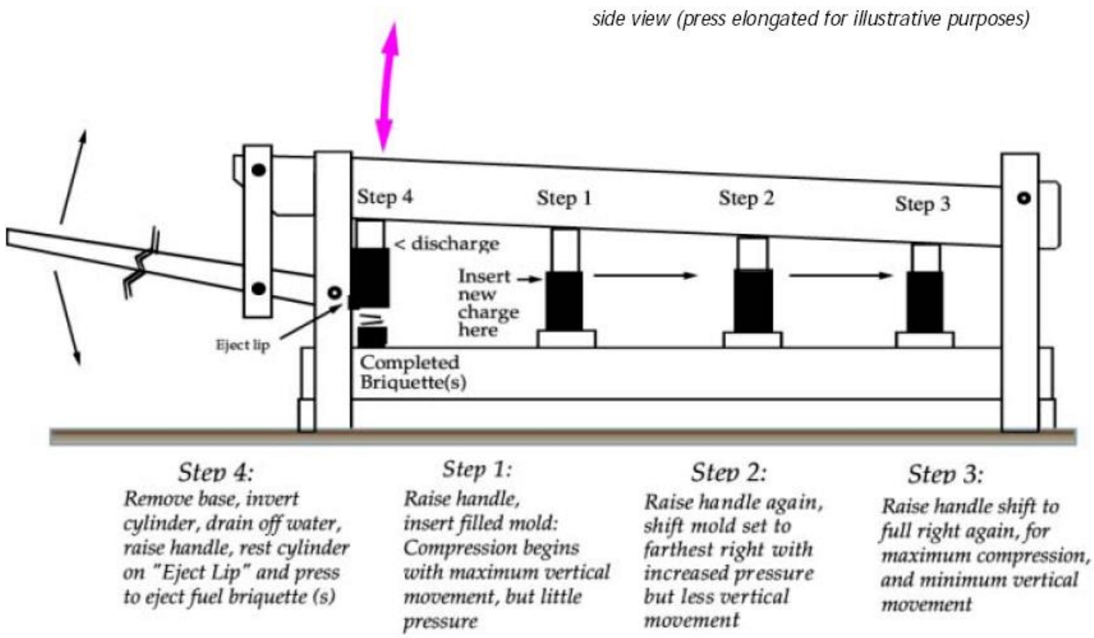

Figure 2: Wood presser, applying differential pressure on the briquettes

Figure 3 (a): The Screw-based presser produced by Malawi Industrial Research and Technology Development Centre (MIRTDC)


Figure 3 (b)3: The Screw-based presser used by non-profit organization Paper Making Education Trust (PAMET), based in central Blantyre (now ot functioning)

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This manual was composed on behalf of The Climate Technology Centre & Network (CTCN). CTCN is the operational arm of the UNFCCC Technology Mechanism, hosted by the UN Environment Programme and the UN Industrial Development Organization (UNIDO).

Promotion of Ethanol Cook Stoves

Technology Characteristics	Narrative description of the characteristic
General information	Malawi's cooking energy is dominated by forewood and charcoal that contributes to deforestation and lowering of carbon sink. It is the aim of the Government through policies (e.g energy policy and national charcoal strategy) to switching to cleaner fuels, such as ethanol. Also, having access to clean fuels is one strategy for dealing with the problems of the health effects caused by the smoke and other pollutants released in enclosed cooking areas. Alcohol burning stoves based on ethanol do not produce pollutant emissions but the technology is more expensive than traditional biomass stoves, both in terms of purchasing the stoves and the costs related to the supply chain for the ethanol. Ethanol is an alcohol that is produced by fermentation of sugars from various crops, such as maize, sorghum, wheat, cassava and sugarcane. It can be used for different energy applications varying from boiler heating in industries to water heating and cooking. This description focuses on the latter service. There are several ethanol stoves and among their differences is the form of the fuel used. This can either be a liquid or a gel. Ethanol is a liquid, while 'Greengel', which has been developed in South Africa, is an ethanol fuel that is thickened and also contains colourants and flavouring agents. This makes it not as dangerous as the liquid as it does not spread if spilled. Greengel can be burned in a 'greengel' stove (see the image above), but also in other stoves. Alcohol burning stoves (Figures 1 and 2) based on ethanol can be used for cooking, water heating and heating of buildings. The technology can be applied in households, institutions (*e.g.* schools) and industries where it is used for boiler heating. Ethanol is produced from sugar plants or other sources of biomass. Malawi Ethanol and methanol are high-potential fuels that is produced based on plant material. In Malawi, Ethanol is available in abundance since it is easy to extract as a by-product in sugar production from sugarcane molasses and there are two big sugar production sites in the country, namely: Ethanol Company in Dwangwa and Presscane in Chikwawa. Both company have ethanol output production of over 18 million litres. Ethanol for use in stove would compete with other ethanol fuel use such as blending with petrol. The ethanol production would also compete with food production. Ethanol could be produced from other energy crops,, some of which are wide-spread and growing wild in Malawi as well. An ethanol stove should be used for cooking has to fulfill certain criteria, which in the past has created some challenges. It has to ensure that the ethanol is burnt stable, i.e. in a way that it will not explode, and the flame has to reach certain heat levels (blue flame) to ensure that the energy is used efficiently. There are cookers burning liquid ethanol directly, which is quite risky, as well as stoves using indirect combustion, transferring the liquid ethanol into a gas stadium, and hybrids between the two. Gelfuel, a jelly produced from Ethanol, is a more user-friendly way of burning Ethanol, but hasn't yet gained wide acceptance in Malawi, probably due to

	its high price of both fuel and stoves and the bad quality of gelfuel stoves available in the market. In recent years, Malawian company BluWave Technology Ltd., has developed and patented a prototype of the “Superblu Stove” which promises safe, highly cost-efficient and healthy, smoke-less cooking, but is still awaiting market introduction. A study in peri-urban Malawi to evaluate the ethanol stove (SperBlu) against an improved ceramic charcoal stove, revealed that the ethanol stove was potentially appropriate for use but suffered from manufacturing problems, with further work required on safety, performance and emissions. However, the SuperBlu Stove can be made appropriate with some seemingly achievable development. The study recommended that for the stove to be made both affordable and accessible to users, the ethanol market would need some marked changes to reduce price, increase available volumes and develop alternative feedstocks. Some of the benefits of ethanol as a cooking fuel are as follows: (i). Ethanol is a biofuel, and thus can be made by fermenting plant biomass.Some of these plants are very efficient photosynthesizers, such as the C4 plants, and thus make great energy sources. (ii). Ethanol is a liquid, so it can be stored and handled with a fuel infrastructure essentially identical to that of kerosene. When kerosene replaced whale oil it was appreciated (like whale oil) for the fact that it could be more easily transported and used than solid fuels. During the transition between whale oil and kerosene, ethanol mixed with turpentine (made from pine trees) was used for lamp oil. (iii). As a biofuel, ethanol is part of a CO2 lifecycle process (e.g. its combustion releases CO2 that was fixed through photosynthesis). Cleanly combusted, ethanol is CO2-neutral. Certain plants return and store carbon in the soil, and if these plants are used for ethanol production ethanol fuel is CO2-negative. (iv). Fermentation and the distillation of ethanol are highly scalable, meaning they can be carried out on large or small scales. (v). Fermentation and distillation are well understood- they have been carried out for thousands of years. The production of ethanol by this means continues to advance technologically, becoming increasingly efficient. (i). Ethanol is much less toxic than any other liquid fuel (OSHA PEL 8H TWA 1,000 ppm compared to 100 ppm for kerosene). (ii). As a distilled fuel, ethanol is almost completely free of contaminants. (iii). Azeotrope ethanol (~95%) burns well. u・ Ethanol is water-soluble; an ethanol fire is extinguishable by water. (iv). Ethanol biodegrades rapidly in the environment. (v). Ethanol produces almost no soot or black carbon during combustion. (vi). The properties that characterize ethanol as a fuel (lower and upper

	flammability limits, flash point, auto ignition temperature, vapor pressure, boiling point, vapor density relative to air, etc.) can all be managed for safe and efficient storage, handling, combustion, and use in small appliances. While care is required, the properties of ethanol present no drawbacks, and in fact offer distinct advantages when compared to other fuels. (vii). When combusted efficiently, ethanol burns with a flame temperature similar to propane. (viii). Ethanol mixes with methanol, the other simple alcohol, in any proportion. Methanol, with more oxygen, promotes more complete combustion of ethanol, especially if it contains higher alcohols.
Physical component/innovative technique	The physical component of the ethanol stove are presented as follows according to the types **1. Pressure Alcohol Stoves** Pressure alcohol stoves store alcohol as a liquid in a fuel tank under pressure. The tank is pressurized by means of a hand pump. The liquid is pushed through a tube to a nozzle and sprayed into the burner. When the burner is hot, the tiny droplets of liquid ethanol vaporize at the burner surfaces and feed a flame supported by the burner. The burner is designed to promote air mixing and to produce a flame of a particular size and shape. The pressure stoves require frequent pumping to maintain pressure in the tank, while only a few psi are required to promote good fuel supply and atomization at the burner. The fuel tanks of these stoves tend to leak because alcohol dehydrates the gasket material around the pump shaft connected to the tank. This promotes the failure of the gasket. Alcohol, with its low molecular attraction, is able to penetrate through even the smallest opening because its molecule is tiny and does not stick to other molecules, instead moving through capillary action. As a result, gasketed seams need to be repaired regularly to prevent leaking. **2. Non-pressure Stoves** Non-pressure stoves hold alcohol in an open container, where it is burned immediately above its surface. The alcohol is either liquid or may be gelled with a hydrocolloid. If liquid, the alcohol may be contained in a porous or fibrous medium that wicks the ethanol to its surface through direct contact with a reservoir of ethanol below. Stoves are being developed with a remote reservoir where fuel is fed by gravity through a small tube to the burner. Care must be taken not to flood the burner and spill ethanol. If the burner is fitted with a porous medium it will prevent a flame within the structure (given that there is less oxygen content), but will still allow a flame over its surface. Where fuel is gravity fed, the fuel flow must match the fuel consumption of the burner to prevent overflow. Ethanol can be gelled and also can be formed into waxy blocks. The gel is burned from a can, as in a chafing dish stove. The waxy blocks can be burned like any solid fuel. Solid blocks of ethanol burn very cleanly and can be used in open-air restaurants because they do not produce smoke or dangerous emissions. The most common non-pressure stoves are gel fuel stoves, fondue and chafing dish stoves, and Sterno stoves. These may not achieve optimal combustion of the alcohol due to poor fuel-to-air mixing. A consequent problem is that they do not burn as hot as stoves that achieve

	good air mixing. There are several reasons why gel fuel stoves do not burn at peak temperature. First, often combustion in these stoves is incomplete, evidenced by the higher than expected production of carbon monoxide (the simple alcohols are normally low CO-producing fuels because they contain little carbon). Second, fuel may contain less energy because water is usually added for better gelling of the ethanol (Most gel fuels contain 20% water). If the ethanol burns with a lazy, rolling flame, this indicates that the flame is not hot enough and likely does not have enough air mixing. **3. Self-pressurizing Stoves** This stove converts alcohol from a liquid to a gas in a restricted space and uses the consequent pressure to force it out of a series of small openings, nozzle, burner element, or mantle into a flame. The Primus stove uses this principle too, but also relies on pressure in the fuel tank. Camping stoves like the Swedish Trangia, "Pepsi Can," stove are examples of stoves that contain liquid alcohol in the same cavity where the fuel is vaporized and pressurized. The vaporized fuel is then forced out through openings where it burns. These stoves are small, with compact burners and limited fuel reservoirs, usually burning for 15 to 30 minutes. The fuel reservoir is close to the flame and essentially is contained within the burner. Their small size generally makes them safe to use. It is uncertain whether they could be sized larger and redesigned to overcome their operational limitations to become a suitable stove for family cooking, or if this would cause prohibitive safety hazards. Overall, these stoves suffer from safety and consumer "usability" issues- hazards of explosion, inability to adjust flame, inability to turn on and off, small size, shortness of cooking time, as well as other issues. The Britelyt stove combines features of the pressurized and self-pressurizing stoves to create a variant that requires only light pumping; generating most of its operational pressure, around one or two psi, from boiling the ethanol in a heat loop in the fuel feed tube before it reaches the burner. This is adapted from the Britelyt lantern, which uses a mantle (the mantle, super-heated by the burning alcohol, produces a bright light). The stove's burner structure acts as a diffuser to promote mixing with air. Like the Primus stove, this stove has to be primed (preheated) to be lit. The Britelyt stove derived from the kerosene mantle lantern developed by the German Petromax Company in the early 20th century. This Petromax design was adapted to use alcohol in 2002 as part of the research conducted by Project Gaia. The advantage of this variant on pressurized stoves is that it takes full advantage of the volatility of ethanol in transport from the tank to the burner. Since ethanol burns as a gas, vaporizing it before it makes contact with the burner increases performance. This stove overcomes the usability limitations of the self-pressurizing camping stoves described above. **4. Evaporative Stoves** The Evaporative Stoves stove represents a fourth category of alcohol stove. It has a unique fuel storage and delivery system that allows the ethanol to be delivered to the stove burner as a gas through evaporation. The stove may be the only example of this type of stove. The tpcal example of the stove, the CLEANCOOK stove, was developed in 1978 by Bengt Ebbeson of the ORIGO Company of Halmstad, Sweden, and

	represents a breakthrough technology for burning alcohol in a stove. Liquid ethanol is poured into a fuel canister through an opening in its top. The canister must be taken out of the stove to be filled. The opening in the canister is wide (8 cm diameter) relative to the volume of the canister (1.2 liters). The fuel is then is adsorbed onto the surface of a densely packed refractory ceramic fiber contained inside the canister. The liquid alcohol moves by capillary action from all parts of the canister to the evaporative surface at the top. The canister opening is sized to fit under the combustion chimney in the stove body so that ethanol from the fuel canister will evaporate directly into the chimney. Air is let into the chimney from side vents. Ethanol and air vapor form a combustible mix in the chimney. To light the stove, a flame is introduced at the top of the chimney. It ignites the vapor, which combusts in the chimney above the surface of the fuel canister. As the chimney heats, a selfpressurizing effect is achieved, as the rate of alcohol evaporation from the fuel canister increases. Since the stove combustion chimney heats quickly, this peak flow is achieved in only a few seconds. Increased convection pulls more air in through the side vents. A flame spreader at the top of the chimney acts as a diffuser and promotes fuel-air mixing at the top of the flame. The size of the flame (the rate of fuel flow) into the combustion chimney is controlled by a regulator that slides across the mouth of the canister, adjusting the size of the evaporative surface of the canister mouth. As the evaporative surface is reduced less ethanol is evaporated into the combustion chimney. When the regulator is slid across the entire surface, the ethanol vapor is shut off and the flame is extinguished. This stove was designed with the properties of ethanol in mind to exploit its advantages as a fuel. The volatility of ethanol is used as the way to deliver fuel to the burner. The low surface tension of ethanol is exploited to promote safe storage on the extensive surface area of the ceramic fiber densely packed in the fuel canister. When charged into the canister, the liquid ethanol will not drip or leak out unless the capacity of the surface area of the fiber in the canister has been exceeded. The operator can easily determine this when he or she sees ethanol pooling in a depression inside the canister mouth. Capillary action in ethanol is used to direct fuel through the fiber to the canister mouth. Ethanol has a high latent heat of evaporation, meaning the when the ethanol evaporates from the canister the liquid ethanol in the canister cools as the heat is released in the evaporated vapor. The lower and upper flammability limits of alcohol have been considered in designing the fuel canister and the combustion chimney. The alcohol vapor lacks enough oxygen to burn in the fuel canister but reaches an ideal mix with air for combustion in the chimney. The careful design of the stove in accordance to the fuel properties assures that cooking can be done safely, conveniently, and efficiently- outdoing other alcohol stoves. The CLEANCOOK stove is fueled with liquid ethanol, stores it as if a solid, and burns it as a gas.
Feasibility of technology and operational necessities	The production of ethanol as fuel for stove follows a typical process of ethanol production. Although there are various ways ethanol fuel can be produced, the most common way is via fermentation. The basic steps for large-scale production of ethanol are: microbial (yeast) fermentation of sugars, distillation, dehydration (requirements vary, see Ethanol fuel

	mixtures, below), and denaturing (optional). Prior to fermentation, some crops require saccharification or hydrolysis of carbohydrates such as cellulose and starch into sugars. Saccharification of cellulose is called cellulolysis (see cellulosic ethanol). Enzymes are used to convert starch into sugar. **Fermentation** Ethanol is produced by microbial fermentation of the sugar. Microbial fermentation currently only works directly with sugars. Two major components of plants, starch and cellulose, are both made of sugars—and can, in principle, be converted to sugars for fermentation. Currently, only the sugar (e.g., sugar cane) and starch (e.g., corn) portions can be economically converted. There is much activity in the area of cellulosic ethanol, where the cellulose part of a plant is broken down to sugars and subsequently converted to ethanol. **Distillation** For the ethanol to be usable as a fuel, the yeast solids and the majority of the water must be removed. After fermentation, the mash is heated so that the ethanol evaporates. This process, known as distillation, separates the ethanol, but its purity is limited to 95–96% due to the formation of a low-boiling water-ethanol azeotrope with maximum (95.6% m/m (96.5% v/v) ethanol and 4.4% m/m (3.5% v/v) water). This mixture is called hydrous ethanol and can be used as a fuel alone, but unlike anhydrous ethanol, hydrous ethanol is not miscible in all ratios with gasoline, so the water fraction is typically removed in further treatment to burn in combination with gasoline in gasoline engines. **Dehydration** There are three dehydration processes to remove the water from an azeotropic ethanol/water mixture. The first process, used in many early fuel ethanol plants, is called azeotropic distillation and consists of adding benzene or cyclohexane to the mixture. When these components are added to the mixture, it forms a heterogeneous azeotropic mixture in vapor–liquid-liquid equilibrium, which when distilled produces anhydrous ethanol in the column bottom, and a vapor mixture of water, ethanol, and cyclohexane/benzene. When condensed, this becomes a two-phase liquid mixture. The heavier phase, poor in the entrainer (benzene or cyclohexane), is stripped of the entrainer and recycled to the feed—while the lighter phase, with condensate from the stripping, is recycled to the second column. Another early method, called extractive distillation, consists of adding a ternary component that increases ethanol's relative volatility. When the ternary mixture is distilled, it produces anhydrous ethanol on the top stream of the column. With increasing attention being paid to saving energy, many methods have been proposed that avoid distillation altogether for dehydration. Of these methods, a third method has emerged and has been adopted by the majority of modern ethanol plants. This new process uses molecular sieves to remove water from fuel ethanol. In this process, ethanol vapor under pressure passes through a bed of molecular sieve beads. The bead's pores

	are sized to allow adsorption of water while excluding ethanol. After a period of time, the bed is regenerated under vacuum or in the flow of inert atmosphere (e.g. N_2) to remove the adsorbed water. Two beds are often used so that one is available to adsorb water while the other is being regenerated. This dehydration technology can account for energy saving of 3,000 btus/gallon (840 kJ/L) compared to earlier azeotropic distillation. Recent research has demonstrated that complete dehydration prior to blending with gasoline is not always necessary. Instead, the azeotropic mixture can be blended directly with gasoline so that liquid-liquid phase equilibrium can assist in the elimination of water. A two-stage counter-current setup of mixer-settler tanks can achieve complete recovery of ethanol into the fuel phase, with minimal energy consumption. **Post-production water issues** Ethanol is hygroscopic, meaning it absorbs water vapor directly from the atmosphere. Because absorbed water dilutes the fuel value of the ethanol and may cause phase separation of ethanol-gasoline blends (which causes engine stall), containers of ethanol fuels must be kept tightly sealed. This high miscibility with water means that ethanol cannot be efficiently shipped through modern pipelines, like liquid hydrocarbons, over long distances. The fraction of water that an ethanol-gasoline fuel can contain without phase separation increases with the percentage of ethanol. For example, E30 can have up to about 2% water. If there is more than about 71% ethanol, the remainder can be any proportion of water or gasoline and phase separation does not occur. The fuel mileage declines with increased water content. The increased solubility of water with higher ethanol content permits E30 and hydrated ethanol to be put in the same tank since any combination of them always results in a single phase. Somewhat less water is tolerated at lower temperatures. For E10 it is about 0.5% v/v at 21 °C and decreases to about 0.23% v/v at −34 C. **Consumer production systems** While biodiesel production systems have been marketed to home and business users for many years, commercialized ethanol production systems designed for end-consumer use have lagged in the marketplace. In 2008, two different companies announced home-scale ethanol production systems. The AFS125 Advanced Fuel System from Allard Research and Development is capable of producing both ethanol and biodiesel in one machine, while the E-100 MicroFueler from E-Fuel Corporation is dedicated to ethanol only.
Institutional framework for adoption and diffusion	Not available
Cost	The cost of developing the technology depends on size. Generally, ethanol stove at household level relatively of low cost
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	Creation of jobs for stove manufacturers as well as from ethanol sales Also, cooking with ethanol could be cheaper that using charcoal
Social	Improved heath resulting from reduced/prevention emissions and

	particulate matter as a result of switching from cooking using firewood and charcoal.
Environment	An advantage of the technologies is that ethanol burning does not have the air pollution problems of simple biomass burning for cooking purposes. As ethanol provides a higher heat flux with no soot or smoke, cooking and hot water production can take place faster and pollution free Switching from firewood and charcoal to cooking suing ethanol saves trees, enhancing air quality, ecosystem management and reduction in environmental degradation
GHG mitigation potential	The greenhouse gas emission reduction contribution from ethanol cookstoves depends on the feedstock used for the ethanol, the distance from feedstock location to ethanol production, and what it replaces
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in a short term
Size (household and large-scale)	The technology could be applied at both household and large-scale (commercial) levels

*On Applicability of the technology

- Applicability of technology is define as follows: short term is the technology that is proven to be liable and is commercially ready in similar market
- Medium term refers to the technology that is in pre commercial in a similar market
- Long term refers the technology that is still under research and Technology phase

Figures

Figure 1(b) Ethano stove, (b) lit ethanol stove
Source: Renewnablemalawi

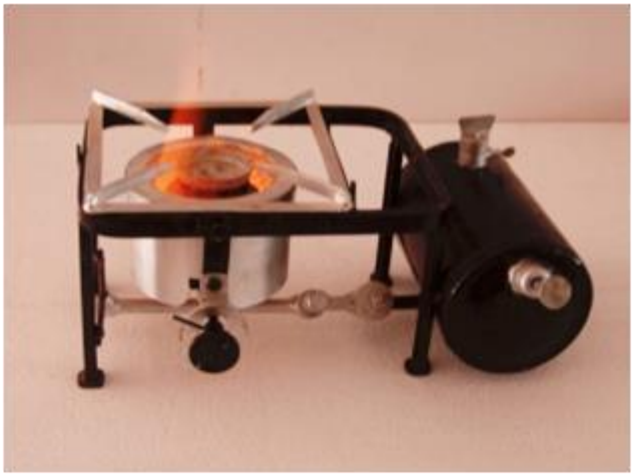
Figure 2: NARI ethanol stove

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Promotion of Ethanol Cook Stoves

Technology Characteristics	Narrative description of the characteristic
General information	Malawi's cooking energy is dominated by forewood and charcoal that contributes to deforestation and lowering of carbon sink. It is the aim of the Government through policies (e.g energy policy and national charcoal strategy) to switching to cleaner fuels, such as ethanol. Also, having access to clean fuels is one strategy for dealing with the problems of the health effects caused by the smoke and other pollutants released in enclosed cooking areas. Alcohol burning stoves based on ethanol do not produce pollutant emissions but the technology is more expensive than traditional biomass stoves, both in terms of purchasing the stoves and the costs related to the supply chain for the ethanol. Ethanol is an alcohol that is produced by fermentation of sugars from various crops, such as maize, sorghum, wheat, cassava and sugarcane. It can be used for different energy applications varying from boiler heating in industries to water heating and cooking. This description focuses on the latter service. There are several ethanol stoves and among their differences is the form of the fuel used. This can either be a liquid or a gel. Ethanol is a liquid, while 'Greengel', which has been developed in South Africa, is an ethanol fuel that is thickened and also contains colourants and flavouring agents. This makes it not as dangerous as the liquid as it does not spread if spilled. Greengel can be burned in a 'greengel' stove (see the image above), but also in other stoves. Alcohol burning stoves (Figures 1 and 2) based on ethanol can be used for cooking, water heating and heating of buildings. The technology can be applied in households, institutions (*e.g.* schools) and industries where it is used for boiler heating. Ethanol is produced from sugar plants or other sources of biomass. Malawi Ethanol and methanol are high-potential fuels that is produced based on plant material. In Malawi, Ethanol is available in abundance since it is easy to extract as a by-product in sugar production from sugarcane molasses and there are two big sugar production sites in the country, namely: Ethanol Company in Dwangwa and Presscane in Chikwawa. Both company have ethanol output production of over 18 million litres. Ethanol for use in stove would compete with other ethanol fuel use such as blending with petrol. The ethanol production would also compete with food production. Ethanol could be produced from other energy crops,, some of which are wide-spread and growing wild in Malawi as well. An ethanol stove should be used for cooking has to fulfill certain criteria, which in the past has created some challenges. It has to ensure that the ethanol is burnt stable, i.e. in a way that it will not explode, and the flame has to reach certain heat levels (blue flame) to ensure that the energy is used efficiently. There are cookers burning liquid ethanol directly, which is quite risky, as well as stoves using indirect combustion, transferring the liquid ethanol into a gas stadium, and hybrids between the two. Gelfuel, a jelly produced from Ethanol, is a more user-friendly way of burning Ethanol, but hasn't yet gained wide acceptance in Malawi, probably due to its high price of both fuel and stoves and the bad quality of gelfuel stoves available in the market. In recent years, Malawian company BluWave Technology Ltd., has developed and patented a prototype of the "Superblu

	Stove" which promises safe, highly cost-efficient and healthy, smoke-less cooking, but is still awaiting market introduction. A study in peri-urban Malawi to evaluate the ethanol stove (SperBlu) against an improved ceramic charcoal stove, revealed that the ethanol stove was potentially appropriate for use but suffered from manufacturing problems, with further work required on safety, performance and emissions. However, the SuperBlu Stove can be made appropriate with some seemingly achievable development. The study recommended that for the stove to be made both affordable and accessible to users, the ethanol market would need some marked changes to reduce price, increase available volumes and develop alternative feedstocks. Some of the benefits of ethanol as a cooking fuel are as follows: (i). Ethanol is a biofuel, and thus can be made by fermenting plant biomass.Some of these plants are very efficient photosynthesizers, such as the C4 plants, and thus make great energy sources. (ii). Ethanol is a liquid, so it can be stored and handled with a fuel infrastructure essentially identical to that of kerosene. When kerosene replaced whale oil it was appreciated (like whale oil) for the fact that it could be more easily transported and used than solid fuels. During the transition between whale oil and kerosene, ethanol mixed with turpentine (made from pine trees) was used for lamp oil. (iii). As a biofuel, ethanol is part of a CO2 lifecycle process (e.g. its combustion releases CO2 that was fixed through photosynthesis). Cleanly combusted, ethanol is CO2-neutral. Certain plants return and store carbon in the soil, and if these plants are used for ethanol production ethanol fuel is CO2-negative. (iv). Fermentation and the distillation of ethanol are highly scalable, meaning they can be carried out on large or small scales. (v). Fermentation and distillation are well understood- they have been carried out for thousands of years. The production of ethanol by this means continues to advance technologically, becoming increasingly efficient. (ix). Ethanol is much less toxic than any other liquid fuel (OSHA PEL 8H TWA 1,000 ppm compared to 100 ppm for kerosene). (x). As a distilled fuel, ethanol is almost completely free of contaminants. (xi). Azeotrope ethanol (~95%) burns well. u・ Ethanol is water-soluble; an ethanol fire is extinguishable by water. (xii). Ethanol biodegrades rapidly in the environment. (xiii). Ethanol produces almost no soot or black carbon during combustion. (xiv). The properties that characterize ethanol as a fuel (lower and upper flammability limits, flash point, auto ignition temperature, vapor pressure, boiling point, vapor density relative to air, etc.) can all be managed for safe and efficient storage, handling, combustion, and use in small appliances. While care is required, the properties of ethanol present no drawbacks, and in fact offer distinct advantages

	when compared to other fuels. (xv). When combusted efficiently, ethanol burns with a flame temperature similar to propane. (xvi). Ethanol mixes with methanol, the other simple alcohol, in any proportion. Methanol, with more oxygen, promotes more complete combustion of ethanol, especially if it contains higher alcohols.
Physical component/innovative technique	The physical component of the ethanol stove are presented as follows according to the types **1. Pressure Alcohol Stoves** Pressure alcohol stoves store alcohol as a liquid in a fuel tank under pressure. The tank is pressurized by means of a hand pump. The liquid is pushed through a tube to a nozzle and sprayed into the burner. When the burner is hot, the tiny droplets of liquid ethanol vaporize at the burner surfaces and feed a flame supported by the burner. The burner is designed to promote air mixing and to produce a flame of a particular size and shape. The pressure stoves require frequent pumping to maintain pressure in the tank, while only a few psi are required to promote good fuel supply and atomization at the burner. The fuel tanks of these stoves tend to leak because alcohol dehydrates the gasket material around the pump shaft connected to the tank. This promotes the failure of the gasket. Alcohol, with its low molecular attraction, is able to penetrate through even the smallest opening because its molecule is tiny and does not stick to other molecules, instead moving through capillary action. As a result, gasketed seams need to be repaired regularly to prevent leaking. **2. Non-pressure Stoves** Non-pressure stoves hold alcohol in an open container, where it is burned immediately above its surface. The alcohol is either liquid or may be gelled with a hydrocolloid. If liquid, the alcohol may be contained in a porous or fibrous medium that wicks the ethanol to its surface through direct contact with a reservoir of ethanol below. Stoves are being developed with a remote reservoir where fuel is fed by gravity through a small tube to the burner. Care must be taken not to flood the burner and spill ethanol. If the burner is fitted with a porous medium it will prevent a flame within the structure (given that there is less oxygen content), but will still allow a flame over its surface. Where fuel is gravity fed, the fuel flow must match the fuel consumption of the burner to prevent overflow. **Variant: Gelled and Solid Fuel Stoves** Ethanol can be gelled and also can be formed into waxy blocks. The gel is burned from a can, as in a chafing dish stove. The waxy blocks can be burned like any solid fuel. Solid blocks of ethanol burn very cleanly and can be used in open-air restaurants because they do not produce smoke or dangerous emissions. The most common non-pressure stoves are gel fuel stoves, fondue and chafing dish stoves, and Sterno stoves. These may not achieve optimal combustion of the alcohol due to poor fuel-to-air mixing. A consequent problem is that they do not burn as hot as stoves that achieve good air mixing. There are several reasons why gel fuel stoves do not burn at peak temperature. First, often combustion in these stoves is incomplete, evidenced by the higher than expected production of carbon monoxide (the simple alcohols are normally low CO-producing fuels because they

	contain little carbon). Second, fuel may contain less energy because water is usually added for better gelling of the ethanol (Most gel fuels contain 20% water). If the ethanol burns with a lazy, rolling flame, this indicates that the flame is not hot enough and likely does not have enough air mixing. **3. Self-pressurizing Stoves** This stove converts alcohol from a liquid to a gas in a restricted space and uses the consequent pressure to force it out of a series of small openings, nozzle, burner element, or mantle into a flame. The Primus stove uses this principle too, but also relies on pressure in the fuel tank. Camping stoves like the Swedish Trangia, "Pepsi Can," stove are examples of stoves that contain liquid alcohol in the same cavity where the fuel is vaporized and pressurized. The vaporized fuel is then forced out through openings where it burns. These stoves are small, with compact burners and limited fuel reservoirs, usually burning for 15 to 30 minutes. The fuel reservoir is close to the flame and essentially is contained within the burner. Their small size generally makes them safe to use. It is uncertain whether they could be sized larger and redesigned to overcome their operational limitations to become a suitable stove for family cooking, or if this would cause prohibitive safety hazards. Overall, these stoves suffer from safety and consumer "usability" issues- hazards of explosion, inability to adjust flame, inability to turn on and off, small size, shortness of cooking time, as well as other issues. The Britelyt stove combines features of the pressurized and self-pressurizing stoves to create a variant that requires only light pumping; generating most of its operational pressure, around one or two psi, from boiling the ethanol in a heat loop in the fuel feed tube before it reaches the burner. This is adapted from the Britelyt lantern, which uses a mantle (the mantle, super-heated by the burning alcohol, produces a bright light). The stove's burner structure acts as a diffuser to promote mixing with air. Like the Primus stove, this stove has to be primed (preheated) to be lit. The Britelyt stove derived from the kerosene mantle lantern developed by the German Petromax Company in the early 20th century. This Petromax design was adapted to use alcohol in 2002 as part of the research conducted by Project Gaia. The advantage of this variant on pressurized stoves is that it takes full advantage of the volatility of ethanol in transport from the tank to the burner. Since ethanol burns as a gas, vaporizing it before it makes contact with the burner increases performance. This stove overcomes the usability limitations of the self-pressurizing camping stoves described above. **4. Evaporative Stoves** The Evaporative Stoves stove represents a fourth category of alcohol stove. It has a unique fuel storage and delivery system that allows the ethanol to be delivered to the stove burner as a gas through evaporation. The stove may be the only example of this type of stove. The tpcal example of the stove, the CLEANCOOK stove, was developed in 1978 by Bengt Ebbeson of the ORIGO Company of Halmstad, Sweden, and represents a breakthrough technology for burning alcohol in a stove. Liquid ethanol is poured into a fuel canister through an opening in its top. The canister must be taken out of the stove to be filled. The opening in the canister is wide (8 cm diameter) relative to the volume of the canister (1.2

	liters). The fuel is then is adsorbed onto the surface of a densely packed refractory ceramic fiber contained inside the canister. The liquid alcohol moves by capillary action from all parts of the canister to the evaporative surface at the top. The canister opening is sized to fit under the combustion chimney in the stove body so that ethanol from the fuel canister will evaporate directly into the chimney. Air is let into the chimney from side vents. Ethanol and air vapor form a combustible mix in the chimney. To light the stove, a flame is introduced at the top of the chimney. It ignites the vapor, which combusts in the chimney above the surface of the fuel canister. As the chimney heats, a selfpressurizing effect is achieved, as the rate of alcohol evaporation from the fuel canister increases. Since the stove combustion chimney heats quickly, this peak flow is achieved in only a few seconds. Increased convection pulls more air in through the side vents. A flame spreader at the top of the chimney acts as a diffuser and promotes fuel-air mixing at the top of the flame. The size of the flame (the rate of fuel flow) into the combustion chimney is controlled by a regulator that slides across the mouth of the canister, adjusting the size of the evaporative surface of the canister mouth. As the evaporative surface is reduced less ethanol is evaporated into the combustion chimney. When the regulator is slid across the entire surface, the ethanol vapor is shut off and the flame is extinguished. This stove was designed with the properties of ethanol in mind to exploit its advantages as a fuel. The volatility of ethanol is used as the way to deliver fuel to the burner. The low surface tension of ethanol is exploited to promote safe storage on the extensive surface area of the ceramic fiber densely packed in the fuel canister. When charged into the canister, the liquid ethanol will not drip or leak out unless the capacity of the surface area of the fiber in the canister has been exceeded. The operator can easily determine this when he or she sees ethanol pooling in a depression inside the canister mouth. Capillary action in ethanol is used to direct fuel through the fiber to the canister mouth. Ethanol has a high latent heat of evaporation, meaning the when the ethanol evaporates from the canister the liquid ethanol in the canister cools as the heat is released in the evaporated vapor. The lower and upper flammability limits of alcohol have been considered in designing the fuel canister and the combustion chimney. The alcohol vapor lacks enough oxygen to burn in the fuel canister but reaches an ideal mix with air for combustion in the chimney. The careful design of the stove in accordance to the fuel properties assures that cooking can be done safely, conveniently, and efficiently- outdoing other alcohol stoves. The CLEANCOOK stove is fueled with liquid ethanol, stores it as if a solid, and burns it as a gas.
Feasibility of technology and operational necessities	The production of ethanol as fuel for stove follows a typical process of ethanol production. Although there are various ways ethanol fuel can be produced, the most common way is via fermentation. The basic steps for large-scale production of ethanol are: microbial (yeast) fermentation of sugars, distillation, dehydration (requirements vary, see Ethanol fuel mixtures, below), and denaturing (optional). Prior to fermentation, some crops require saccharification or hydrolysis of carbohydrates such as cellulose and starch into sugars. Saccharification of cellulose is called cellulolysis (see cellulosic ethanol). Enzymes are used to convert starch

	into sugar. **Fermentation** Ethanol is produced by microbial fermentation of the sugar. Microbial fermentation currently only works directly with sugars. Two major components of plants, starch and cellulose, are both made of sugars—and can, in principle, be converted to sugars for fermentation. Currently, only the sugar (e.g., sugar cane) and starch (e.g., corn) portions can be economically converted. There is much activity in the area of cellulosic ethanol, where the cellulose part of a plant is broken down to sugars and subsequently converted to ethanol. **Distillation** For the ethanol to be usable as a fuel, the yeast solids and the majority of the water must be removed. After fermentation, the mash is heated so that the ethanol evaporates. This process, known as distillation, separates the ethanol, but its purity is limited to 95–96% due to the formation of a low-boiling water-ethanol azeotrope with maximum (95.6% m/m (96.5% v/v) ethanol and 4.4% m/m (3.5% v/v) water). This mixture is called hydrous ethanol and can be used as a fuel alone, but unlike anhydrous ethanol, hydrous ethanol is not miscible in all ratios with gasoline, so the water fraction is typically removed in further treatment to burn in combination with gasoline in gasoline engines. **Dehydration** There are three dehydration processes to remove the water from an azeotropic ethanol/water mixture. The first process, used in many early fuel ethanol plants, is called azeotropic distillation and consists of adding benzene or cyclohexane to the mixture. When these components are added to the mixture, it forms a heterogeneous azeotropic mixture in vapor–liquid-liquid equilibrium, which when distilled produces anhydrous ethanol in the column bottom, and a vapor mixture of water, ethanol, and cyclohexane/benzene. When condensed, this becomes a two-phase liquid mixture. The heavier phase, poor in the entrainer (benzene or cyclohexane), is stripped of the entrainer and recycled to the feed—while the lighter phase, with condensate from the stripping, is recycled to the second column. Another early method, called extractive distillation, consists of adding a ternary component that increases ethanol's relative volatility. When the ternary mixture is distilled, it produces anhydrous ethanol on the top stream of the column. With increasing attention being paid to saving energy, many methods have been proposed that avoid distillation altogether for dehydration. Of these methods, a third method has emerged and has been adopted by the majority of modern ethanol plants. This new process uses molecular sieves to remove water from fuel ethanol. In this process, ethanol vapor under pressure passes through a bed of molecular sieve beads. The bead's pores are sized to allow adsorption of water while excluding ethanol. After a period of time, the bed is regenerated under vacuum or in the flow of inert atmosphere (e.g. N_2) to remove the adsorbed water. Two beds are often used so that one is available to adsorb water while the other is being

	regenerated. This dehydration technology can account for energy saving of 3,000 btus/gallon (840 kJ/L) compared to earlier azeotropic distillation. Recent research has demonstrated that complete dehydration prior to blending with gasoline is not always necessary. Instead, the azeotropic mixture can be blended directly with gasoline so that liquid-liquid phase equilibrium can assist in the elimination of water. A two-stage counter-current setup of mixer-settler tanks can achieve complete recovery of ethanol into the fuel phase, with minimal energy consumption. **Post-production water issues** Ethanol is hygroscopic, meaning it absorbs water vapor directly from the atmosphere. Because absorbed water dilutes the fuel value of the ethanol and may cause phase separation of ethanol-gasoline blends (which causes engine stall), containers of ethanol fuels must be kept tightly sealed. This high miscibility with water means that ethanol cannot be efficiently shipped through modern pipelines, like liquid hydrocarbons, over long distances. The fraction of water that an ethanol-gasoline fuel can contain without phase separation increases with the percentage of ethanol. For example, E30 can have up to about 2% water. If there is more than about 71% ethanol, the remainder can be any proportion of water or gasoline and phase separation does not occur. The fuel mileage declines with increased water content. The increased solubility of water with higher ethanol content permits E30 and hydrated ethanol to be put in the same tank since any combination of them always results in a single phase. Somewhat less water is tolerated at lower temperatures. For E10 it is about 0.5% v/v at 21 °C and decreases to about 0.23% v/v at −34 C. **Consumer production systems** While biodiesel production systems have been marketed to home and business users for many years, commercialized ethanol production systems designed for end-consumer use have lagged in the marketplace. In 2008, two different companies announced home-scale ethanol production systems. The AFS125 Advanced Fuel System from Allard Research and Development is capable of producing both ethanol and biodiesel in one machine, while the E-100 MicroFueler from E-Fuel Corporation is dedicated to ethanol only.
Institutional framework for adoption and diffusion	Not available
Cost	The cost of developing the technology depends on size. Generally, ethanol stove at household level relatively of low cost
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	Creation of jobs for stove manufacturers as well as from ethanol sales Also, cooking with ethanol could be cheaper that using charcoal
Social	Improved heath resulting from reduced/prevention emissions and particulate matter as a result of switching from cooking using firewood

	and charcoal.
Environment	An advantage of the technologies is that ethanol burning does not have the air pollution problems of simple biomass burning for cooking purposes. As ethanol provides a higher heat flux with no soot or smoke, cooking and hot water production can take place faster and pollution free Switching from firewood and charcoal to cooking suing ethanol saves trees, enhancing air quality, ecosystem management and reduction in environmental degradation
GHG mitigation potential	The greenhouse gas emission reduction contribution from ethanol cookstoves depends on the feedstock used for the ethanol, the distance from feedstock location to ethanol production, and what it replaces
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in a short term
Size (household and large-scale)	The technology could be applied at both household and large-scale (commercial) levels

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Figures

Figure 1(b) Ethano stove, (b) lit ethanol stove
Source: Renewnablemalawi

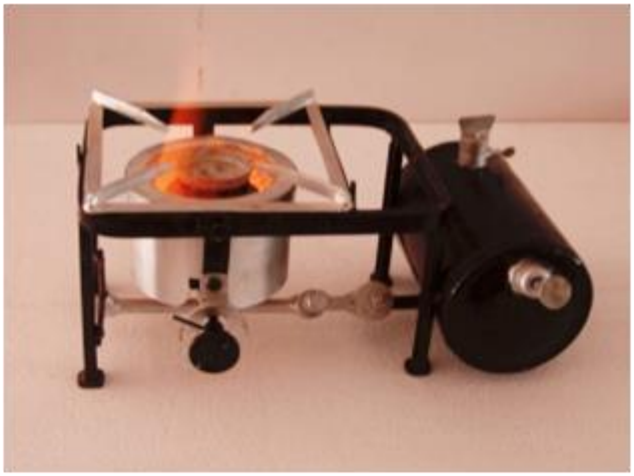
Figure 2: NARI ethanol stove

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Promotion of efficient firewood cookstove

Technology Characteristics	**Narrative description of the characteristic**
General information	Firewood is the dominant source of fuel for cooking and other thermal application in households, and some large degree to some institutions and industries in Malawi. It is often sourced unsustainably from forests, reducing carbon sink since and contributing to global warming. Rate of deforestation could be slowed down from reducing the amount of wood required to provide a unit thermal service e.g cooking. This is done by using efficient firewood cooking stove, replacing an inefficient 3-stone open fore cookstove (Figure 1). The stove is efficient by limiting the loss of heat to the ambient, but designing the stove in such a way the fire zone (combustion chamber) is relatively insulated and the fire directed to the pot. One such example of the stove is the Chitetezo Mbaula (Refer to Figure 2.), that has been developed and disseminated by ProBEC, which is reported to save up to 60% of wood for cooking compared to the traditional 3-stone firestood that still in majority in Malawi. Use of efficient firewood stoves is support by many polices and strategies in Malawi as one of the plausible solutions to deforestation. Despite interventions to introduce efficient firewood cooking stove such as Chitetezo Mbaula (piloted in some districts such as Mulanje and Ntcheu), the efficient firewood cooking stove is yet to popularised, reaching the entire part of Malawi. The other one introduced with success is The Changu Changu Moto (Figure 2), which is locally produced fuel-efficient cookstove made out of just 26 mud bricks and a mud mortar mix. The stove is being promoted by Ripple Africa, which states that they have reached about 40,000 households with Changu Changu Moto cookstove, replacing their inefficient three stone fires. Apart from saving forests, contributing t climate change mitigation, efficient firewood cooking stoves are have found useful in creating income generating activities in the rural areas. The technology has also been reported to have reduced harmful emissions during cooking, thus contributing to efficient human health. Also, the construction of stoves, from clay, is championed by local communities using local resources, thus have high chance of popularisation.
Physical component/innovative technique	The technology of efficient biomass firewood stove, like any other efficient cook stoves, lie on having efficient combustion process. This is achieved through minimisation of losses and having close to complete combustion. The stove performance depends on all elements of the cooking system, which includes the cookstove, fuel, cooking vessel (e.g.,pot), user, and kitchen. All of these elements influence the impacts that a cookstove has on the user and environment. The cookstove should have the following general design specifications: Performance The stove should have a high energy conversion effeciency, should have reduced GHG gaseous emissions and particulate matter, It should be safe

	to use and should be durable. The performance of the stove is also evaluated through answering the following questions: (i). Is the air supply to the critical parts of the fire too much or not enough? (ii). Is it possible to add preheated secondary air in the combustion zone and/or riser? (iii). Can you consult a testing center about how these changes impact performance? (iv). Does the design allow using different types of fuel with different properties (e.g., size, moisture content, calorific value)? Affordability The cookstove, especially firewood cookstove, should not be expensive t buy, it should have a long service life and a lower fuel consumption. The affordabiity of the stove cold also be answered through the following questions: (i). Do features that improve ignition performance of the cookstove (e.g., efficient insulation, added airflow) have a significant impact on manufacturing cost? (ii). Is faster and cleaner ignition a feature that the user will value and pay for?Will users be able to afford the designed cookstove? (iii). Will subsidies in help to make your fuel more affordable? Usability The efficient cookstove should be have elements that make could make it more convenient to be used for cooking. It should save cooking time, it should be relatively not heavy, it should have good user-interface characteristics, and it should be easy to ignite. Some of the questions to be answered to determine cookstock usability are given as follows: (i). How much fuel is needed to carry out typical cooking tasks? Will your stove deliver the energy needed for these tasks? Will users need to refuel the stove? (ii). Is the fuel you are designing for similar to the fuel(s) that users are familiar with? (iii). Will it be challenging for users to change to a new or different fuel type? (iv). How much fuel is needed to carry out typical cooking tasks? Will the stove deliver the energy needed for these tasks? Will users need to refuel the stove? (v). Is the fuel that is designed for similar to the fuel(s) that users are familiar with? (vi). Will it be challenging for users to change to a new or different fuel type? Can demonstrations or instructions help users to make these changes? (vii). Do you anticipate that users will add your stove or fuel into their stacking behavior? Availability The fuel to fire cookstove and materials to manufacture the must be available locally. The following questions could assist to have a viable cookstove project: (i). What types of fuel are available in your target market? (ii). Can you partner with a fuel manufacturer to optimize a stove-fuel

	combination? Manufacturing (i). If the feedstove fuels are manufactured, can they be processed to achieve properties that match with your target stove design or stoves commonly used in your market? (ii). Will using fuels different from the intended fuel change the stove performance?
Feasibility of technology and operational necessities	The efficient cookstove must have air supply. This could be from natural draft or forced draft (Figure 4), where a fan is incorporated. The combustion chamber, where heat is released for cooking (refer to equations below) has its wall insulated to reduce losses (convective and radiative). The design of natural draft cookstove (Figure 3). To enhance combustion, the feedstock fuel must be broken down to smaller pieces for complete supply of air. The air should be supplied more that what is just needed for complete combustion (excess air). When combustion is incomplete (refer to equations below), gaseous products of combustion (PIC) are emitted causing health and environmental impacts. $fuel + O_2 \rightarrow heat + CO_2 + H_2O$ $fuel + O_2 \rightarrow heat + CO_2 + H_2O + PICs$
Institutional framework for adoption and diffusion	Department of Environmental Affairs would provide a framework for adoption and diffusion of the efficient cookstove
Cost	The cost of developing the technology efficient cookstove is relatively low
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	Cookstoves generate employment for rural communities
Social	Efficient stove reduce indoor air pollution and improve health
Environment	Efficient cooking stove reduce demand for fuel wood hence one of means of halting forest degradation.
GHG mitigation potential	The saved forest from use of efficient cookstove translates to reduction of GHG emissions through enhancing carbon sink.
Applicability* of the technology in Malawi (short, medium and long term)	Promotion of the efficient firewood cookstove could be applied in short time
Size (household and large-scale)	Promotion of the efficient firewood cookstove are applied at household level

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Figures


Figure 1: 3-stone open firewood stove


Figure 2: Efficient firewood cookstove (Chitetezo mbaula)

Figure 3:

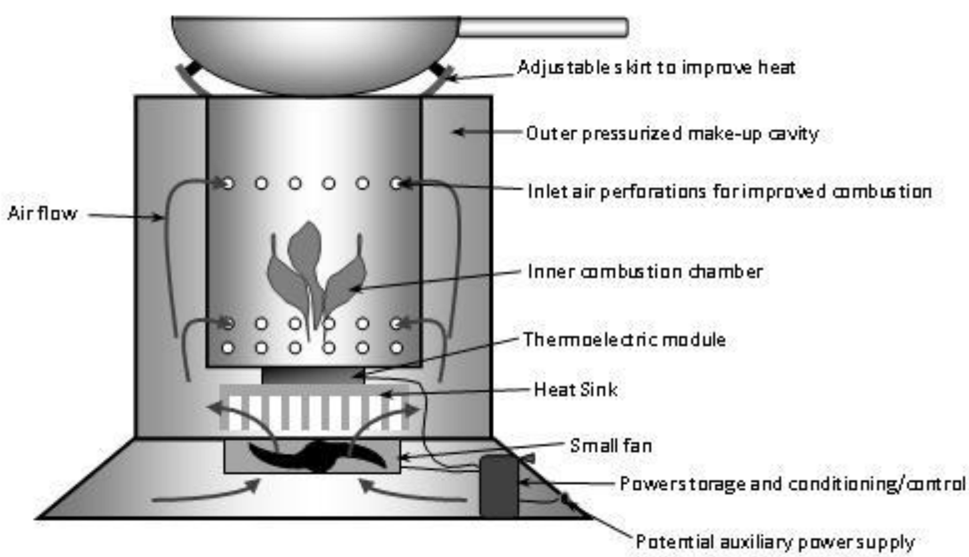

Figure 4: basic parts of an efficient cookstove

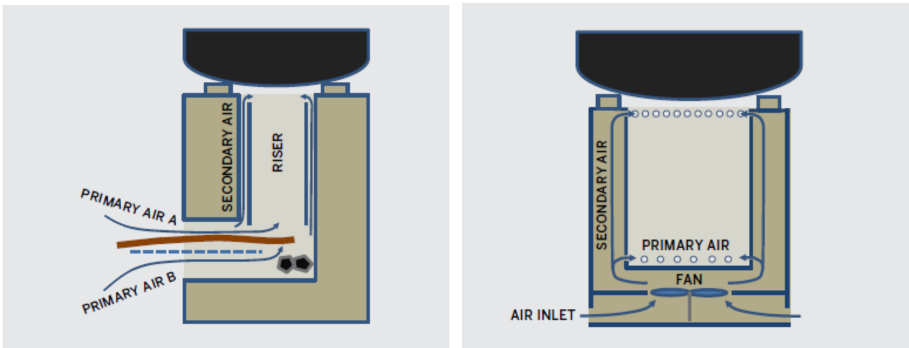

Figure 5: Natural draft (a) and forced draft cookstoves (b)

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Lake hydrokinetic-electric power technology

Technology Characteristics	Narrative description of the characteristic
General information	Hydropower can be generated, based on head (potential energy) and based on flow velocity (kinetic energy). The conventional hydropower generation has been that working on head. Thus, there is an enormous potential from harnessing hydropower from flowing water sources such as rivers, lakes and oceans. These could be from tides, waves and from maximum water flow velocity during its course of flow. Hydropower extracted due to water velocity (kinetic energy) is called hydrokinetic power, its potential given by the following governing equation. $$P = \frac{1}{2} C_p \rho A V^3$$ Where P is the mechanical power generated by the turbine, C_p is the power factor, ρ is the density of water, A is the area of the rotor blades, V is the fluid velocity. The power coefficient is a measure of how much the turbine can harness the mechanical power from the available hydraulic power. Since water is denser than air, hydrokinetic power technology represents a highly-concentrated and clean energy resource compared to wind turbine. The hydrokinetic power can be extracted, from Lake Malawi, or any other lake that has water flowing. From science, due to boundary layer phenomenon, the velocity of water flow increases from the lake bed with height until reaching the maximum velocity, and then it decreases unto to the water surface. It is thus, possible to place a turbine at a position of maximum water flow velocity to harness maximum hydrokinetic power. The location of maximum velocity is site-specific, hence extracting the most electricity from each hydrokinetic project will depend heavily on site selection.
Physical component/innovative technique	The physical composition of the hydrokinetic power technology is similar to the wind turbine. It has the turbine, which converts kinetic energy in the water to the shaft power. The turbine is coupled to the generator through mechanical system, to generate electricity. The system must have a strong support system so that the kinetic energy does not destroy or displace the installed power system. The electricity generated will be a function of the flow velocity, and thus must have a voltage control system to produce quality electricity.
Feasibility of technology and operational necessities	The technology is has gone through research and development. For the cake of Lake Malawi, there is need to firstly assess the potential and then design the power system. The designed power system could be arranged in a cascade form through most of the entire length of the Lake. However, it will require trained technical personnel to operate and maintain it.
Institutional framework for adoption and diffusion	This technology requirement working relationship between research institutions and the power generation company (EGENCO). The Department of Energy Affair and MERA could provide the necessary support for its implementation
Cost	The cost of the technology depends on size and location. Since the technology is relatively new compared to ducted hydropower systems, the

	cost for generating 1 kWh for hydrokinetic power would be higher
Benefits	Benefits of this technology are categorized into economic, social, environment and GHG mitigation potential. They are discussed henceforth.
Economic	The technology has potential to increase the electricity generating capacity, which will provide adequate power for economic activities. The excess electricity generated could be sold outside Malawi.
Social	The electricity generated will help to reduce power shortages , increasing the social aspects of Malawians such as health and education
Environment	The technology will increase of share renewable energy in the energy supply sector. This will have a positive impact on the environment
GHG mitigation potential	This is the renewable energy generation technology. Thus, if the power generated replaces fossil fuel based power, the mitigation potential is very high.
Applicability* of the technology in Malawi (short, medium and long term)	The technology could be applied in the longer term
Size (household and large-scale)	The technology is a large scale one

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