Republic of Rwanda

TECHNOLOGY NEEDS ASSESSMENT AND TECHNOLOGY ACTION PLANS FOR CLIMATE CHANGE MITIGATION and ADAPTATION

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS and ACRONYMS

BRALIRWA: Brasserie et Limonaderie du Rwanda
CCI: Cross Cutting Issues
CDM: Clean Development Mechanism
CH_4: Methane Gas
CO: Carbon Monoxide
CO_2: Carbon Dioxide
COP: Conference of Parties
COVNM: Non Methane Volatile Organic Compounds
CSP: Concentrating Storage Hydropower
DNA: Designated National Authority
EAC: East African Community
EACCCP: East African Community Climate Change Policy
EDPRS: Economic Development and Poverty Reduction Strategy
ENDA: Environmental Development Action in Third World
ESMAP: Energy Sector Management Assistance Programme
EST: Environmentally Sound Technology
EWASA: Energy, Water and Sanitation Authority
FAO: Food and Agriculture Organization
FONERWA: Fund for Environment and Climate of Rwanda
GEF: Global Environmental Facility
Gg: Gigagrams
Gl: Gigalitres
GHG: Greenhouse Gases

GoR: Government of Rwanda

GIZ: Germany Technical Cooperation Agency

GWh: Gigawatt hour

HIV: Human Immunodeficiency Virus

ICT: Information and Communication Technology

IDP: Integrated Development Programme

IWRM: Integrated Water Resources Management

KIST: Kigali Institute of Science and Technology

KWh: Kilowatt hour

MDGs: Millennium Development Goals

MINAGRI: Ministry of Agriculture and Animal Resources

MINECOFIN: Ministry of Economic Development and Finance

MINEDUC: Ministry of Education

MINICOM: Ministry of Trade and Industry

MININFRA: Ministry of Infrastructure

MINIRENA: Ministry of Natural Resources

MSW: Municipal Solid Waste

MWh: Megawatt hour

N_2O: Nitrous Oxide

NAPA: National Adaptation Plans of Actions

NGO: Non Governmental Organization

NOx: Oxide Nitrogen

PRSP: Poverty Reduction Strategic Plan

PSF: Private Sector Federation

RAB: Rwanda Agriculture Board

REMA: Rwanda Environment Management Authority

RENGOF: Rwanda Environmental NGOs Forum

RNRA: Rwanda Natural Resources Authority

SEZ: Special Economic Zone

SNC: Second National Communication on Climate Change under the UNFCCC

SOx: Sulphuric Oxides

TAP: Technology Action Plan

TNA: Technology Needs Assessment

TVET: Vocational Education & Training

UNEP: United Nations Environmental Programme

UNFCCC: United Nations Framework Convention on Climate Change

URC: UNEP Risoe Centre

USD: United States Dollars

FOREWORD

Technology transfer has been under focus since the Rio Summit in 1992, where issues related to technology transfer were included in Agenda 21 as well as in the United Nations Framework Convention on Climate Change.

Technology Need Assessment (TNA) project in Rwanda was intended to produce four main reports notably TNA, Barrier Analysis & Enabling framework, National Technology Action Plans (TAPs) and Project Ideas for each prioritised technology.

The review of the four reports was carried out at different levels. At the national level, the reports were reviewed by the TNA Steering Committee, National TNA Team members and other different stakeholders from the energy and the agriculture sectors. At the internationally level, the review was carried out by experts from Environment et Développement du Tiers Monde (ENDA) and UNEP Risø Centre.

The ultimate goal of these reports is to guide political decision makers and national planners on selected economic sectors with highest vulnerability characteristics to the effects of climate change. They further highlight most appropriate technologies which would support these sectors and the country in general, to mitigate or adapt to the effects of climate change.

On behalf of the Government of Rwanda, I thank all stakeholders from public and private sectors who participated in different consultation and validation meetings held to evaluate the selection and prioritization of the sectors and technologies. Their inputs were invaluable and deeply appreciated. Lastly, I extend my gratitude to the Global Environmental Facility (GEF) for providing financial support. I also thank the UNEP Division of Technology, Industry and Economics, the UNEP Risoe Centre and ENDA for their technical support and guidance.

Caroline R. Kayonga
Permanent Secretary
Ministry of Natural Resources

EXECUTIVE SUMMARY

1. Introduction

Technology transfer has been under focus since the Rio Summit in 1992, where issues related to technology transfer were included in Agenda 21 as well as in Articles 4.3, 4.5 and 4.7 of the UNFCCC (United Nations Framework Convention on Climate Change). Following this, GEF (Global Environmental Facility) was requested to provide funding to developing country Parties. The country Parties would use this funding to enable them identify and submit to the COP, their prioritized technology needs, especially concerning key technologies needed in particular sectors of their national economies. The technologies should be conducive to addressing climate change and minimizing its adverse effects.

It is in this regard that Rwanda, through Rwanda Environment Management Authority, the Ministry of Natural Resources, in collaboration and with support of United Nations Environment Programme Risø Centre (URC), initiated a project entitled Technology Needs Assessment (TNA). TNA Project started officially in March 2011 with the signing of a Memorandum of Understanding between the Government of Rwanda and UNEP Risø Centre. The purpose of TNA is to assist Rwanda to identify and analyze technology needs in mitigation and adaptation to climate change. Such technologies should form the basis for a portfolio of Environmentally Sound Technology (EST) projects and programmes to facilitate the transfer of, and access to the ESTs.

2. Institutional arrangement for the TNA and stakeholders involvement

The organizational structure of the TNA project for Rwanda consists mainly of the National TNA Team and facilitators, with the flow of resources and outputs. The structure of the project is detailed as follows:

- TNA Coordinator: The TNA project is coordinated by the Director of Climate Change and International Obligations Unit in Rwanda Environment Management Authority (REMA) which is a contact Entity. TNA coordinator is assisted by Climate Change Mitigation Officer and Climate Change Adaptation Officer for quality assurance of both mitigation and adaptation components of the reports. The two officers are employees of REMA.

- Sectoral Working Groups: The sectoral working groups have a core constituency and are formed according to the relevance of their job description in their respective institutions with climate change and TNA project. They are able to co-opt additional members on a needs basis. Based on sector prioritization (chap.3), the two working groups are Agriculture and Energy. Each member of a sectoral working group can be consulted using different methodologies including guided interview, group discussion and workshops. Stakeholders were identified according to their expertise, decision making positions, involvement and knowledge of sectors and technologies. A close follow-up was set up through personal contacts and individual meetings in order to ensure the full involvement of stakeholders in the process.
- National Consultants: The bulk of the technical work is carried out by 2 consultants. One is the TNA Consultant on Mitigation (Dr. Museruka Casimir) who has expertise in Mitigation options for Energy sector and TNA Consultant on Adaptation (Mr. Charles Mugabo) who has expertise in adaptation options for Agriculture sector.
- National TNA Committee: The National TNA Committee is the core group of decision makers and includes representatives responsible for implementing policies from concerned ministries as well as members familiar with national development objectives, sector policies, climate change science, potential climate change impacts for the country, and adaptation needs.
- The National Steering Committee provides conducive political environment to the TNA process within the country and is responsible for: Appointment of the National TNA Committee and Political acceptance for the Technology Action Plan. The National Steering Committee is composed of decision makers from the above mentioned institutions represented in the Technical Committees

3. Sector selection

Regarding mitigation, prioritization was based on the last findings in the establishment of the national GHG emissions inventories as published in the Second National Communication on Climate Change in Rwanda which qualifies the energy sector as one of the sectors with high GHG emissions. The energy sector contributes 17% to the total GHG emissions of the country.

Although Rwanda agriculture sector was classified as the first contributor in total GHG emissions with a share of 78%, it was also selected as the Rwanda's' most adaptation sector based mainly on its level of vulnerability to the effects of climate change. Other important reasons for this selection are:

- Its nature of being almost 100% rain-fed,
- a sector which sustains 80% of the Rwandan population lives,
- its highest contribution (34%) to the GNP and
- its highest contribution (71%) to the country's overall export revenues.

In addition, agriculture sector is the main source of revenues for 87% of the population making it the engine of economic growth in the country. Furthermore, previous reports such NAPA and SNC give it the top position as a national adaptation priority sector. Apart from the above discussed criteria, the energy and agriculture sectors are among the most priority sectors in the country's development plans and programs.

4. Technology prioritization

Different criteria have been selected by stakeholders in order to be able to choose the most relevant technology options for the energy and the agriculture sectors previously selected for climate change mitigation and adaptation respectively. Selected criteria for technology prioritization in the energy sector are:

- GHG reduction,
- diffusion and deployment,
- capital cost,
- sustainability of energy resources,
- operation and maintenance costs,
- social and economic benefits,
- national priority,
- efficiency and

- Capacity factor.

Regarding the agriculture sector, selected criteria for technology prioritization include:

- Reduction of adverse impacts of climate change,
- Contribution to socio development,
- National priority,
- Vulnerability of the technology to climate change,
- Ensuring food security and poverty alleviation.

Using multi criteria analysis (MCA) and based on preselected criteria, technologies were prioritized. Listed in their descending order, prioritized technologies are:

- Lake Kivu methane CCGT,
- Small Hydro,
- Geothermal,
- Biogas BTA,
- Solar CSP,
- Peat IGCC,
- Biomass-steam power BSP,
- Peat-bed ECBM,
- Biodiesel BICG,
- Large Solar PV,
- Pumped Storage Hydropower and
- Wind for the energy sector.

Regarding the agriculture sector, first five technology options have been ranked as follow:

- Seed and grain storage,
- Agro forestry,
- Radical terraces,
- Drip irrigation and
- Rainwater harvesting.

Other considered technologies but with a reduced importance in terms of practicability and relevance are: Integrated fertilizers and pesticide management, Biotechnology of crops for climate change adaptation and Sprinkler irrigation for the agriculture sector.

CHAPTER 1: INTRODUCTION

1.1 Background of TNA project

Technology transfer has been under focus since the Rio Summit in 1992, where issues related to technology transfer were included in Agenda 21 as well as in Articles 4.3, 4.5 and 4.7 of the UNFCCC. Following this, GEF was requested to provide funding to developing country Parties. . The country Parties would use this funding to enable them identify and submit to the COP their prioritized technology needs, especially concerning key technologies needed in particular sectors of their national economies. The technologies should be conducive to addressing climate change and minimizing its adverse effects.

The TNA involves amongst others in-depth analysis and prioritization of technologies, analysis of potential barriers hindering the transfer of prioritized technologies as well as issues related to potential market opportunities at the national level. National Technology Action Plans (TAPs) agreed upon by all stakeholders at the country level will be prepared so as to be consistent with both the domestic and global objectives. Each TAP will outline the essential elements of an enabling framework for technology transfer. It will consist of market development institutional, regulatory and financial measures. It will contain human and institutional capacity development requirements and will also include a detailed plan of action to implement the proposed policy measures and estimate the need for external assistance to cover additional implementation costs.

1.2 TNA project in Rwanda

Rwanda ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1998 and became legally a party who is encouraged to adopt and implement policies and measures designed to mitigate the effects of climate change and to adapt to such changes (MINIRENA, 2011). Rwanda Environment Management Authority (REMA) as a regulatory agency is responsible of the implementation of climate policies and measures with respect to the fulfillment of the country's obligations under the convention.

In this regard, Rwanda has developed the National Adaptation Programme of Action to Climate Change (MINIRENA, 2006) and the National Strategy on Climate Change and Low Carbon Development Growth, Economic Cost of Climate Change in Rwanda and National Communications. In these documents, a number of potential projects and activities are identified that Rwanda could undertake or implement that could assist its development process while contributing positively to its response to climate change.

Based on these documents and TNA handbook, TNA in Rwanda will consider priority sectors including Energy (production, distribution, consumption.) under mitigation and agriculture under adaptation (UNDP, 2010). Technology for implementation of activities in the above-mentioned areas and sectors vary in terms of appropriateness and cost. In order to use scarce and valuable resources as efficiently as possible there is a need to do an assessment of available technology and the cost of transfer and diffusion.

The Technology Needs Assessment project, funded by the Global Environment Facility ,managed by United Nations Environment Programme (UNEP) and UNEP Risø Centre (URC), is executed by Rwanda Environment Management Authority through the Ministry of Natural Resources. The project started officially in March 2011 with the signing of a Memorandum of Understanding between the Government of Rwanda and URC.

1.3 Objective of the study

The overall objective of this project is to assist Rwanda identify and analyze priority technology needs, which can form the basis for a portfolio of Environmentally Sound Technology (EST) projects and programmes to facilitate the transfer of, and access to the ESTs and know-how in the implementation of Article 4.5 of the UNFCCC. Hence TNAs are central to the work of Rwanda on technology transfer and present an opportunity to track an evolving need for new equipment, techniques, practical knowledge and skills, which are necessary to mitigate GHG (Greenhouse Gas) emissions and/or reduce the vulnerability of sectors and livelihoods to the adverse impacts of climate change.

The specific objectives thus are:

- To identify and prioritize through country-driven participatory processes, technologies that can contribute to mitigation and adaptation goals of Rwanda, while meeting its national sustainable development goals and priorities (TNA).
- To identify barriers hindering the acquisition, deployment, and diffusion of prioritized technologies.
- To develop Technology Action Plans (TAP) specifying activities and enabling frameworks to overcome the barriers and facilitate the transfer, adoption, and diffusion of selected technologies in Rwanda.
- Develop at least three project ideas and one full project proposal by sector for identified technologies

1.4 Policies and strategies related to development priorities in Rwanda

1.4.1 Vision 2020

The VISION 2020 seeks to fundamentally transform Rwanda into a middle-income country by the year 2020. This will require achieving annual per capita income of US$ 900 (US$ 290 today), a poverty rate of 30% (64% today) and an average life expectancy of 55 years.
The six pillars of Vision 2020 will be interwoven with three cross-cutting issues including protection of environment and sustainable natural resource management.

1.4.2 Economic Development and Poverty Reduction Strategy I (EDPRS I)

Economic Development and Poverty Reduction Strategy I (EDPRS) is the Government of Rwanda's medium-term strategy for economic growth, poverty reduction and human development, covering the period 2008 to 2012. However, the weakness of EDPRS I was the non inclusion of climate change. Therefore, climate change is on top during the mainstreaming in formulation of priorities of EDPRS II (2013-2018).

1.4.3 Millennium Development Goals (MDGs)

The Government of Rwanda (GoR) has expressed its commitment to achieving the Millennium Development Goals. There are eight MDGs with 18 targets and 49 proposed indicators. Most of the targets are set for 2015 against a baseline of data gathered in 1990.
Climate change and environment in general are addressed in Millennium Development Goal Seven (MDG7) which is to ensure environmental sustainability.

1.4.4. Environmental policy in Rwanda

The National Environment Policy established in 2003 sets out overall and specific objectives as well as fundamental principles for improved management of the environment, both at the central and local level, in accordance with the country's current policy of decentralisation and good governance. The policy sets out also institutional and legal reforms with a view to provide the country with a coherent and harmonious framework for coordination of sectoral and cross-cutting policies.

1.5 Policies and strategies related to Climate change priorities in Rwanda

1.5.1 East African Community (EAC) Climate Change Policy

The overall objective of the East African Community Climate Change Policy (EACCCP) is to guide Partner States and other stakeholders on the preparation and implementation of collective measures to address Climate Change in the region while assuring sustainable social and economic development.

1.5.2 National Green growth and climate resilient strategy

This Strategy was developed in 2011 and aims to guide the process of mainstreaming climate resilience and low carbon development into key sectors of the economy. It provides a strategic framework which includes a vision for 2050, guiding principles, strategic objectives, 14 programmes of action (.1Sustainable intensification of small-scale farming; 2.Agricultural diversity of markets; 3.Sustainable land use management; 4.Integrated water resource management; 5.Low carbon energy grid; 6.Small scale energy access in rural areas; 7. Disaster management; 8. Green Industry and private sector development; 9. Climate compatible mining; 10. Resilient transport systems;11. Low carbon urban system; 12. Ecotourism, conservation and payment of ecosystem services; 13. Sustainable forestry, agroforestry and biomass; and 14. Climate predictions), enabling pillars and a roadmap for implementation.

1.5.3 National Communications

Through the climate change project under REMA, Rwanda formulated its Initial National Communication in 2005 and second national Communication in 2011. The third National communication will start soon and it will be coordinated under the Department of Climate change and international obligations in REMA.

National Communication includes the following main parts: National Circumstances; National Greenhouse gases inventory; Measures to facilitate adequate adaptation to climate change; Measures to mitigate climate change; other relevant information to achieve the objectives of the convention (Transfer of technologies, research and systematic observation, Education training and public awareness, capacity building, information and networking) and constraints and gaps, as well as related financial, technical and capacity needs

1.5.4 National Adaptation Programs of Action (NAPA)

National adaptation programs of action (NAPAs) communicate priority activities addressing the urgent and immediate needs and concerns of the least developed countries (LDCs), relating to adaptation to the adverse effects of climate change. In 2006, Rwanda formulated a National Adaptation Programs of Action to Climate Change (NAPA). The NAPA report outlines overall actions, strategies, approaches and priority projects.

1.5.5 Clean Development Mechanism

Through the application of Article 12 of the Kyoto Protocol on CDM, the DNA in Rwanda was created in September 2005. Due to lack of personnel operating budget this institution hosted by REMA was not fully operational until August 2009.
In addition to CDM projects, there are also currently ongoing voluntary carbon market projects in Rwanda. These projects are at various stages of advancement.

CHAPTER 2: INSTITUTIONAL ARRANGEMENT FOR THE TNA AND STAKEHOLDERS' INVOLVEMENT.

Climate change is a cross cutting issue. Therefore, there are a good number of government and private institutions as well as NGOs which intervene in climate change adaptation and mitigation including different Ministries, regulatory authorities, Government Agencies and higher institutions of learning.

2.1 Organizational structure of the TNA project

The organizational structure of the TNA project for Rwanda is shown in figure 3. It consists mainly of the National TNA Team and facilitators, with the flow of resources and outputs as indicated by the arrows defined in the legend. The structure of the project can be detailed as follows:

- TNA Coordinator: The TNA Coordinator is the focal point for the effort and manager of the overall TNA process. This will involve providing vision and leadership for the overall effort, facilitating the tasks of communication with the National TNA Committee members, National Consultants and stakeholder groups, formation of networks, information acquisition, and coordination and communication of all work products.

  The TNA project is coordinated by the Director of Climate Change and International Obligations Unit in Rwanda Environment Management Authority (REMA) which is a the contact Entity. TNA coordinator is assisted by Climate Change Mitigation Officer and Climate Change Adaptation Officer for quality assurance of both mitigation and adaptation components of the reports. The two officers are employees of REMA.
- Sectoral Working Groups: The technical work of technology identification, prioritization and technology action plan development will be carried out at the level of multi-stakeholder sectoral working groups. The sectoral working groups have a core constituency and they are formed according to the relevance of their job description in their respective institutions with climate change and TNA project. They are able to co-opt additional members on a needs basis. Based on sector prioritization (see chapter 3) the two working groups are Agriculture and Energy. Each member of a sectoral working group can be consulted using different methodologies including guided interviews, group discussion and workshops.

- National Consultants: The bulk of the technical work is carried out by a group of 2 consultants. One is the TNA Consultant on Mitigation (Dr. Museruka Casimir) who has expertise in Mitigation options for the Energy sector and TNA Consultant on Adaptation (Mr. Charles Mugabo) who has expertise in adaptation options for the Agriculture sector. The responsibilities of both National consultants are to facilitate the consultation process and to prepare all required reports including TNA Report, barrier analysis and enabling framework report, Technology Action Plan, and two project ideas;

- National TNA Committee: The National TNA Committee is the core group of decision makers and includes representatives responsible for implementing policies from concerned ministries as well as members familiar with national development objectives, sector policies, climate change science, potential climate change impacts for the country, and adaptation needs. The role of the National TNA Committee is to provide leadership to the project in association with the TNA coordinator. However the specific responsibilities include:
- Identifying national development priorities and priority sectors from thereon;
- Deciding on the constitution of sector / technological workgroups;
- Approving technologies and strategies for mitigation and adaptation which are recommended by sector workgroups and
- Approving the Sector Technology Action Plan (a roadmap of policies that will be required for removing barriers and creating the enabling environment) and developing a cross cutting National Technology Action Plan for mitigation and adaptation.

The TNA Committee is composed by representatives from the following institutions: Ministry of Finance and Economic Planning (MINECOFIN), Ministry of Natural Resources (MINIRENA), Ministry of Infrastructure (MININFRA), Ministry of Agriculture and Animal Resources (MINAGRI), Ministry of Trade and Industry (MINICOM), Rwanda Agriculture Board (RAB), Rwanda Development Board (RDB), Rwanda Natural Resources Authority (RNRA), Energy, Water and Sanitation Authority (EWASA), Rwanda Environmental NGOs Forum (RENGOF), National University of Rwanda (UNR), Kigali Institute of Science and Technology (KIST), Private Sector Federation (PSF) and Rwanda Environment Management Authority (REMA).

- National Steering Committee: The National Steering Committee is envisaged as the top most decision making body of the project. In line with TNA handbook recommendations, the National Steering Committee should comprise of members responsible for policy making from all relevant ministries as well as key stakeholders from the private sector. The National Steering Committee provides conducive political environment to the TNA process within the country and would be responsible for: Appointment of the National TNA Committee and Political acceptance for the Technology Action Plan. National Steering Committee is composed of decision makers at Director's level from the following institutions: Ministry of Finance and Economic Planning (MINECOFIN), Ministry of Natural Resources (MINIRENA), Ministry of Infrastructure (MININFRA), Ministry of Agriculture and Animal Resources (MINAGRI), Ministry of Trade and Industry (MINICOM), Rwanda Agriculture Board (RAB), Rwanda Development Board (RDB), Rwanda Natural Resources Authority (RNRA), Energy, Water and Sanitation Authority (EWASA), Rwanda Environmental NGOs Forum (RENGOF), National university of Rwanda (UNR), Kigali Institute of Science and Technology (KIST), Private Sector Federation (PSF) and Rwanda Environment Management Authority (REMA).

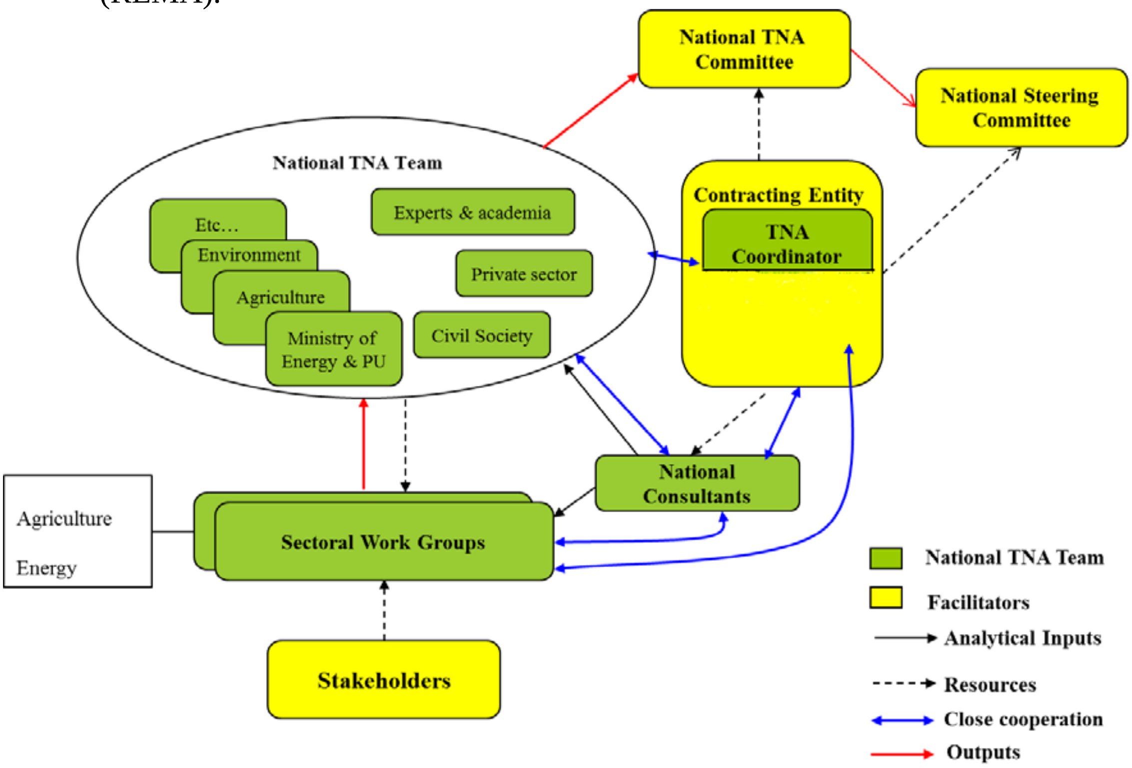

Figure 1: Organizational structure of the TNA project, Rwanda.

2.2 Stakeholder Engagement Process followed in TNA – Overall assessment

Stakeholder engagement process in TNA report has been done at different stages and using different methodologies to ensure an effective consultation. The consultation was conducted during inception and training workshop and guided interviews.

- **Consultation during Inception and training workshop**

In a bid to speed up the implementation of TNA project, REMA, as the implementing agency, convened this training. This training gathered a pool of experts and directors from different government institutions, private sector, NGOs, and National Consultants on TNA who are members of national TNA team (see annex I). The workshop took place at La Palme Hotel, Musanze, from the 3rd to the 5th July 2012. The workshop was conducted by two ENDA facilitators, namely Libasse Ba and Touria Dafrallah in collaboration with the Rwandan TNA Coordinator, Faustin Munyazikwiye from REMA.

The following topics have been covered : Selecting technologies for mitigation & adaptation; Presenting the process of selecting technologies and reporting the outcomes in the TNA Report; Familiarization with database support – Climate Techwiki, Guidebooks and Helpdesk facility; Identifying barriers and inefficiencies by using market mapping and other tools; Identifying activities aimed at overcoming the identified barriers and inefficiencies; Identifying activities to accelerate technology deployment; Developing TAPs describing activities and enabling frameworks to overcome the barriers and facilitate the transfer, adoption and diffusion of selected technologies in the participating countries.

Making reference to the methodology used during this training and the profile of participants, consultation was conducted through the group work/ discussion along the training on each of above mentioned topics. Groups were formed according to the agreed prioritized sectors including Agriculture for adaptation and Energy for mitigation. The results of facilitated group works were the basis of ground work done by National consultants.

- **Guided interviews**

After inception and training workshop, National consultants together with National TNA team identified other relevant stakeholders who can contribute to the exercise of selection of technologies in each priority sector. Identified experts (list in annex II) in both sectors (Agriculture and Energy) were interviewed one by one since the time was not permiting to gather them and discuss in one group. Information provided during those interviews supplemented that given during the inception workshop.

- **TNA report validation workshop**

The present TNA report was validated during a National TNA Committee workshop held on 4th September 2012 at Umubano Hotel, Kigali which was attended by stakeholders from the ministry of: Infrastructure; Agriculture and Animal Resources; Government agencies like Rwanda Environmental Management Authority; Rwanda Natural Resources Authority; Rwanda Agriculture Board; Energy, Water and Sanitation Authority; National TNA consultants; academia like the Kigali Institute of Science and Technology; the Private Sector and NGO's and was facilitated by TNA coordination team at national level.

CHAPTER 3: SECTOR SELECTION

The selection of both mitigation and adaptation sectors was particularly based on the information found in two official documents namely NAPA and SNC under the UNFCCC.

3.1 An overview of sectors, projected climate change and the GHG emission status and trends of the different sectors

The GHG data has been extracted mainly from the inventory of greenhouse gases in Rwanda and previous studies linked to the national communication within the context of climate change mitigation.

For the baseline year 2005, the results from the studies undertaken on the GHG inventory that Rwanda has contributed to the emissions of: 530.88 Gg of CO_2, 71.31 Gg of CH_4, 10 Gg of N_2O, 16 Gg of NO_x , 2,327 Gg of CO, 42 Gg of COVNM and 18 Gg of SO_x (MINIRENA, 2011).

Predictions up to the year 2030 have also been elaborated and graphical results are presented below. For instance for the year 2005, energy sector produced 72% of total CO_2 emissions, 28% of total CH_4 emissions and 3% of total N_2O (MINIRENA, 2011). Within the energy sector, the rate of contribution to CO_2 emission by the transport subsector was about 70% in 2005 i.e about 50% of total CO_2 emission against 30% by the industrial processes.

The PRG100 global warming potential is of course considered for estimation of net contribution of these three main gases to global warming due to among others the greenhouse phenomenon. Therefore the total net GHG direct emissions (CO_2, CH_4 and N_2O) presented in the table below will be respectively affected by the coefficients 1; 21 and 310 (MINIRENA, 2011). Thus and within such conditions, direct emission are equivalent to 530.388 Gg (i.e. 10%), 1471Gg (i.e. 29%) and 3100 Gg (i.e. 61%) respectively for CO_2, CH_4 and N_2O.

Table 2. Trends in GHG Emissions

Emissions [Gg]	**2003**	**2004**	**2005**	**2006**
DIRECT GHG				
Total Carbon Dioxide [CO_2]	442.37	483.89	530.88	**601.05**
Industrial Processes	145.118	148.47	150.52	153.91
Energy	307.19	335.42	380.36	447.14
Total Biomass	6747.19	6983.35	7227.6	7493.68
Total Methane [CH_4]	64.27	68.75	71.31	**74.1**
Energy	18.54	19.19	19.86	20.6
Agriculture	43.5	47.1	48.9	50.7
Waste	2.23	2.46	2.55	2.8
Total Nitrous Oxide [N_2O]	3.53	7.93	9.83	**11.73**
Energy	0.24	0.25	0.26	0.27
Agriculture	3.2	7.6	9.5	11.4
Land use, land use change and forestry	0.09	0.08	0.07	0.06
INDIRECT GHG				
Carbon Monoxide [CO]	1963.08	2006.76	2327	2652.482
Nitrogen Oxide [NO_x]	15.316	15.217	16.008	16.799
NMVOCs/COVNMs	38.96	40.37	41.78	43.57
Sulfur Oxides [SO_x]	16.6	16.94	18.07	18.48

Source: MINIRENA, 2011

The total GHG emissions, direct (CO_2, CH_4 and N_2O) as well as indirect ones (CO, NO_x, NMVOC and SO_x) regularly increased between 2003 and 2006 as indicated in the figures below for the CO_2. The increase rate for emissions is about 37 Gg per year.

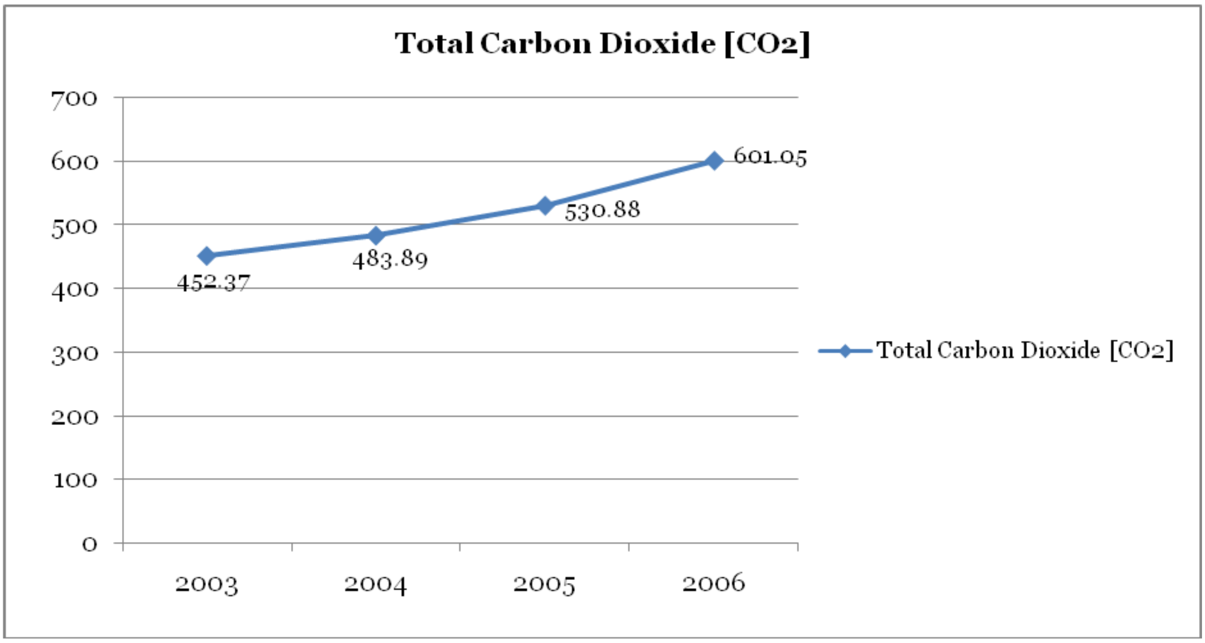

Figure 2. Total CO_2 emissions [in tonnes/year]

While such emissions seem to be a small amount, the speed of increase is itself expected to increase as far as the development priorities in Rwanda are requiring higher amount of energy resources for the supply to key economic sectors: industry, transport and mainly electric and heat sub-sectors. But the carbon sequestration and natural absorptions are expected to continue to contribute in a favourable balance via photosynthesis. This is a natural and crucial phenomen associated to, among others, the absorption of CO_2 for the production of hydrocarbon components resulting in further wood fuels. Such a sort of cycle for the carbon dioxide is playing a great role in natural transfer of such a gas and its sequestration.

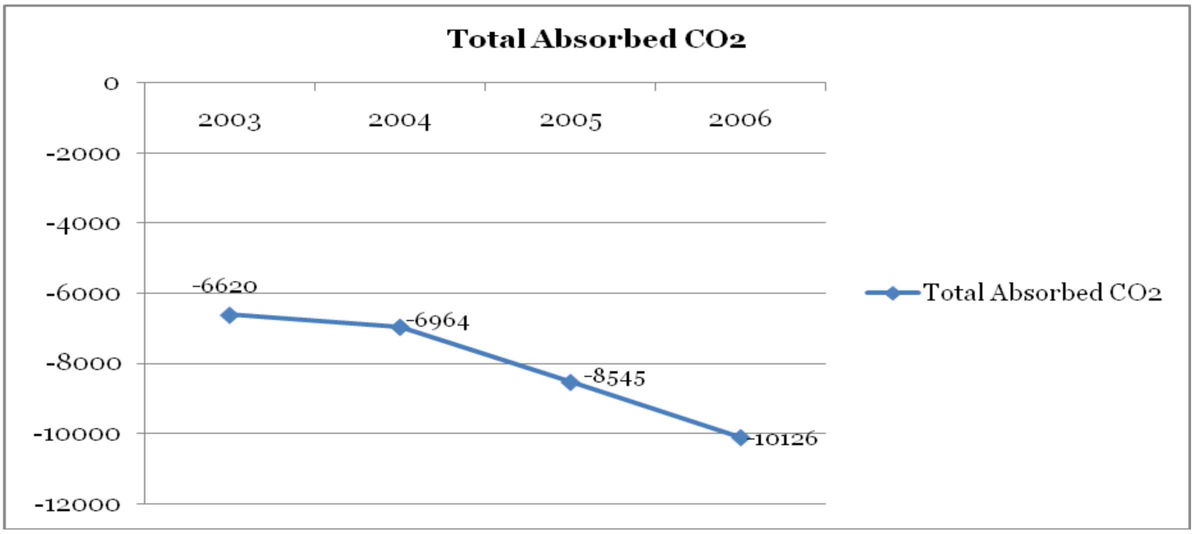

Figure 3: Natural absorption of carbon dioxide from atmosphere

With reference to such a cycle of carbon dioxide and the role of biomass considered as an important source of energy especially in a country like Rwanda where it contributes up to about 90 percent of total energy needs, the energy sector is an important contributor to the total CO_2 emissions. It is also playing a significant role in emissions of other pollutants and greenhouse gases. Taking into account the CO_2 sequestration, the net balance is favourable for Rwanda. The real impact of using charcoal and wood fire is deforestation and related consequences of environmental degradation and indoor pollution effects.

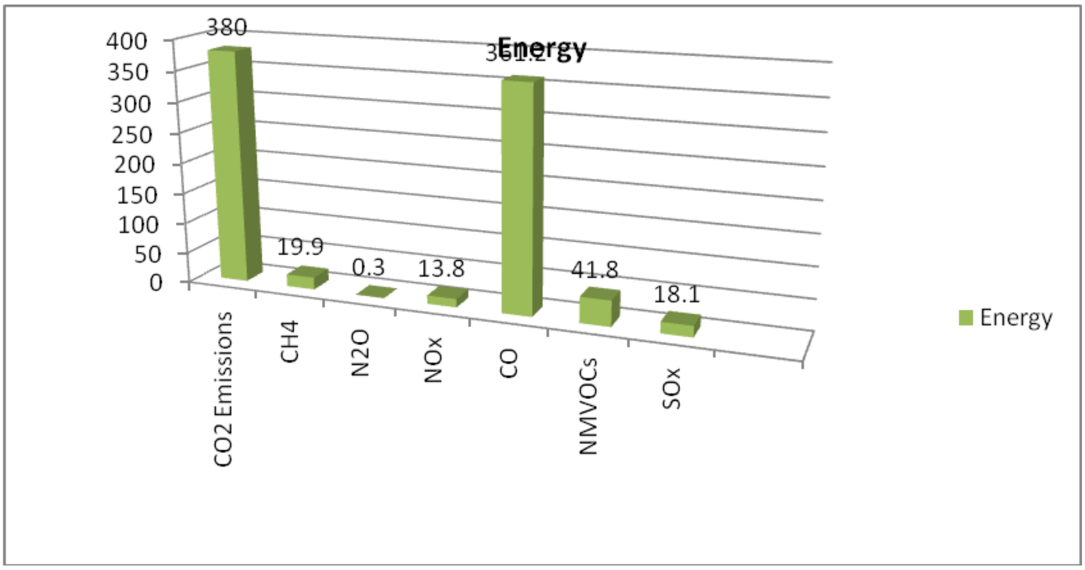

Figure 4: The total GHG Emissions [in Gg] for the Energy Sector in 2005

In order to consider the individual irradiative forcing effect, the above results can be converted into CO_2 equivalent, in fact the GWP (global warming potential) is 1, 21 and 310 respectively for CO_2, CH_4 and N_2O. Thus the total for direct GHG emissions is 891Gg CO_2eq in year 2005 by the energy sector.

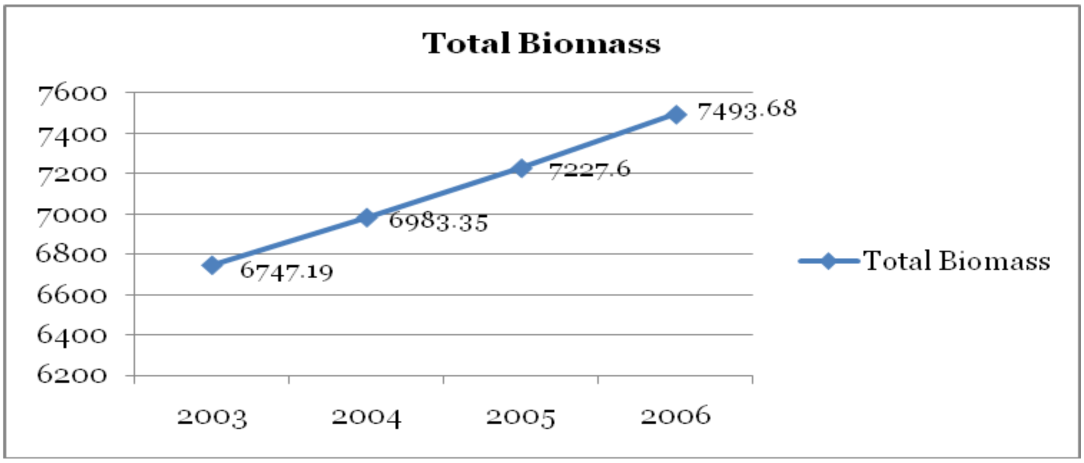

Figure 5. Total CO_2 emissions [in tonnes] from Biomass

Energy sector

- **Assumptions**

The rate of access to electricity services within the context of climate change mitigation projected to the year 2030 is about 60% in rural areas (i.e. 36% of the total population) and 100% in urban areas. The urbanization is estimated at 60%, for a population of 18.5 million. The number of households with electricity connection is expected to be 3 522 000 in 2030.

- **Cooking**

Table 2. Different energy sources used for cooking (the year 2030 projections)

SN	Energy Resource		Urban [40% of Total Population]	Electrified Rural [36% of Total Population]	Non Electrified Rural [24% of Total Population]	Total for the energy consumption in Rwanda
S1	Charcoal	Percentage of users	20%	10%	5%	12.8%
		Annual Consumption /household	420 kg	420 kg	420 kg	
		Total	118355 tonnes	53260 tonnes	17753 tonnes	189368 tonnes
S2	Wood	Percentage of users	10%	10%	35%	16%
		Annual Consumption /household	1600 kg	1600 kg	1600 kg	
		Total	225408 tonnes	202867 tonnes	473357 tonnes	901632 tonnes
S3	Gas	Number of users Percentage of users	50%	70%	60%	59.6%
		Annual Consumption /household	300 litres	300 litres	300 litres	
		Total	211.32 megalitres	266.25 mega-litres	152.14 megalitres	629.7 megalitres
S4	Electricity		20%	10%	00%	11.6%
		Annual Consumption /household	9 125 kWh	9 125 kWh	0	
		Total	2571GWh	1157 GWh	0 GWh	3728 GWh

Total	Percentage of users	100%	100%	100%	100%

Source: MINIRENA, 2011

In 2030, the total annual consumption of charcoal is expected to be 189368 tonnes i.e. 6249 GJ against 901632 tonnes (14.4 million of GJ) of wood fuel, while the total gas and electricity are respectively 630 mega-litres and 3728 GWh. Such an above scenario shows that the CC mitigation linked to the charcoal and wood fuels seems to be crucial. Given that carbon sequestration is resulting in a favourable balance (emissions lower than absorptions), reduction in charcoal and wood fire use is expected to contribute to the stability of forests and other ecosystems. There is hence a great need of increasing substantially electricity generation even towards a scenario of full electrification both for urban and rural areas instead of having, for instance in year 2030, a fraction of rural population without access to electricity.

Regarding the cooking energy sources, about 12.8%, 16%, 59.6%, and 11.5% of total population are expected to use charcoal, wood, gas and electricity respectively. In order to guarantee the availability of at least 50 litres of gas and 1737 kWh of electricity per-capita and per year in the context of limiting the use of charcoal to 80 kg per-capita and wood fuel to 305 kg per capita, great efforts have to be focused on both gas production (biogas, Kivu methane) and on electricity generation.

In fact, “an important reduction in the use of wood fuel and charcoal shall lead to a clear decline” of total GHG emissions from the year 2005 in Rwanda (MINIRENA, 2011). The above observations influenced our focus on energy sector in line with Climate Change mitigation for further CDM opportunities.

As mentioned above, the use of wood and charcoal will continue to contribute to deforestation and land degradation. During recent decades, Rwanda has experienced an important decrease in forest cover as shown by the facts below:

- the Nyungwe forest cover, located in the South-Western part of Rwanda, decreased on an average of 750 hectares per year between 1958 and 1977;
- the volcano national park in the North-West lost 700 hectares to the advantage of human settlement and 1050 hectares were converted to agricultural land;

- the Gishwati forest also in the west decreased from 28 000 hectares in 1960 to 700 hectares in 2005;

- Akagera National Park in the East lost about a third of its original size in 1997 (MINIRENA, 2011).

- **Lighting**

During the year 2004, the main sources of energy for lighting was provided through traditional and artisanal micro-lamps for 64% of households, wood for 17.5% and kerosene lamps for 10.2 % over the whole country. It is important to remember that the use of such sources of lighting is not limited to the non-electrified areas. In fact, in Kigali city, at that time, only 36.6 % of households were using electricity (MINECOFIN, 2005).

The main sources of energy targeted for electric power generation are expected to be more focusing on hydropower, Lake Kivu methane gas, geothermal, solar and peat. In fact, the mitigation scenarios will take into account the application of carbon capture and sequestration:

- The carbon dioxide associated with the exploitation of Kivu methane is re-injected in water 90 m deep;
- The peat-fired steam technology is part of the national priority in the power sector and appropriate mitigation measures are required.

Such an approach based on the objective of “getting rid of thermal electric power production and replacing it by clean energy alternative”, is in line with the goals of the TNA project and will influence our process of selecting the recommended technologies of electricity sub-sector.

Industry sector

- Projections on the CC mitigation for industry sector in addition to different institutions, services and business companies are based mainly on the substitution of wood fire and charcoal by biogas, Kivu methane gas, best performing furnaces and electricity. New technologies like thermal solar and solar concentrators can be also introduced. The sequestration of carbon is also expected through reforestation.
- According to the latest Second National Communication under the UNFCCC, increased GHG emissions are forecast as follows via the scenario of business-as-usual in Rwanda for oil fuel (9 225 tonnes in year 2005 and 19 315 tonnes in 2030. i.e. about 2 times more) and for wood (337 Gg in year 2005 and 529 Gg in year 2030)

- The CC mitigation projections suggest a production of methane gas fuel and biogas respectively estimated at 28.7 Gl (i.e. 1 Gl = 1 km^3) and 121.4 Gl (MINIRENA, 2011).

Transport sector

The contribution of the transport sub-sector to the total of 530 Gg of CO_2 emission was in year 2005 about 50% against 28% by industrial process and 22% by electricity sub-sectors. About 70% of total imported gasoline and diesel fuels are consumed by the road transport sub-sector

Like the industry sector, the transport sector is expected to contribute more and more in GHG emissions. For instance, in case of CO_2 emission, from 2015 to year 2030, emissions from the transport sector will increase from 17 Gg to 1676 Gg against 569 Gg and 938 Gg by the industry sector (MINIRENA, 2011). Given that these GHG emissions are linked to the energy for transport and industry sectors, we consider these two latter as sub-sectors of energy sector.[1]

Projected Climate Change Mitigation

The Government vision expects that by 2020 Rwanda would have reduced the quantity of wood used as a source of energy from 90% to 40%. Within the framework of 2020 vision, and especially in the government's recent PRSP, some objectives have been adopted to ensure a growth rate of energy consumption of 9.6% per year, to ensure a rural electrification rate of 30% and to enable the population from 6% to 35% to have access to electricity. The hypotheses of GHG emissions mitigation in the industry sector are based on the following energy alternatives:

- The substitution of fossil fuel by Kivu Lake methane gas,
- The substitution of one quarter of firewood used in institutions by biogas
- Installation of furnaces with high energy performance and
- Reforestation to increase the quantity of firewood and the size of forest cover to sequestrate greenhouse gas emissions.

Figure 6 below shows a variation from 2005 to 2030 linked to GHG baseline and mitigation scenarios for the energy sector demand based on three sub-sectors (households, industry and transportation) as well as the energy transformation. A specific method provided different results from those presented in table 1. But it is important to remember that such gaps among

[1] Due to a relatively short time allocated to our consultancy activities, our study has been limited to three sub-sectors of energy:

results from different models in forecasting cannot influence the information and findings about the increase in GHG emissions for the scenario of business as usual. The baseline is in fact a reference, and can even be taken as arbitrary.

In the business-as-usual case, GHG emissions can reach an amount of 3 352 Gg in year 2030; the climate change mitigation projects, once implemented, can result in a significant decrease from 2 034 Gg in year 2005 to 1 376 Gg in year 2030.

Below in figure 6, the effects of a potential mitigation are shown and a significant decrease in GHG emissions is expected at local level in Rwanda at an average rate of about 25 Gg every year against an increase rate of about 50.7 Gg per year in case of the scenario of the business-as-usual.

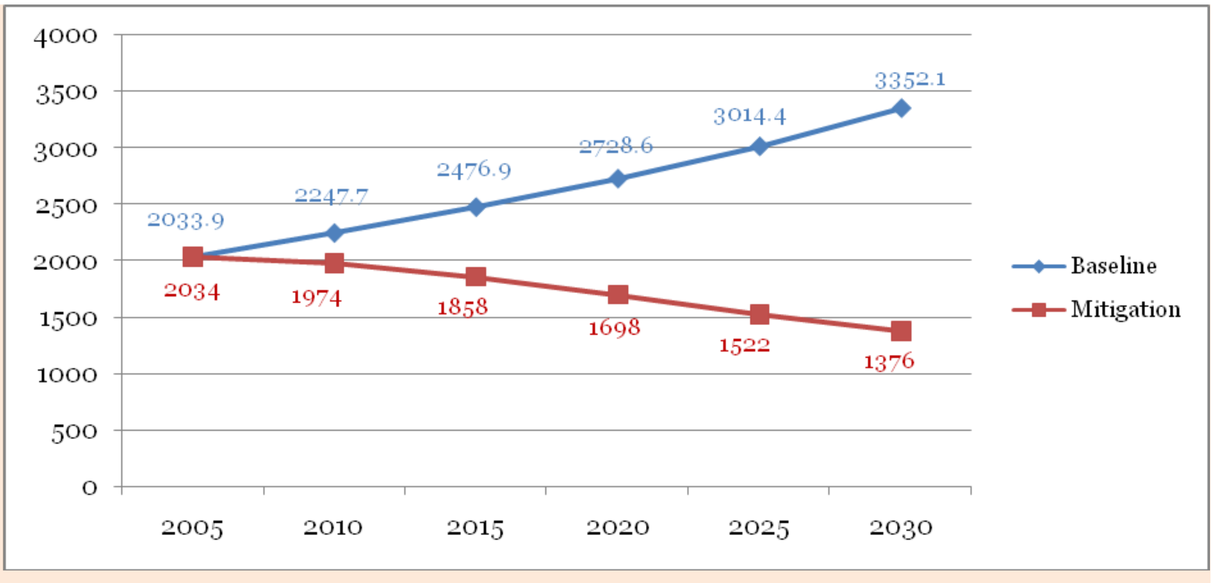

Figure 6. Total Emissions [in Gg CO_2eq] for Energy Demand

3.2 An overview of expected climate change and impacts, sectors vulnerable to climate change

With reference to the results on climate change situation analysis as published in the NAPA report, climate change was observed through following phenomenon:

The Inter-annual variability and abnormalities of rainfall, variability and abnormalities in ambient temperatures and extreme variability in surface water levels (great lakes). The same report presented climate change impacts which included: Occurrence of extreme phenomena such as draughts and floods which would have negative influence on agricultural production thus compromising food security and exposure of resources/infrastructures to the same climate risks.

For example prolonged seasonal drought, recurrent drought on two or three successive years as well as low precipitations have an important impact of spatial area of 1000 km^2, leading to a loss of 1000 lives, economic losses of 1.000.000 FRW/capita among the affected population. The occurrence tendency of these events is very important and of high frequency.
In particular intense rains coupled with short droughts (dry spells) alternating with low precipitations in rainy seasons also present a recurring risk with localized impacts in an area of 100 km^2, a loss of 100 human lives and economic losses of 100.000 FRW/capita among the affected populations. The occurrence tendency of these events is considered as average but of high frequency. Different sectors are expected to be affected by climate change in Rwanda, these include but not limited to:

Water resources

Prolonged droughts episodes affected water resources through the decrease of surface water levels resulting in low river flows and disturbance of hydraulic cycle in general and loss of aquatic fauna in some areas. For example, hippopotamus deaths were recorded in the Gabiro-Akagera valley in 1999-2000 due to general decrease of water levels as a result of prolonged dry seasons.

Agriculture

Rwandan agriculture is still rain fed which makes it highly vulnerable to the effects of climate changes especially droughts which threatened agriculture production and led to the proliferation of crop parasites. In fact, the eastern region of the country recorded fluctuation in production through decreasing yields in banana, maize and beans in 1999-2000. Also, erosion resulting from heavy rains and floods becomes an important factor for low agricultural production and food insecurity.

Forestry

Forestry is also vulnerable to indirect effects of prolonged droughts as this increases the possibility of having wild fires thus limiting the overall forest production potential.

Health

Vulnerability of the health sector is associated with proliferation of mosquitoes and diseases of water-borne origin (malaria, diarrhea, etc) resulting in loss of human and animal lives.

Infrastructures

Heavy rains and flood result in destruction of anti erosive systems, destruction of economic infrastructures (roads, bridges, schools, hospitals, houses, etc.).

Ecosystems

Vulnerability issues in ecosystems include: Problems related to water pollution and invasion by aquatic pollutants and plants (toxic products, water hyacinth), loss of soil fertility by leaching of arable lands, increase of sediments on arable land at the outlets of slopes, local risks of landslides, risks of irreversible land leaching, soil erosion and degradation, intensive silting in rivers, lakes and other water reservoirs.

3.3 Process, criteria and results of sector selection

The identification and selection of the mitigation and adaptation sectors took place during the TNA inception workshop at la Palme Hotel from 3rd to 5th July 2012 in Musanze, Northern Province-Rwanda. It was attended by 24 people, representing ministries, government and non-government organizations, intergovernmental organizations, academia and the private sector. The workshop was facilitated by two experts from ENDA Mr Libasse and Mrs Touria, the inception meeting was conducted with the National TNA coordinator as the moderator. Through an open discussion between participants/stakeholders with more clarifications and orientations from ENDA experts, sector selection criteria were set for both mitigation and adaptation sectors.

For mitigation sector, prioritization was based on last findings in the establishment of the national GHG emissions inventories as published in the Second National Communication on Climate Change in Rwanda which qualifies the energy sector as one of the sectors with high GHG emissions. The sector contributes 17% to the total GHG emissions of the country.

Although Rwandan agriculture sector was classified as the first contributor in total GHG emissions with a share of 78%, it was also selected as the Rwanda's' most adaptation sector based mainly on its level of vulnerability to the effects of climate change. Other important reasons for the selection of the Agriculture sector are:

- Its nature of being almost 100% rain-fed,
- A sector which sustains 80% of the Rwandan population lives,
- Its highest contribution (34%) to the GNP and
- Its highest contribution (71%) to the country's overall export revenues.

In addition, agriculture sector is the main source of revenues for 87% of the population making it the engine of economic growth in the country. Furthermore, previous reports such NAPA and SNC gives it the top position as a national adaptation priority sector. Apart from the above discussed criteria, the energy and agriculture sectors are among the most priority sectors in the country's development plans and programs.

CHAPTER 4: TECHNOLOGY PRIORITIZATION FOR THE ENERGY SECTOR

4.1 GHG emissions and existing technologies in the energy sector

4.1.1 Biomass

Biomass fuel (wood fire and charcoal) for urban and rural populations, industry sector and institutions covers about 94% of national energy needs. Average increase in consumption of wood fuel is about 162 982 tonnes per year.

Table 3: Wood consumption and projection (tonnes per year)

Year	2005	2006	2007	2008	2009	2010
Fuel wood (urban areas)	81,916	86,831	92,041	97,564	103,417	109,622
Fuel wood (rural areas)	2,805,431	2,871,907	2,939,317	3,007,623	3,076,787	3,146,761
Wood for charcoal (urban areas)	1,643,655	1,732,734	1,836,698	1,946,900	2,063,714	2,187,537
Wood for charcoal in rural area	123,409	126,333	129,298	132,303	135,346	138,424
Wood for industries/ institutions	336,652	344,629	352,718	360,915	369,214	377,611
Total	**4,982,063**	**5,162,434**	**5,350,072**	**5,545,305**	**5,748,478**	**5,959,956**

Source: REMA, 2009

4.1.2 Petroleum products

The petroleum products are all imported and, in addition to their high contribution to pollution via GHG emissions into the atmosphere, are very expensive. With reference to table 4 below, the average increase in consumption was 1,536 tonnes/year from 2002 to 2006 (REMA, 2009).

About 42 % of the electricity produced in Rwanda is produced by diesel generators. However, the transport sector remains the main fuel consumer (about 70% of all imported petroleum products). The Table presents the progressive distribution of petroleum products imports during the period of 2002-2006 (REMA, 2009).

Table 4: Evolution in the importation of petroleum products 2002-2006 (tonnes)

Year	**2002**	**2003**	**2004**	**2005**	**2006**
Gasoline for vehicles	39,506	41,114	42,818	43,441	50,342
Fuel for airplanes		2 .67	1,114	15,632	17,914,9
Diesel	26,145	28,357	43,701	57,818	79,394
Kerosene	13,543	16,818	16,698	25,327	19,259
Fuel oil	11,550	14,823	14,736	15,794	18,534
Liquefied Petroleum Gas	0.65	237	215	310	0
Total	**90,745**	**101,349**	**118,168**	**142,690**	**167,528**

Source: REMA, 2009

4.1.3 Hydropower and diesel plants

Since 2004 the production of hydroelectric power has declined and this power loss was compensated by thermoelectric power to reach 44 MW of current demand. Note that domestic production of electricity is around 70%, import 29%, export 1%.

The table below is an electricity balance from year 2005 to year 2009. The annual rate of increase is about 22 077 MWh/year, such an additional annual electric demand is proving that energy production has to be regularly increased every year. Instead, during many years in Rwanda, the electricity capacity remained stagnant and investment remained poor.

Table 5: Electricity production, importation and exportation (kWh) from 2005 to 2009

Total Production (kWh)electric	**2005**	**2006**	**2007**	**2008**	**2009**
	115,856,932	**168,699,973**	**165,448,004**	**194,473,021**	**248,318,483**
Gihira(hydro1.8MW)	5,908,750	6,029,050	7,196,241	6,430,650	5,666,000
Gisenyi (hydro)	4,380,560	3,814,850	5,590,620	6,425,190	1,219,631
Jabana (diesel)	25,397,799	19,237,640	11,029,740	5,122,100	16,325,766
Gatsata (diesel)	14,071,873	1,184,000	1,979,000	0	73,866,951
Rental POWER I	10,653,130	82,256,473	79,214,470	78,203,264	73,866,951
Rental POWER II Mukungwa		27 594 260	30 726 706	38 733 648	42 820 811
Ntaruka (hydro)	15 350 620	5 703 000	5 528 000	15 095 700	29 413 000
Mukungwa (hydro)	40 094 200	22 880 700	24 058 944	44 153 377	62 599 700
Solar PV Energy Jali			124 283	309 092	362 917
Gaz Methane	0	0	0	0	3 311 590
Exportation	**1 822 661**	**2 033 200**	**2 146 300**	**2 154 950**	**2 914 851**
Cyanika-Gisoro	1 806 552	2 033 200	2 144 300	2 108 950	2 622 837
Mururu Ii	0	0	0	20 000	94 220
Goma (Elgz)	16 109	0	2 000	26 000	197 794
Importation	**89 098 300**	**64 097 400**	**80 517 740**	**84 688 127**	**62 386 306**
Rusizi I (Snel)	20 891 800	20 528 400	19 792 640	20 186 127	14 337 080
Rusizi II (Snelac)	64,564,000	40,784,000	60,051,600	64,258,000	47,488,000
Kabale (Ueb)	3,594,337	2,785,000	673,500	244,000	475,500
Goma(Snel/RDC)	48,163	0	0	0	125,726

Source: NISR, 2010

The above power plants are either hydropower (Gisenyi/1.2MW, Ruzizi/SNEL: 3.5MW, Rusizi /SINELAC: 12MW, Ntaruka/11.7MW, Mukunngwa/12.5MW) or based on thermal /diesel power technologies (Jabana /7.8 MW, Gatsata/6.6MW, rental POWER I at Kigali/Gikondo/10 MW and rental POWER II at Mukungwa /5MW). Exportation and importation only concerns electricity energy through interconnected lines with UEB/Uganda, SNEL/Rep. Dem. Congo and SNELAC/Burundi/Congo/Rwanda.

In addition to the main existing hydro-electricity production, the Ministry of Infrastructure has developed a Micro Hydro Atlas that has identified all potential sites for small hydro power plants. About 333 such sites have been identified. In March 2012, a tender was announced for 109 sites for a total potential capacity of about 9 MW. Studies and construction works for some of these sites have been undertaken and are at different stages of implementation.

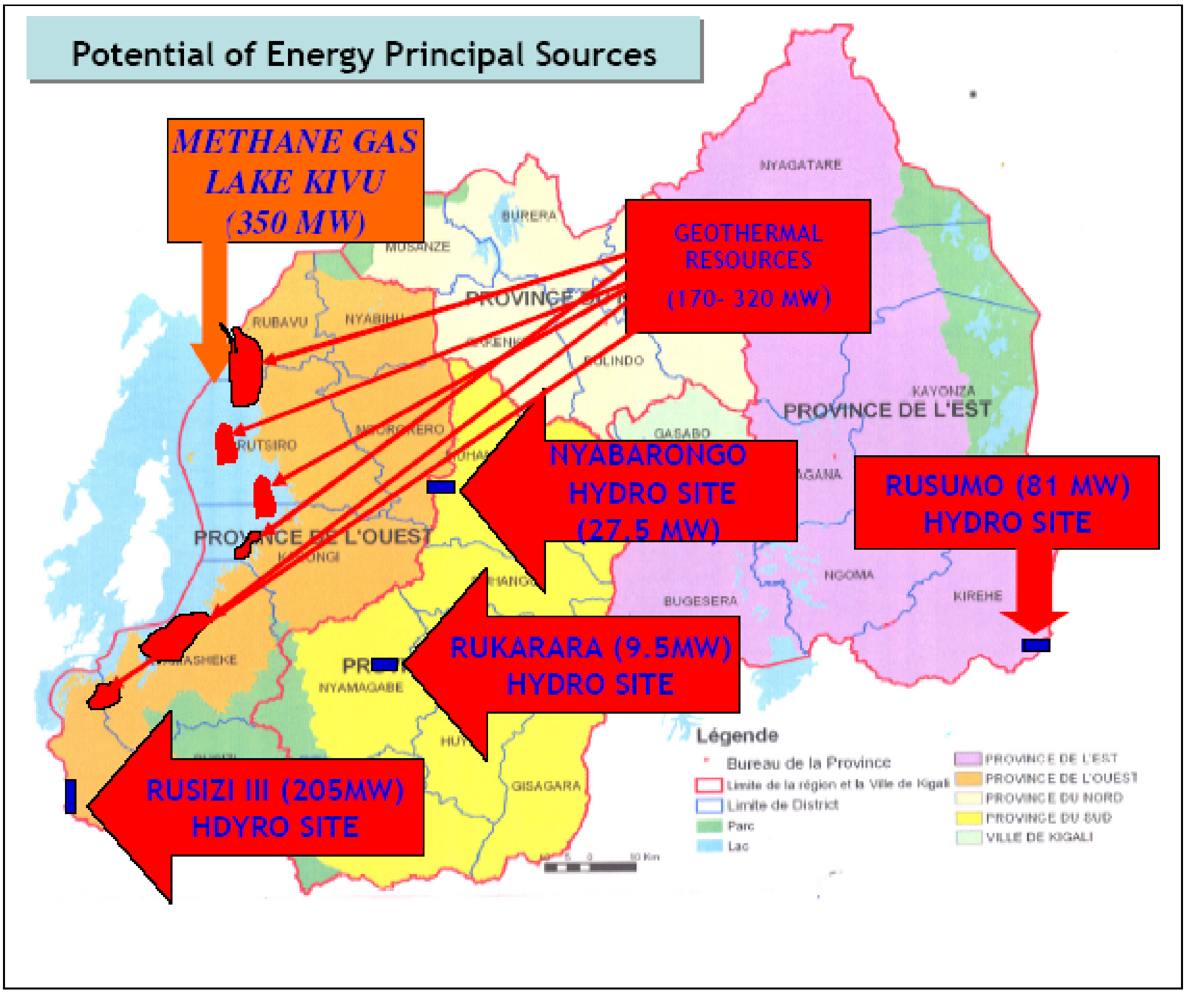

Figure 7: Power generation source and potential around Rwanda

The Rwanda potential of main energy resources is estimated as follows:

- ✓ Hydropower: 350MW
- ✓ Methane gas: 55 billion Nm^3 with a rated capacity of 700 MW
- ✓ Geothermal power: 170-340 MW
- ✓ Solar power energy: 5.2 kWh/day/m^2 for the global solar radiation, and 4 to 6 kWh/day.m^2 for the direct normal solar component which can be tracked for optimization.
- ✓ Peat reserves which are about 155 million tonnes of dry matter

As indicated in the atlas of energy in Rwanda, some important projects of hydropower are shared with Burundi and Democratic Republic of Congo for the case of Rusizi river and with Burundi/Tanzania for Rusumo on the Akagera river.

4.1.4 Methane gas

One of the biggest inputs into the electricity grid in the near future will be power generated from methane gas extracted from the bottom layers of Lake Kivu. It is estimated to contain about 55 billion m^3 of dissolved methane gas (MININFRA 2009b). Lake Kivu offers the best alternative for energy because of its relatively low construction cost and low estimated operating costs and is a key government priority. The first efforts to utilize the methane deposits were undertaken in the late 1950s with 1.5 million cubic meters of gas being supplied annually to the nearby BRALIRWA Brewery in Rubavu District. The plant was shut down in 2004.

According to a rough estimate, the methane potential in the Lake is equivalent to 40 million tonnes of oil equivalent, meaning that an estimated 700 MW can be produced by power plants continuously at least over a period of 55 years for an extraction rate of one billion cubic meters of methane per year. Prior to current efforts to extract methane gas, extensive studies were conducted to evaluate potential environmental impacts and these included evaluation of leakage levels that would potentially contribute to global warming (MININFRA 2003).The results of studies have guided the equipment design and other social and environmental management measures in the area. In 2009, the methane gas power plant installed at Lake Kivu produced 3,331,590 kWh.

4.1.5 Peat

Rwanda has peat reserves estimated at 155 million tonnes and therefore has the potential to replace wood, charcoal and fuel oil (MININFRA 2008b). It is estimated that about a third of resources is commercially extractable and can be used for direct use as source of heat or for production of electricity. While power production from peat is still in a planning stage, the use of peat as burning fuel has already been tested in community institutions, for brick production and in the cottage industry (MININFRA 2009a). However the environmental impacts of commercial exploitation will need to be considered before any substantial use of peat as a realistic energy alternative.

4.1.6 Geothermal

Rwanda possesses geothermal resources in the form of hot springs along the belt of Lake Kivu with a power generation potential of about 170-340 MW. Preliminary technical exploration studies are currently being conducted.

4.1.7 Wind

The potential of wind as a source of energy is currently being investigated. A national wind atlas is going to be developed with support from the Belgian Government. Available results proved that wind velocity at about 40 meters above ground surface is 3.4 m/s at Kibungo site/ Ngoma district in the South-East, 4m/s at Kayonza East, 3.4m/s in North-East, 2.3m/s in the North at Byumba / Gicumbi district and 3.1m/ in the South-West.

4.1.8 Solar

Using meteorological models and daily sunshine duration data covering 20 years, an assessment of Global solar radiation over Rwanda (C. Museruka and A. Mutabazi, 2007) has been conducted and resulted in the following:

- The minimum average value is 4.3 kWh/m^2/day;
- The maximum average value is 5.2 kWh/m^2/day;
- The annual mean values for selected sites are: Kigali (4.70 kWh/ m^2/day), Gabiro (4.60 kWh/ m^2 /day), Karisoke/Ruhengeri (4.54 kWh/m^2/day), Gikongoro/Nyamagabe (4.70 kWh/ m^2/day) and Karama/Bugesera (4.74 kWh/ m^2/day).

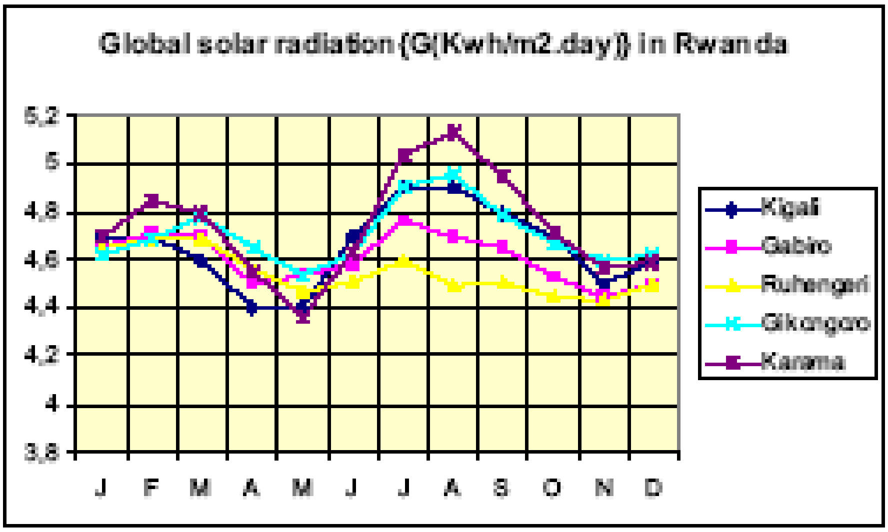

Figure 8: Global Solar radiations in Rwanda (kWh/m^2/day)

The solar plant mounted at the peak of Mount Jali with an installed capacity of 250 KW is the largest PV project in Rwanda. Power produced by the plant has been connected to the national grid. The solar system is jointly owned by a German utility company, Stadtwerke Mainz and the City of Kigali.

Regarding the application and development of the concentrated solar power CSP technology, there is a great need in establishing both an atlas for the global solar radiation and the tractable direct normal solar resources used as an input in solar concentrators i.e. at high temperatures exceeding 400 °C.

4.1.9 Biogas

A National Domestic Biogas Program is in place, aiming at construction of 15, 000 biogas digesters, with support from the Netherlands Government and the Germany Technical Cooperation. The beneficiaries shall be households with at least two cows. Gas for cooking and lighting is to be produced.

4.1.10 Prospect for oil exploration in Rwanda

Rwanda has recently registered an increased interest in oil exploration - especially in the western Rift Valley of the country. The motivation is the recent oil discovery in the northern part of the Rift Valley in Uganda. The presence of methane gas dissolved in the deep waters of Kivu, which originates partly from the earth crust, is interpreted by some experts as an indication of a probable oil presence below the Lake sediments. Area under preliminary survey is the western part of Rwanda along Lake Kivu, covering 1631 km^2. After studying existing literature, the consultant Van Gold embarked on a satellite study of the lake that suggests that there are a number of oil seeps on the surface of Lake Kivu.

4.2 An overview of possible mitigation technology options for the energy sector and their mitigation benefits

4.2.1 Pre-selected technology options for the electricity sub-sector

With reference to the data adapted from studies and results of an assessment by the ESMAP/World Bank in the year 2007, we present below indicative costs for different pre-selected technologies of electricity energy sub-sector potentially applicable in Rwanda as discussed shown in Table 6 below.

Table 6. Year 2005 power technology option of comparative generating costs

Technology	**Rated Output [MW]**	**Levelized Capital Cost** [US Cents/kWh]	**Average Total generating Cost** [US Cents/kWh]
Solar PV	5	40.36	41.57
Wind	10	5.85	6.71
Solar-Thermal with Storage	30	10.68	12.95
Solar-Thermal without Storage	30	13.66	17.41
Geothermal Binary	20	5.02	6.72
Geothermal Flash	50	3.07	4.27
Biomass Gasifier	20	3.09	7.02
Biomass Steam	50	2.59	5.95
MSW/Landfill Gas	5	4.95	6.49
Mini-Hydro	5	5.86	6.95
Large-Hydro	100	4.56	11.01
Pumped Storage	150	34.08	34.73
Bio-diesel [2]	50	0.91	9.25
Fuel Cell/(only renewable[3]	5	5.59	14.36
Combustion Turbines Natural Gas with CCS	150	5.66	13.08

[2] Such non renewable option are expected to be associated with systems of carbon capture and sinks
[3] Only renewable scenarios are recommended: Solid oxide fuel cells, polymer electrolytes, molten carbonates

Combined Cycle Natural Gas	300	0.95	5.57
Peat IGCC (without FGD & SCR) with CCS	300	1.76	5.39
Peat AFBC (without FGD & SCR) with CCS	300	1.75	4.11
Advanced Oil combined cycle /Steam[4] with CCS	300	1.27	7.24

Source: ESMAP, 2007

[4] Based on the double objective of climate change mitigation and socio-economic development, any application of non renewable option has to consider additional systems of carbon sinks and capture

Table 7. Comparison for Forecasted initial capital costs for some possible mitigation technology options in Rwanda

SN	Technology Name	Technology Symbol	Energy Cost [USD cents/kWh]	Initial Capital Cost [USD/kW]
1	Large Solar PV (5 MW or more)	PV	42	5500
2	Pumped Storage Hydropower	PSH	34	3050
3	Concentrated Solar Power (with Molten Salt Storage System)	CSPm	17	3820
4	CSP without Storage	CSPw	13	1960
5	Mini Hydropower	MHP	7	2250
6	Wind Turbine	WT	6.7	2300
7	Geothermal Binary	Geoth	6.7	3730
8	Biomass Steam; DLE; Waste to Energy	BST	6.5	1520
9	Combined Cycle Gas Turbine	CCGT	6	420
10	Peat -Fired Steam Turbine	CST	5	1050
11	Oil-Fired Steam Turbine	OST	7	800
12	Biodiesel	Gen	9.2	550
13	Natural Gas Combustion turbine[5]	CT	13	420

[5]Even though such a technology can be improved through an increase of efficiency by means of CHP (Combined Heat Power, we have just included it on our list for purpose of cost comparison as far as it is the cheapest); but it is easily possible to focus on different scenarios of CO2 capture in the context of rich gas resources in lake Kivu. Instead of keeping methane unexploited from the Lake Kivu, it is better to use it and sequestrated the resulting CO_2.

Technology based on natural gas and peat resources are expected to become low-carbon options in case of exploiting their scenarios of sequestrating GHG emissions:

- Peat IGCC (Integrated Gasification Combined Cycle) with CO_2 capture option
- Lake Kivu methane gas CCGT with an option of capturing and using CO_2 for industrial purposes including the enhanced peat-bed methane recovery, an option of extracting the methane gas from the peat seams.

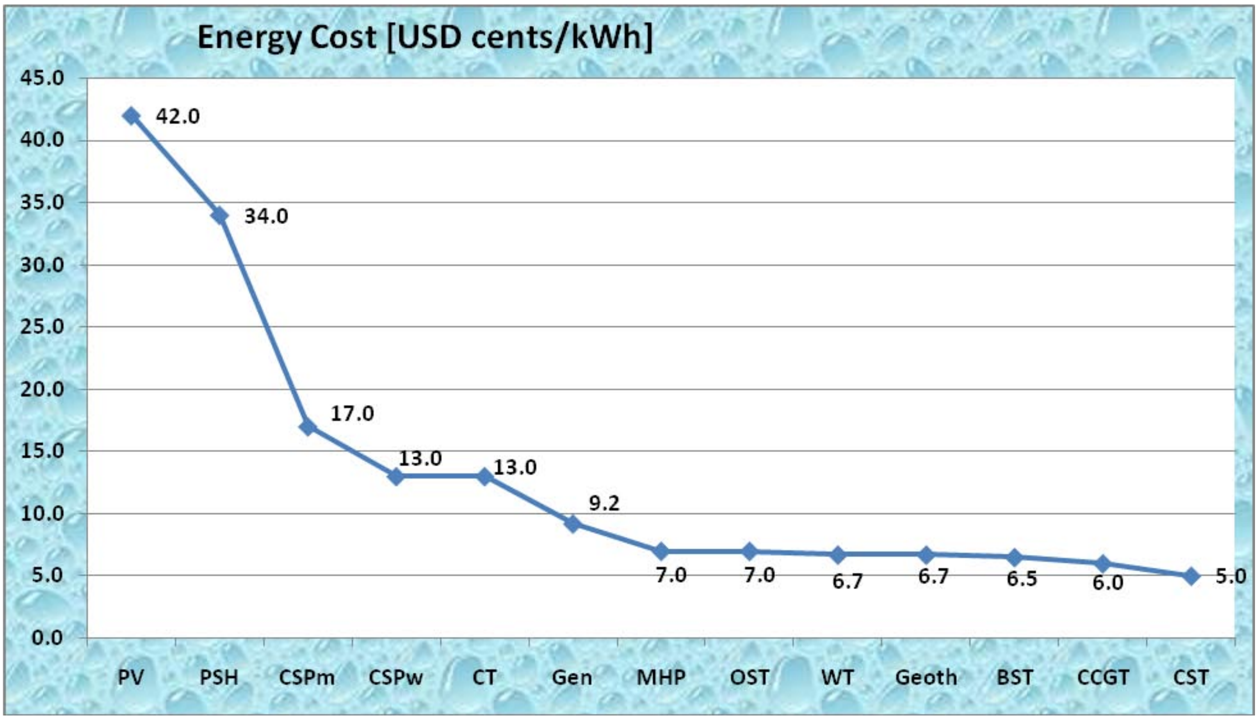

Figure 9: Power unit cost per technology (USD cents/kWh)

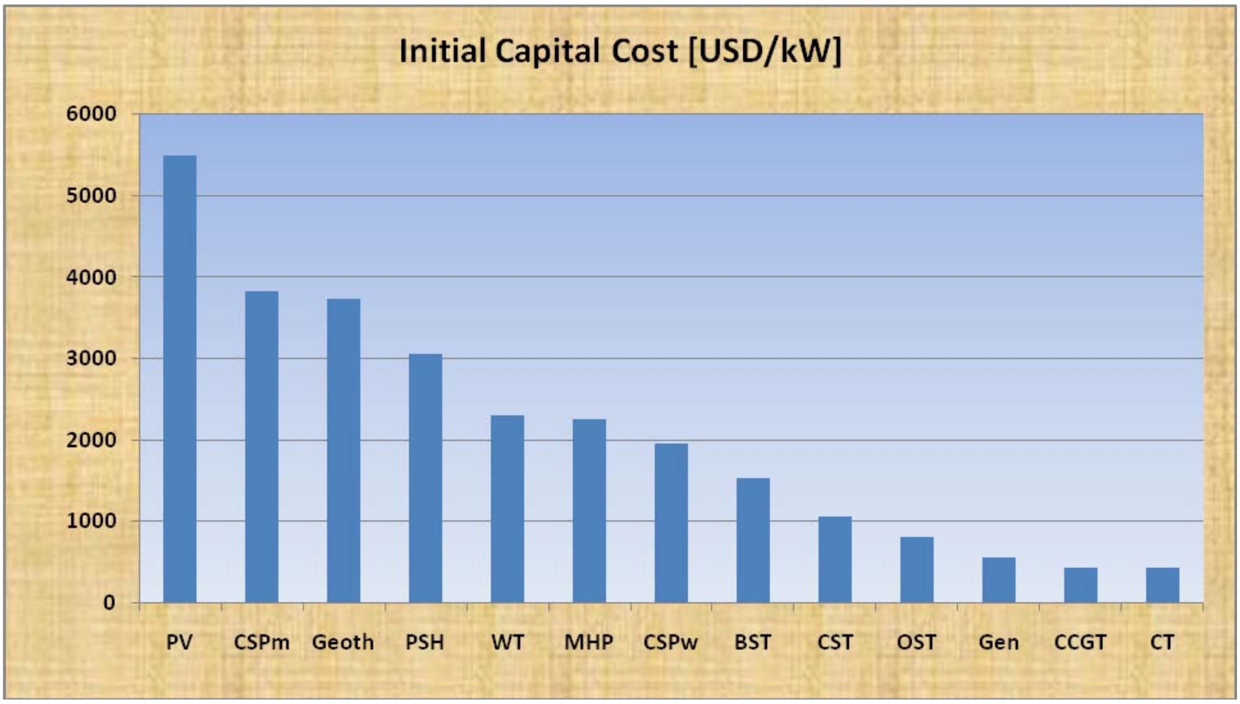

Figure 10: Initial capital per power unit per technology options (USD/kWh)

4.2.2 Pre-selection of energy technologies in transport sub-sector

Apart from the conventional gasoline and diesel vehicles operational in Rwanda, there is an opportunity of improving the sub-sector of road transport and introducing new options which result in a significant climate change mitigation. We suggest hybrid electric vehicles and wider use of common public transport buses.

Regarding prioritization of energy technologies, we focus on only the plug-in hybrid vehicles (PHEV) consuming both electricity through rechargeable batteries and efficient gasoline and diesel internal combustion engines.

4.2.3 Pre-selection of energy technologies in sub-sector of heat production

Referring to the handbook for conducting needs assessment for climate change, heating for domestic and industrial use can require among others; technologies based on Lake Kivu methane gas conversion, high efficiency furnaces and boilers, solar concentrating systems associated power plants, direct use of geothermal resources, biomass wood and charcoal fuels, biogas, systems of storage like molten salts or bio-fuels.

Among such technologies listed above we hereby suggest, , the «one family at least one cow» program in Rwanda.for wider promotion of biogas production at small scale in rural areas.

4.2.4 Pre-selection of technologies of carbon capture and sequestration

While the available options of carbon capture and sequestration(CCS) remain very expensive and very difficult especially for capturing gases from small and mobile sources (transport vehicles, buildings, commercial units,..) the CCS technology is highly recommended for the case of large sources of flue gases like industrial processing plants, manufacturing cement (case of CIMERWA in Bugarama/Rusizi district). Or chemical units or power plants (case of thermal units generating about 44% of total electric domestic production in Rwanda). System of capture can be for instance pre-combustion capture system, post-combustion capture system, or industrial process capture (IPCC, 2005).

The technologies for capture of CO_2 are mainly:

- Separation by use of solid sorbent or liquid solvent;
- Separation with membranes allowing selective migration of gases;
- Distillation of liquefied gases;
- The post-combustion capture system based on separation through solid or liquid solvents can be recommended for the case of existing plants sources of flue gases and any coming large unit in industrial and energy sectors;
- Once CO_2 is captured from its sources and separated from other components of flue gases it has to be compressed and transported through pipelines to a storage unit;
- Thus, such a network is in fact combined carbon capture and storage or sequestration(CCS technology);
- The most recommended option remains the storage of CO_2 in deep geological(offshore, onshore) formations. Such an option is an economically proven option (IPCC; 2005);
- For this TNA project, we selected the CCS technology based on a post-combustion capture system, separation (with a solid sorbent or liquid absorbent) and geological storage.

4.2.5 Description of pre-selected technology options

Selecting energy technologies for increase of energy supply in Rwanda is a process involving both the mitigation objectives and the affordability and feasibility of such technologies. In fact, a given technology can be interesting for such a region, but not affordable. This is the case for solar photovoltaic. Thus the challenge is for instance to develop any technology using an affordable resource while it is polluting atmosphere like the case of peat option in Bugesera, Nyanza and Rusizi districts for instance.

Combination and diversification of different possible hybrid options can thus be considered as an alternative instead of generating electric energy by thermal power plants consuming diesel fuels imported from far at high cost in addition to their negative contribution to increasing GHG in atmosphere. Another challenge for the energy sector in Rwanda is obviously the limited number of qualified human resources for significant involvement in research for adoption, operation and maintenance of new technologies (among others CCGT, CSP, Hydrogen fuels, Spark ignition for Lake Kivu CH_4 gas, geothermal options and DLE waste-to-energy).

Considering the above constraints, challenges, assets and national context of development priorities, we present below a list of possible mitigation technology options for further increased supply of energy with regard to mitigation benefits and rapid growth of the economy in Rwanda.

4.3 Criteria and Process of technology prioritization for the energy sector

4.3.1 Selection criteria

Given that the main objectives of the TNA and TAP projects are focusing on a further maximization of the mitigation to the Climate Change Effects, the selection and prioritization of the recommendable technologies for energy sector are hereby considering the following fundamental issues:

- Priority to renewable energy resources (Conventional Solar, Concentrating Solar, Wind, Water for Hydropower, Geothermal, Biomass and Waste-to-power).
- In case of a technology based on combustion of fossil fuels (Kivu methane gas, Peat), associated scenarios of carbon capture and sequestration (CCS) will be recommended for a further optimal reduction of GHG emissions to the atmosphere. For such a mitigation, the scenarios of CO_2 storage in appropriate geological or water body reservoirs are

expected to be feasible. In case of use of peat in industrial cement factories, more attention is required for any GHG mitigation. The capture and storage of CO_2 extracted from flue gases is required.

- Availability and sustainability of energy resources and deployment for power generation;
- Optimization of mitigation scenarios by applying the CCS option for large sources of GHG emission;
- Priority in use of renewable energy for electricity generation instead of using fossil fuels. In fact, for small and mobile applications (buildings, households, transport sub-sector, small industries), the CCS is expensive and hence not appropriate.

Therefore and with regard to national context and contribution to Rwanda Vision 2020 and sustainable socio-economic development through the priorities detailed by the EDPRS I and II, acceptable criteria selected through consultations with stakeholders (in meeting n° 1 at Musanze, questionnaires, distributed sheets and discussions mainly at Kigali and Huye district) were weighted and highlighted as follows.

Table 8. Description of criteria for technology selection in the energy sector

SN	Criterion	Description/Comments	Weight	Relative Weight
1	GHG reduction i.e. mitigation	- Contribution to reduction and stabilization of GHG in atmosphere are considered as an obligation at local and international scale - The TNA project is based on objectives for the GHG mitigation - Such a criterion will obviously influence the coming support to enhance electric power technologies - While renewable energy resources are GHG-clean, options based on peat and gas are pollutant and contributing to GHG emissions; but once combined to the CCS option, such technologies contribute to mitigation implementation	78	0.118
2	Diffusion and Deployment	- With regard to our national context of low level of access to electricity services and with target of generating 1000 MW by year 2015, we need options which are marketable and applicable enough - Applicability of technology is linked to its potential diffusion - Further diffusion and deployment of	52	0.079

		technologies in the market of end-users and demand have to be properly investigated before any investment - Diffusion of new technologies like the PHEV is not easy and requires sufficient promotion and campaigns - Where barriers to deployment of technology are found important, such a criterion will influence the prioritization process		
3	Capital Cost	- It is crucial to remember that off grid PVs are very interesting, but they are very expensive - The initial investment for acquisition of equipments, construction and installation of a given power plant is a criterion of high consideration - While it is not expensive for some technologies, it can be very heavy for others (like solar photovoltaic) - The capital cost influences greatly the total levelized generation cost	74	0.112
4	Sustainability of Energy Resources	- Selecting a technology using a scarce resource is not appropriate even though such technology is popular in other countries - Availability and sustainability of energy resource are crucial and very important for development and promotion of any energy (heat and electric power) technology - For some cases, seasonal or inter	85	0.128

		annual variability of resource can be linked to climate change impacts (e.g. hydrological changes resulted in shortage and decrease in hydropower production in Rwanda in years 2001-2004)		
5	Operation and maintenance costs	- Such costs can be considered as for long term and shared by beneficiaries - Usually, installed power plants have lifespan greater than 202 years; thus, costs for maintenance and operation have to be properly planned - In addition to the fuel cost, technologies like gasoline/diesel-engine generator require high costs of maintenance - Particular storage process can be avoided by opting for direct connection to existing electric grid networks: case of concentrating solar and large solar photovoltaic, but also wind power	50	0.076
6	Socio and economic benefits	- For any Country where the installed electric capacity is small, this criterion is very important - Economic effects expected from any selected and prioritized technology for generation of electric and heat energies are issued linked to growth of GDP and to alleviation of endemic poverty - Social and environmental benefits	80	0.121

		are also awaited from promotion of new technologies		
7	National Priority	- With reference to strategies and policies related to the development, technologies as geothermal, Kivu methane gas, biogas and hydropower at different scales are part of high priorities in Rwanda	100	0.151
8	Efficiency	- Attention must be paid to technologies presenting high efficiency of converting fuel resource into electric energy - Technologies based on thermodynamic cycles are characterized by a limited efficiency; it is also the case for the popular solar photovoltaic	72	0.109
9	Capacity Factor	- The criterion represents the number of daily operating hours for any power - Hydropower and geothermal-based power technologies are characterized by a high capacity factor; it is not the case for intermitted wind and solar	70	0.106

4.3.2 Weighted criteria

- Criteria for selection of technology priorities are either benefits or costs
- As averages, resulting from consultation and views from stakeholders, we adopted the following weights for further ranking process after relative weighting
- Among others, "National Priority, Resource and GHG" are highly weighted
- In any case, we have to keep in mind that prioritization of technologies "is not to look for the cheapest option, but to identify the most appropriate technologies within a country in terms of benefit-to-cost ratio (UNDP, 2011).

4.3.3 Specific relative contribution to reduction of GHG emissions

Table 9 below gives an illustration on replacing fossil fuels by energy mitigation options based on the fact that half of total electricity in Rwanda is currently provided by thermal (oil fired/gas turbine) power plants using imported liquid fossil fuels. From 2005 to 2008, total electricity production was respectively 115.8, 230.4, 248.6 and 276.5 GWh/year. Thus the average increase per year is 40 GWh. Therefore in the coming three years i.e by 2015, about 558 GWh, will be required. In case of business-as-usual about 280 GWh will be provided by thermal oil power plants.

Table 9: Contribution to GHG mitigation, peat as a worst and nuclear as a better

Resource	**Technology**	**Standardized score for GHG mitigation**	**Average CO_2 Emission (grams /KWh)**	Total Average CO_2 emission	Comparative Reduction
Peat	Peat fired ; steam	0	1075	301 000 tons/year	N.A
Oil	Internal combustion; GT	0.31	750	210 000 tons/year	0
Kivu methane gas	CCGT	0.42	630	176 400 tons/year	16%
Geothermal	Steam turbine	0.82	197	55 100 tons/year	74%
Solar	PV	0.86	155	43 400 tons/year	79%
Biomass	Bio-steam	0.95	58	16 200 tons/year	92%
Solar	CSP	0.97	43	12 000 tons/year	94%
Wind	Wind turbine	0.97	43	12 000 tons/year	94%
Water	Water turbine; hydropower	0.97	43	12 000 tons/year	94%
Peat ECBM[6]	-Gas turbine; -directly fired for thermal use	0.42	630	176400 tons/year	16%

[6] ECBM: enhanced coal/peat-bed methane recovery by use of CO_2 injected into seams and pumping methane through drilled wells; the outputs are : methane production and the carbon sequestration(underground storage)

Biodiesel BICG[7]	Internal combustion engine	0.97	43	12 000 tons/year	94%
Peat IGCC[8]	Gas turbine; steam turbine; heat recovery	0.42	630	1764000 tons/year	16%
Nuclear	Steam-turbine	1	11	NA	NA

Note that the nuclear option taken as the best baseline reference in the matter of the lowest contributor to GHG emissions is not considered within this TNA project. It is facing particular political and environmental constraints.

[7] BICG: biodiesel-based internal combustion engines
[8] IGCC: peat-based integrated gasification combined cycle

4.4 Results of technology prioritization for the energy sector[9]

Referring to the above main nine criteria (Table 8) for selection and prioritization of key energy technologies in this context of the TNA Project, 13 technologies for energy production were selected and scores were assigned to them (Refer to tables 10 and 11 below). Through the classic relative weighting, standardization and ranking the results of prioritization are presented . Small hydro, Kivu methane–based CCGT combined to the CCS, Geothermal power, the PHEV and the Large Solar PV are the top five most highly ranked as presented .

With reference to the applicability of energy technologies, it was found that a number of options potentially benefitting to Climate Change mitigation are still in their pre-commercial stages. Such options are not included in this list of 13 selected technologies.

Among these 13 energy technologies, it is important to remember that the CCS technology is quite new for Rwanda but useful for reducing significantly the GHG emissions from the Kivu methane CCGT, the peat based IGCC gasification and the peat based ECBM options. Another new technology recommended is the PHEV. Finally and within these 13 technologies possible for GHG mitigation, at short term and in this context of the TNA project, only five options are prioritized in the following descending order: Small hydro (84%), Kivu methane CCGT with CCS (80.3%), Geothermal (76.6%), PHEV (67%) and large solar PV (62.5%).

[9] With regard to the last two workshops held in Rwanda on the TNA project, it was recommended to postpone the study of transport sector to future occasion; but if more time is provided for this step of TNA project, then we can also focus on such an important contributor to GHG emissions.

Table 10. Ranking by standardization

	Availability of Energy Resource	Capital Cost	National Priority	O & M Cost	Social and Economic Impacts	Potential Diffusion and Deployment	Efficiency	Capacity Factor	Contribution to GHG Mitigation
Weighted Criteria	85	70	100	50	80	52	72	74	78
Relative Weight of criteria	0.128	0.106	0.151	0.076	0.121	0.079	0.109	0.112	0.118
Scale	12-50	6-70	15-50	3-28	26-48	25-46	0.14-0.8	0.2-0.8	20-58
Biodiesel BICG[10]	48	70	40	20	46	42	0.14	0.2	58
Small Hydro	50	15	46	14	48	40	0.8	0	58
Biomass-steam(BSP)	46	32	15	7	38	32	0.6	0.2	44
Geothermal	32	12	50	7	46	34	0.7	0.8	45
Large Solar PV	48	25	15	23	38	38	0.3	0.5	44

[10] BICT : Biodiesel, bio fuels/internal combustion engine, but also for vehicles (Transport as a sub-sector of energy)

Peat IGCC with CCS [11]	18	30	28	13	40	25	0.4	0.8	22
Kivu methane CCGT with CCS	42	14	44	12	44	43	0.4	0.7	28
Wind	12	23	18	22	26	25	0.2	0.2	58
Biogas BTA	28	17	38	3	48	46	0.3	0.7	38
Solar CSP	20	35	22	28	42	26	0.3	0.5	36
PHEV	29	6	48	12	46	43	0.3	0.5	38
Peat-based ECBM with CCS [12]	18	20	32	9	38	39	0.4	0.5	20
CCS	18	70	15	13	38	29	0.3	0.5	58

[11] IGCC: Integrated Gasification Combined Cycle(Peat is gasified and both gas turbine and steam turbine are used for generating energy); it must combined to the CCS option

[12] Enhanced coal/Peat-bed methane recovery(the CO_2 from any source of GHG is injected into coal /peat seams; adsorbed methane is displaced and is pumped through a drilled wells)

Table 11: Results of ranking by standardization

	Availability of energy resource		Capital Cost		National Priority		O&M Cost		Social and Economic impacts		Potential Diffusion and Deployment		Efficiency		Capacity Factor		Contribution GHG Mitigation		**Average Standardized Score**
Relative Weight	0.128		0.106		0.151		0.076		0.121		0.079		0.109		0.112		0.118		
Biodiesel BICG	48	0.121	70	0	40	0.108	20	0.024	46	0.11	42	0.064	0.14	0	0.2	0	58	0.118	**54.50%**
Small Hydro	50	0.128	25	0.075	46	0.134	14	0.043	48	0.121	40	0.056	0.8	0.109	0	0.056	58	0.118	**84.00%**
Biomass-steam	46	0.115	32	0.063	15	0	7	0.064	38	0.066	32	0.026	0.6	0.076	0.2	0	44	0.075	**48.50%**
Geothermal	32	0.067	35	0.058	50	0.151	7	0.064	46	0.11	34	0.034	0.7	0.092	0.8	0.112	45	0.078	**76.60%**
Large solar PV	48	0.121	25	0.075	48	0.142	23	0.015	38	0.066	38	0.049	0.3	0.026	0.5	0.056	44	0.075	**62.50%**
Peat IGCC with CCS	18	0.02	30	0.066	28	0.056	13	0.046	40	0.077	25	0	0.4	0.043	0.8	0.112	22	0.006	**42.60%**
CCGT with CCS	50	0.128	6	0.106	44	0.125	7	0.064	50	0.151	43	0.068	0.4	0.043	0.7	0.093	28	0.025	**80.30%**

Wind	12	0	23	0.078	18	0.013	22	0.018	26	0	25	0	0.2	0.01	0.2	0	58	0.118	**23.70%**
Biogas BTA	20	0.027	17	0.088	38	0.099	22	0.018	48	0.121	46	0.079	0.3	0.026	0.7	0.093	38	0.056	**60.70%**
Solar CSP	20	0.027	35	0.058	22	0.03	28	0	42	0.088	26	0.004	0.3	0.026	0.5	0.056	36	0.05	**33.90%**
PHEV	29	0.057	6	0.106	48	0.142	12	0.049	46	0.11	43	0.068	0.3	0.026	0.5	0.056	38	0.056	**67.00%**
Peat ECBM with CCS	18	0.02	20	0.083	32	0.073	9	0.058	38	0.066	39	0.053	0.4	0.043	0.5	0.056	20	0	**45.20%**
CCS	18	0.02	70	0	15	0	13	0.045	38	0.066	29	0.015	0.3	0.026	0.5	0.056	58	0.118	**34.60%**

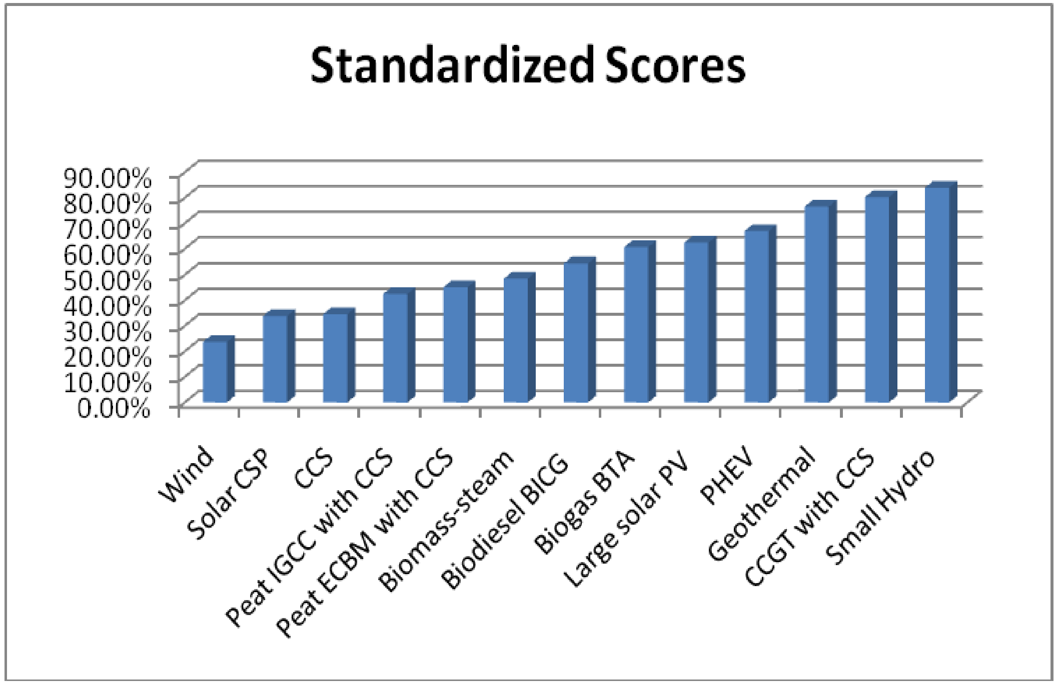

Figure 11: Results of Ranking

The standardized scores for selected technologies are calculated as follows:

Benefits: (N-min)/ (Max-min), a ratio affected by the multiplicative relative weighted criteria

Cost: (max-N)/ (Max-min), a ratio affected by the multiplicative relative weighted criteria. Where N represents the score of each technology and Max-min is the size (interval) of criteria scale.

The top five prioritized energy technologies out of the thirteen selected technologies are: 1.Small Hydropower, 2. Kivu Gas-based CCGT[13] with CCS; 3. Geothermal, 4. PHEV and 5. Large Solar PV. These technologies are characterized by significant benefits based on technical parameters involved in the process of energy generation within a sustainable lifespan. Small hydropower option is quite popular in Rwanda even though the involvement of private investors and local communities is yet limited and is resulting in a low level of electrification especially in rural areas. Compared to these other four prioritized technologies, the small hydro is particularly affordable and private mini grids can boost the programme of energy supply in remote zones.

The CCGT is a newly introduced technology for Rwanda but it is a well known one, in addition to its reliability proven through its commercial tested steps. The combination of steam turbine cycle and gas turbine cycle, in addition to the heat recovery resulting in steam production makes this technology highly efficient. Given that Kivu methane gas is both a relatively rich resource in Rwanda and a non-low-carbon fuel, the CCGT combined to the CCS option is recommended.[14] In fact and in addition to such improvements for further consideration by investors and planners of energy development, we have introduced the CCS option for capturing flue gases from different important sources (cement factories, current thermal diesel power plants, coming Kivu methane CCGT) and storing emitted CO_2 gases into deep geological formations.

It is also interesting to remember that the National Communication largely showed that the abstractions and natural sequestration by forest cover in Rwanda is itself a natural solution to any potential GHG emissions associated to the use of methane gas.

[13] Huge amount of CO_2 are associated to the mixture extracted from the lake Kivu and, after separation, methane is retained while CO_2 is re-injected into the lake; regarding CO_2 emissions from combustion of the methane, if carbon sequestration and storage are applied , thus the CCGT can be considered as a mitigation scenario in addition to its high efficient.

[14] Rate of renewing the formation of the gases under the lake is small, compared to the expected speed of coming extraction; the project can end within 50 years if the potential capacity of 700 MW is made operational soon by the year 2020.

The Geothermal option is also a new power technology to be introduced in Rwanda. The Rift Valley regions in Africa are very rich in such a resource and countries like Ethiopia and Kenya have already gained a great experience to which we, in Rwanda, can benefit from. It is hence a proven, reliable and commercial technology especially in USA, Mexico, Philippines, Ireland and Italy where it started its early steps in 1903.

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The above technologies were followed by other options such as: Biogas for thermal applications, Solar CSP, the IGCC integrated gasification combined cycle, Biomass or waste-to-power. All these technologies are reliable and proven. they are expected to be newly introduced in Rwanda in the medium term. The CCS carbon capture and sequestration technology can be considered and combined to any technology resulting in huge emission of flue gases: options of IGCC, Kivu methane CCGT and ECBM (UNDP, 2011).

The rank of the highly CSP promising technology based on the solar concentrators (Central Receiver Tower, Parabolic through mirrors and dish) is limited due to among others the fact that it is still a new one and hence not yet benefiting from the economy of scales. Fulfilling the requirements for a proper characterization of solar map and direct normal component are of great importance. Other technology options lagging behind are among others the CCS and Wind Power. Their disadvantages are respectively the high initial capital cost of CCS, and the poor frequency of wind resource.

Finally and based on above process of pre-selection, selection and standardized ranking, these five recommended mitigation technologies for short to medium term diffusion and deployment at more large scale are largely feasible in Rwanda.

Apart from the PHEV option introduced more recently into the list of the selected mitigation technologies; all other prioritized technologies (small hydropower, geothermal, large solar PV and Kivu methane CCGT) have been endorsed by the TNA committee. Referring to the recommendation by ENDA and URC team, we reconsidered the Kivu methane CGGT: it has to be associated with the CCS option further completion of mitigation goals by such a crucial methane resource already under its good step of pilot power project of about 3MW.

The alternative of reinjection of CO_2 separated from the gross gas mixture is currently tested and operational.

Therefore, such relevant changes and introduction of PHEV and CCS in TNA report/1 will be presented and discussed through next stages of involvement by stakeholders and TNA committee.

CHAPTER 5: TECHNOLOGY PRIORITIZATION FOR THE AGRICULTURE SECTOR

5.1 Climate Change Vulnerability and Existing Adaptation Technologies in Agriculture Sector

5.1.1 Climate change vulnerabilities in the agricultural sector

According to the NAPA report, recent climate change data analysis showed that: Rain-fed agriculture as being practiced in Rwanda is highly sensitive to the effects of climate change making it vulnerable. In fact, food crops and industrial crops have a very high degree of sensitivity especially during seasons of frequent and prolonged droughts as well as heavy rains. In contrast, large farmers and rural business people present a high degree of sensitivity to seasonal prolonged draught but are relatively less vulnerable due to their possibility of easy access to financial means and their know how that they have to easily adapt to climate hazards.

5 1.2 Existing technologies in the agriculture sector

5.1.2.1 Integrated management of natural endowments

According to the Strategic Plan for the Transformation of Agriculture in Rwanda – Phase II as established by the ministry of agriculture and animal resources, most soils in Rwanda are highly weathered, dominated by kaolinite in the clay fraction, have a low cation exchange capacity and are acid to strongly acid (pH < 5.5 and often < 4.8) often with aluminium toxicity. This means that soils have low natural fertility and a low nutrient retention capacity, indicating that most soils need liming prior to any measures aimed at improving fertility. Altitude, with its slowing effect on plant maturation is a key factor in the quality of some Rwandan products such as tea (MINAGRI, 2009).

Rainfall, while abundant on average in comparison with that of many other countries, is irregular, both spatially and seasonally. The western part of the country, with steeper slopes, receives the heaviest rainfall, while the eastern part is more subject to droughts. Hence in both regions a large investment in water control and harvesting structures, and in practices for water and soil conservation and soil nutrient enhancement, is an absolute necessity to protect this resource base, increase productivity through irrigation, improvement of soil fertility and providing more watering points for livestock (MINAGRI, 2009).

Currently, a marshlands development plan and an irrigation master plan has been completed and will serve as a basis for more systematic and productive development of irrigation systems in those environments.

5.1.2.2 The use of improved seeds

The use of improved seeds is vital to the transformation of the agriculture production. In 2005, only 12 percent of households reported using improved seeds, covering only 2 percent of cultivated land. According to preliminary analysis of the Season A results from the 2005 Agricultural Survey, 90 percent of seed for food crops is saved by the farmer from the previous production cycle (MINAGRI, 2011).

There exist initiatives to distribute improved seeds of maize, sorghum, rice, wheat, and beans, as well as improved virus-resistant planting materials for potato, sweet potato, cassava, and banana. The amount of seed produced remains small, however, and it covers only a small fraction of potential needs (table 17). RAB contracted farmers for seed multiplication and concentrating its own efforts on seed certification. This approach is thought to be the speeding up of the process of producing and distributing improved seeds (MINAGRI, 2011)

Table 12: Production of improved seeds (mt) and demand coverage (%) for the period of 2001-2007

Crop	**2001**		**2002**		**2003**		**2004**		**2005**		**2006**		**2007**	
	Prodn	Cov	Prodn	Cov	Prodn	Cov	Prodn	Cov	Prodn	Cov	Prodn	Cov	Prodn	Cov
Sorghum	495	7.2	64	0.9	58	0.9	206	5.4	206	3.0	19.5	0.3	13.0	0.2
Maize	1,292	11.3	363	3.2	1,228	10.7	1,127	11.6	1,127	9.9	230.8	18.0	438.6	35.0
Wheat	111	1.0	54	0.5	25	0.2	50	0	50	0.5	21.6	4.0	16.4	12.0
Beans	432	0.5	856	0.9	707	0.8	521	0.6	521	0.6	46.5	2.0	79.5	2.0
Soybeans	379	4.0	286	3.0	345	3.7	80	1.8	80	0.9	0	0	16.3	2.0
Potatoes	1,036	0.1	1,020	0.1	1,258	0.1	1,172	0.1	1,172	0.1	512.7	0	1,961	2.0

Source: MINAGRI, 2009

5.2 An overview of possible adaption technology options in the agriculture sector

5.2.1 Agro forestry

Agro forestry is one of the technologies that would help the agriculture sector to adapt to the effects of climate change. In fact, agro forestry systems with high biodiversity and diverse natural resources can adapt by using and integrating underexploited natural resources and diversification is a key strategy for small holder farmers in vulnerable areas. Plantation of shade trees is a potential adaptation measure for farmers in regions vulnerable to reduced water resources and temperature extremes (FAO, 1991). In Rwanda, Agro forestry plantations occupy only ¼ of the available space to be used for the same purpose (MINAGRI, 2009).

Figure 12: Food crops (corn) mixed with agro forestry (fruit) trees

In case of intensive precipitations, plantations stabilize and protect stream banks from erosion. They filter pollutants from runoff water. Also, they provide woody debris that promotes good stream habitat, providing habitat for wildlife and conduits for wildlife movement. They slow erosive winds and promote dust deposition which improves visibility. Benefits to farmers include but not limited to improved income through increased yields: for example millet and sorghum may increase their yields by 50 to 100 per cent when planted directly under Acacia albida (FAO, 1991).

It is estimated that all the sub groups (farming communities, associations and/cooperatives) of the 1 400 000 households involved in farming activities will benefit from agro forestry transfer and diffusion. The average cost to put in place 1 ha of agro forestry plantations is 10 000 $ including land preparation, seedling preparation (seeds purchasing, tubing, shade construction, nursery maintenance) and baby trees plantation

5.2.2 Drip irrigation

Drip irrigation is a technology based on the constant application of a specific and focused quantity of water to soil crops. The system uses pipes, valves and small drippers or emitters transporting water from the sources (i.e. wells, tanks and reservoirs) to the root area and applying it under particular quantity and pressure specifications. Compared to surface irrigation, which can provide 60 per cent water-use efficiency and sprinklers systems which can provide 75 per cent efficiency, drip irrigation can provide as much as 90 per cent water-use efficiency (FAO, 2002). In Rwanda, beneficiaries are estimated at 1 200 000 households which is about 80% of the entire farming community. The technology implementation cost is widely variable and ranges from US$ 800 to US$ 2,500 per hectare depending on the specific type of the system including automatic devices, materials used as well as the amount of labor required.

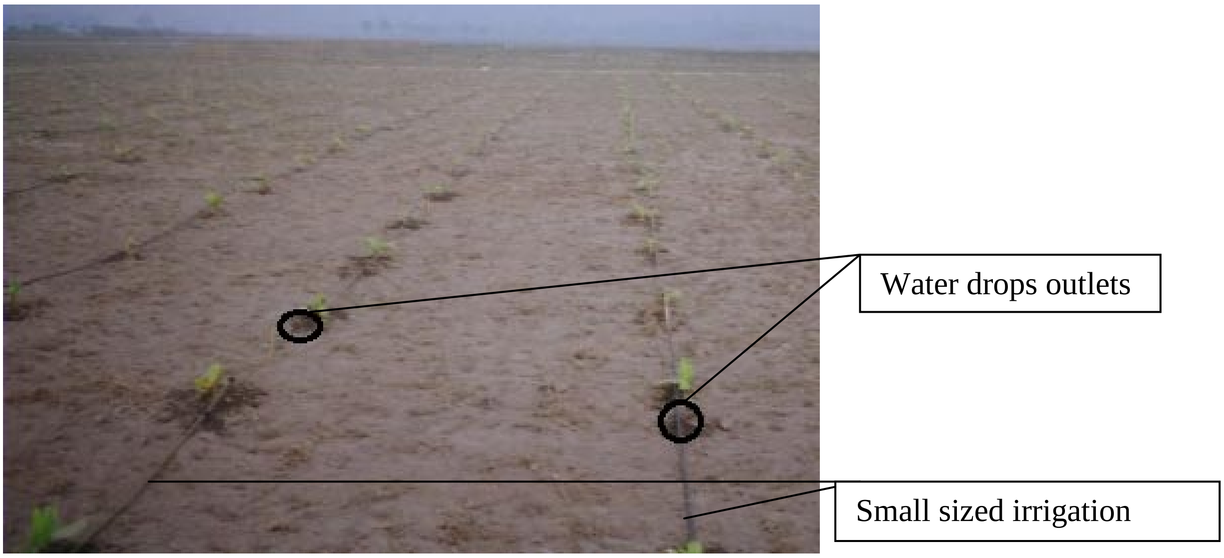

Figure 13: Juvenile crops under drip irrigation

Its adaptation advantages include the conservation of water resources though efficient use as it applies water directly to the roots, which minimizes runoff and evaporation. Rain-shut off devices minimize over-watering after significant rainfall. The technology also preserves wildlife habitat because sub-surface drip irrigation systems promote healthy plant life, which and contributes to wildlife habitat. It also limits CO_2 emissions by conserving fossil fuels because reduced water use can lead to decreased energy needed to pump and treat irrigation water (FAO, 2002).

5.2.3 Radical terracing

Radical terracing refers to a technique of landscaping a pierce of sloped land into a series of successively receding flat surfaces or platforms, which resemble steps, for the purposes of more effective farming. This type of landscaping, therefore, is called terracing. Graduated terrace steps are commonly used to farm on hilly or mountainous terrain. Terraced fields decrease erosion and surface runoff retaining soil nutrients. According to Mupenzi et al. 2012, radical terraces contributed to increase in the farm productivity, fight against erosion and also contributed to poverty reduction in Rwanda. It is estimated that agriculture land with radical terracing potential is owned by 1 000 000 households which are the main part of the Rwandan farming community. The average cost to establish one hectare of radical terraces in Rwanda (including manpower and basic tools such as picks, shovels etc) is $ 1000. The cost for any additional unit (ha) of radical terracing would cost the same amount as the initial unit.

Figure 14: An example of radical terraces

5.2.4 Rain water harvesting

Rain water harvesting is a technology used for collecting and storing rainwater from rooftops, the land surface or rock catchments using simple techniques such as jars and pots as well as more complex techniques such as underground check dams. Commonly used systems are constructed of three principal components; namely, the catchment area, the collection device, and the conveyance system (UNEP, 1997). Figure 19 illustrates an example of small scare (household) rainwater harvesting system with all typical components.

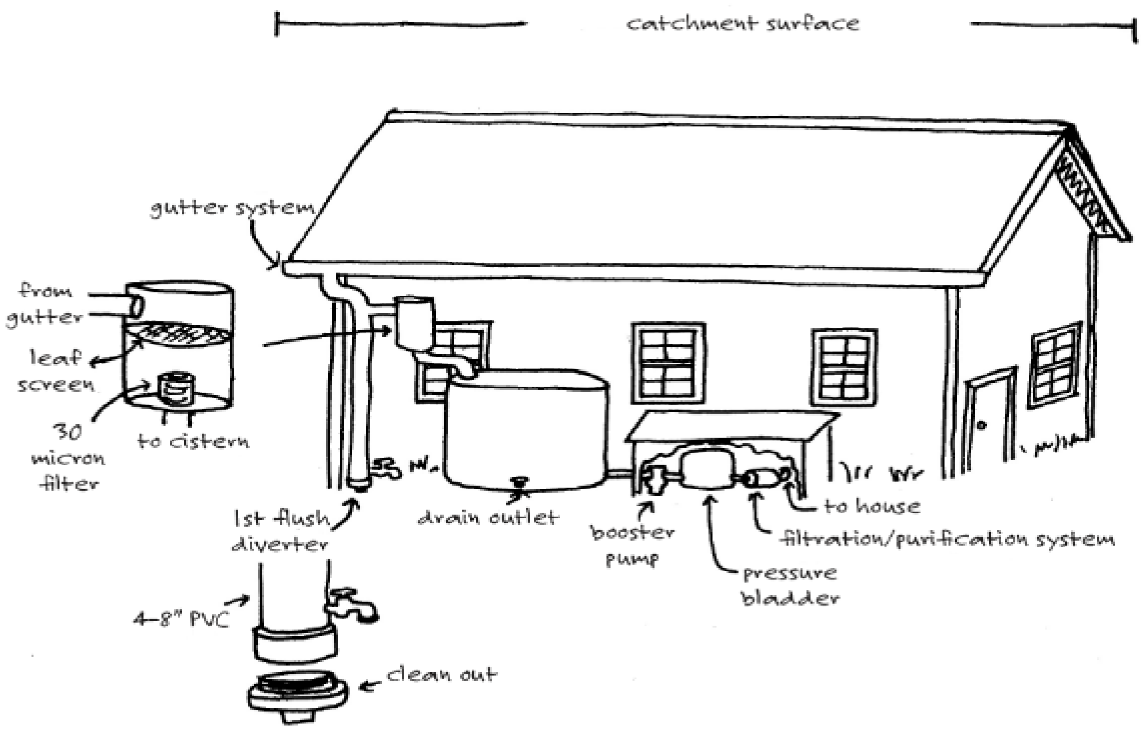

Figure 15: Typical household rainwater harvesting system

All the 1 400 000 households which make the Rwandan farming community could benefit from this technology. The installation of one cubic meter in a small sized (240 m^3) runoff pond system costs: $ 15. To install one cubic meter in rooftop rainwater harvesting system costs:

1. With plastic tank: $ 230
2. Stone and concrete tank: $ 220

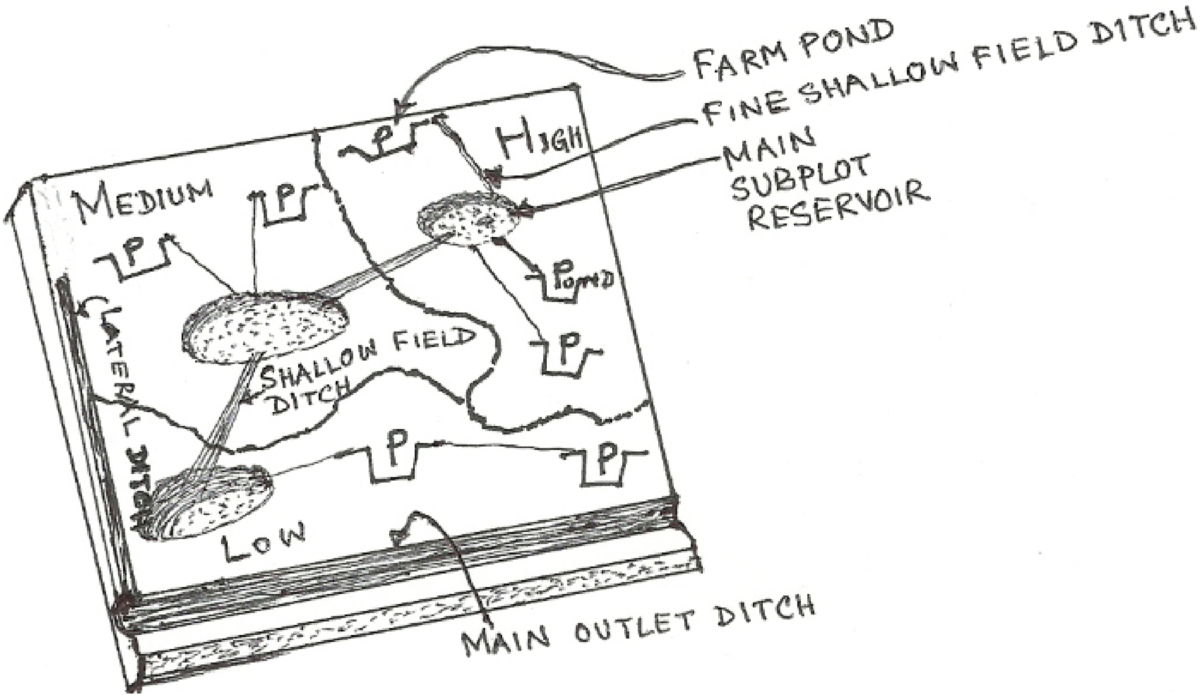

Figure 16: Schematic presentation of a medium scare (farm) rainwater harvesting system

As an adaptation option, rain water harvesting would contribute to the provision of available water for direct use at household (fig. 19) and farm exploitation (fig. 20) level especially during dry season. Rain water harvesting through new dam construction increases accessible runoff by about 10% which increases fresh water options to the continuously increasing human population (UNEP, 1997).

5.2.5 Seed and grain storage

Good seed and grain storage helps ensure household and community food security until the next harvest and commodities for sale can be held back so that farmers can avoid being forced to sell at low prices during the drop in demand that often follows a harvest. While considerable losses can occur in the field, both before and during harvest, the greatest losses usually occur during storage. Therefore the basic objective of good storage (fig.21) is to create environmental conditions that protect the product and maintain its quality and its quantity, thus reducing product loss and financial loss (CARE, 2010). 1 400 000 households will benefit from seed and grain storage technology transfer and diffusion. The cost of the deployment of the technology is estimated as follow: to install storage capacity of 60 000 tons with modern and well studied drying area, management offices and other supporting equipments range from $ 480000 to $ 900000 in local conditions which makes the unit costs ranging from $ 8 to $ 15 / ton, depending on the type of the system (warehouse, silos) and/or the material used.

Figure 17: An example of modern seed and grain storage facility

5.2.6 Sprinkler irrigation

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniformly at the rate to suit the infiltration rate of soil. The trials conducted in different parts of the country revealed water saving due to sprinkler system varies from 16 to 70 % over the traditional method with yield increase from 3 to 57 % in different crops and agro climatic conditions (FAO,1988).

Figure 18: A sprinkler irrigation system with small sized water outlets

5.2.7 Biotechnology of crops for climate change adaptation

Agricultural biotechnology involves the practical application of biological organisms, or their sub-cellular components in agriculture. The techniques currently in use include tissue culture, conventional breeding, molecular marker-assisted breeding and genetic engineering. Tissue culture is the cultivation of plant cells or tissues on specifically formulated nutrient media. Under optimal conditions, a whole plant can be regenerated from a single cell. This is a rapid and essential tool for mass propagation and production of disease-free plants (Ortiz et al. 2007). The major aim of agricultural biotechnology is to enhance productivity and maximize productive capacity of diminishing resources. Conventional landscape management practices and breeding initiatives have contributed significantly to crop adaptations through the development of strains that are resistant to biotic stresses such as insects, fungi, bacteria and viruses (Ortiz et al., 2007).

5.3 Criteria and process of technology prioritization

5.3.1 Selection criteria

A set of criteria were proposed to allow the comparison of technologies and identify the most appropriate for the country. Specifically, questions on sustainable development in its three spheres (economic, environmental and social) were asked and criteria were chosen according to their ability to fit into economical, environmental and social aspects of sustainable development. Technologies should be cost-effective, environmentally sustainable and socially acceptable (UNFCCC, 2006). Chosen criteria were formulated as follow:

Table 13: Technology selection criteria in the agriculture sector

Economic	Food security Poverty alleviation Cost effectiveness
Environmental	Reduction of the adverse impacts of climate change Vulnerability of the technology to climate change
Social	Contribution to socio development expressed in the number of beneficiaries.

5.3.2 Process of technology prioritization

A technology prioritization exercise was carried out by the agriculture sector working group members using Multicriteria Analysis (MCA) and guidelines as provided in the TNA handbook. First of all criteria were proposed, technologies listed and scales defined by stakeholders themselves. Different scales were used including percentage and others depending on the technology and the criteria being analyzed. Based on previously proposed criteria, technologies were attributed values with high grades to those responding better and low grades to those responding less to a given criteria representing an advantage. Regarding criteria representing disadvantage, high grades were given to a technology with less disadvantage. We used one of the two ranking techniques known as standardization. Ponderation was not used due to clearness in standardization grades and a consensus among stakeholders.

5.3.2.1 Technology listing and criteria proposition

Table 14: Proposed technologies and criteria

Technologies	Criteria				
	Reduction of adverse impacts of climate change	Contribution to socio development	National priority	Vulnerability of the technology to climate change	Ensure food security and poverty alleviation
Scale	Percentage %	Number of beneficiaries (households)	Scale (1-10)	Scale (1-5)	Scale (1-5)
Radical terraces	95	1 000 000	10	3	2
Drip irrigation	90	1 000 000	10	4	4
Agro forestry	95	1 400 000	9	3	4
Integrated fertilizers and pesticide management	80	1 400 000	8	4	3
Biotechnology for CC adaptation of crops	90	700 000	7	4	3
Rainwater harvesting	95	1 400 000	8	4	3
Seed and grain storage	90	1 400 000	10	3	5
Sprinkler irrigation	70	500 000	10	5	4

5.3.2.2 Technology ranking

Table 15: Final results of the MCA exercise after standardization

Technologies	**Criteria**					
	Reduction of adverse impacts of climate change (advantage)	Contribution to socio development (advantage)	National priority (advantage)	Vulnerability of the technology to climate change (disadvantage)	Ensure food security and poverty alleviation (advantage)	Average Standardized Score
Standardized scale	**0-1**					
Radical terraces	1	0.5	1	1	0	0.70 (3rd)
Drip irrigation	0.8	0.5	1	0.5	0.6	0.68 (4th)
Agro forestry	1	1	0.6	1	0.6	0.84 (2nd)
Integrated fertilizers and pesticides management	0.4	1	0.3	0.5	0.3	0.5 (6th)
Biotechnology for CC adaptation of crops	0.8	0.2	0	0.5	0.3	0.36 (7th)
Rainwater harvesting	1	1	0.3	0.5	0.3	0.62 (5th)
Seed and grain storage	0.8	1	1	1	1	0.96 (1st)
Sprinkler irrigation	0	0	1	0	0.6	0.32 (8th)

5.4 Results of technology prioritization

Due to financial constraints and limited capacities to be developed for a better implementation of these priority options, specific criteria were utilized to select and make a hierarchy of highly priority options. Selective criteria (table 20) have been analyzed simultaneously showing the measurement of each criterion in relation to its response to the technology option. In consideration of lack of exact data on the real values to attribute to each measure unit of criteria, the measure by scale was preferred by the agriculture sector working group.

With reference to the MCA exercise-technology prioritization results as mentioned in table 20 and through an open discussion among members of the agriculture sector working group, five technology options for the selected adaptation/agriculture sector were prioritized. Listed in the top down manner (from high to low ranked), they include: 1) Seed and grain storage 2) Agro forestry 3) Radical terraces 4) Drip irrigation 5) Rainwater harvesting. These results have been endorsed by the TNA committee during a stakeholders' meeting held at Umubano Hotel on 4th September 2012.

CHAPTER 6: CONCLUSION

The present Technology Needs Assessment has been conducted using multi stakeholder's participatory approach. Through group meetings, interviews, emails and phone calls, stakeholders were approached. They were identified according to their expertise, decision making positions, involvement and knowledge of sectors and technologies. A close follow-up was set through personal contacts and individual meetings in order to ensure the full involvement of stakeholders in the process.

For mitigation sector, prioritization was based on last findings in the establishment of the nation GHG emissions inventories as published in the Second National Communication on Climate Change in Rwanda which qualifies the energy sector as one of the sectors with high GHG emissions. The sector contributes 17% to the total GHG emissions of the country.

The adaptation sector which is agriculture was selected based on its level of vulnerability to the effects of climate change, the highest in Rwanda and to the position that it occupies as a national adaptation priority which is number one. Apart from the level of emissions and vulnerability criteria, the energy and agriculture sectors are among the most priority sectors in the country's development plans and programmes.

Different criteria have been selected by stakeholders in order to be able to choose the most relevant technology options for the energy and the agriculture sectors respectively selected for climate change mitigation and adaptation. Agreed criteria for technology prioritization in the energy sector are: GHG reduction, diffusion and deployment, capital cost, sustainability of energy resources, operation and maintenance costs, socio and economic benefits, national priority, efficiency and capacity factor.

Regarding the agriculture sector, selected criteria for technology prioritization include; reduction of adverse impacts of climate change, contribution to social development, national priority, vulnerability of the technology to climate change, the assurance of food security and poverty alleviation.

Using multicriteria analysis (MCA) and based on preselected criteria, technologies were prioritized. Results are presented in the tables below.

Table 16: Prioritized technologies for the Climate Change mitigation in Rwanda[15]

Mitigation	Technologies
Selected sector: Energy	Small Hydropower
	Kivu methane-based CCGT[16]
	Geothermal[17]
	Biomass-Steam
	Large Solar PV
	Peat-based IGCC
	Solar CSP
	PSH (pumped storage hydro)
	Biodiesel (engine internal combustion)
	Wind power
	ECBM(Enhanced Coal /Peat-bed methane)
	Biogas for thermal applications

[15] The number of technologies has been limited to above 10 options; the range of 6-15 was recommended (UNEP, 2010). In addition some technologies are still in their steps of pre-commercial process/long term: like IGCC (integrated coal/peat gasification combined cycle), Hydrogen-based option; others are facing a risk of low deployment in Rwanda due to lack of fuels for large scale application: biofuels, biomass gasification, advanced oil combined cycle.

[16] CCGT/Peat-steam/Diesel can be considered as low-carbon-options if required techniques for CO_2 storage, sequestration and use (industry; enhanced energy option of coal/peat-bed methane recovery from mines and rock/peat seams ;…) are applied.

[17] Within the current context, geothermal is in its stages of exploration of resources; in case of good results and favorable lessons from the coming pilot projects in Kinigi/Musanze district and Karisimbi/Nyabihu district, geothermal can thus be considered as the most ranked.

Table 17. Prioritized technologies (in descending order) for Climate Change adaptation in Rwanda

Adaptation	**Technologies**
Selected sector: Agriculture	Seed and grain storage
	Agro forestry
	Radical terraces
	Drip irrigation
	Rainwater harvesting
	Integrated fertilizers and pesticide management
	Biotechnology for CC adaptation of crops
	Sprinkler irrigation

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Annexes

Annex I- List of stakeholders- Inception report

No	Names	Post & Institution	Phone	E-mail
1	Aimable Mugabe	Acting Director/Urban Planning and Housing Ministry of Infrastructure	0788475806	mugaible@yahoo.fr
2	Alphonse Mutabazi	Coordinator AAP & LDCF Rwanda Environment Management Authority	0785745057	mutalpho@hotmail.com
3	Barnabe Bahoranimana	Network Maintenance & Calibration Rwanda Meteorological Service	0788744355	
4	Bonaventure Ntirugulirwa	Head of RAB/Ruhande & Researcher in Forestry Dept. Rwanda Agricultural Board	0788471509	ntirugulirwab@yahoo.com
5	Brigitte Nyirambangutse	Assistant Lecturer/Biology Dept. National University of Rwanda	0785473188	nbrite82@yahoo.fr
6	Casimir Museruka	TNA Consultant - Mitigation	0788675437	
7	Charles Mugabo	TNA Consultant - Adaptation	0788215484	cmugabo@gmail.com
8	Donat Harerimana	Electricity Generation Energy, Water and Sanitation Authority	0788567420	
9	Eugenie Umulisa	Project Officer Rwanda Environmental NGOs Forum		eumulisa@yahoo.fr
10	Faustin Munyazikwiye	Director of Climate change and international Obligations	0788462012	mufausi@yahoo.fr

		department and National TNA Coordinator Rwanda Environment Management Authority		
11	Hervé Gilbert Ngenzi	In Charge of Energy Programs Implementation Ministry of Infrastructure	0788780013	
12	Immaculée Uwimana	Climate Change Mitigation Officer Rwanda Environment Management Authority	0788871527	
13	Janvier Kabananiye	Rwanda Environment Management Authority	0788411966	
14	Jean Bosco Rwiyamirira	Member of Technical Team - CDM DNA Private Sector Federation	0788302323	
15	Jean Claude Musabyimana	Irrigation and Mechanization Ministry of Agriculture and Animal Resources	0788612942	musaclo@gmail.com
16	Jean Claude Sebahire	In Charge of Forest Inventory Rwanda Natural Resources Authority/Forestry Department	0783020933	sebajec2002@yahoo.fr
17	Jean de Dieu Karara	Environmental Analyst Rwanda Development Board	0788422184	
18	Marie Josee Yankurije	Receptionist Rwanda Environment Management Authority		
19	Papias Karanganwa	In Charge of Carbon Markets Rwanda Natural Resources Authority	0788656310	karanganwapapias@yahoo.fr
20	Patrick Mugabo	Environmental Conventions Specialist Rwanda Environment Management Authority	0788800038	pmugabo@rema.gov.rw

21	Said Kafumbe	Acting Head, Department of Electrical and Electronics Engineering/Kigali Institute of Science and Technology	0785122736	
22	Theogene Habakubaho	Environment Expert Rwanda Natural Resources Authority	0788643982	htheogene@yahoo.fr
23	Viateur Mugiraneza	Compact Fluorescent Lamps Project Coordinator & Carbon Markets/Energy, Water and Sanitation Authority	0788501673	
24	Yves Tuyishimire	In Charge of Carbon Market Promotion Rwanda Environment Management Authority	0788657451	yvest0@gmail.com

Annex II - List of stakeholders

Annex II-A-Mitigation sector group

Names	**Contact**
Dr. Digne Edmond Rwabuhungu	UNR/Faculty of appl science at Butare/Huye[CCGT;geothermal]
Dr.Fidele Ndahayo	UNR/ Faculty of Science/Dean[hydro;geothermal]
Prof. Dr.Karemera Marembo	*INATEK*/Kibungo ; [solar concentrators]
Eng.Desire Twubahimana	KIST,[civil eng, hydro]
Eng.Habyarimana Fabien	KIST,[solar]
Eng.Jean de D.Mukwiye	Private sector,[solar]
Dr.Jean B.Nduwayezu	IRST, [bioenergy,biomass]
Eng.Fr.Nyaminani	Private sector, [diesel-engine ;pumped hydro]
Dr.Twagiramungu Fabien	KIE, [Peat resources]

Annex II-B-Adaptation sector group

No	Names	Affiliation	Phone	E-mail
1	Bonaventure Ntirugulirwa	Rwanda Agricultural Board	0788471509	ntirugulirwab@yahoo.com
2	Faustin Munyazikwiye	Director of Climate change and international Obligations department and National TNA Coordinator Rwanda Environment Management Authority	0788462012	mufausi@yahoo.fr
3	Jean Claude Musabyimana	Irrigation and Mechanization Ministry of Agriculture and Animal Resources	0788612942	musaclo@gmail.com
4	Jean Claude Sebahire	In Charge of Forest Inventory Rwanda Natural Resources Authority/Forestry Department	0783020933	sebajec2002@yahoo.fr
5	Theogene Habakubaho	Environment Expert Rwanda Natural Resources Authority	0788643982	htheogene@yahoo.fr
6	Paul Benjamin Nzigamasabo	World Agro forestry Center	0788557350	nzigos@yahoo.fr
7	Madeleine Usabyimbabazi	Planning Department Ministry of Agriculture and Animal resources	0788879101	madousa2020@yahoo.fr
8	Damien Niyongabo	Irrigation and Mechanization Ministry of Agriculture and Animal resources	0786426663	niyongabodamien@gmail.com
9	Florien Mugabo	Irrigation and Mechanization	0788768817	flowayesu@gmail.com

		Ministry of Agriculture and Animal resources		
10	Gaston Ndayisaba	CUEP project Rwanda Natural Resources Authority	0783664117	ndagaston@yahoo.fr
11	Camille Ndayishimiye	Land Bureau Bugesera district	0788358252	camillon2001@yahoo.fr
12	Anselme Rubangutsangabo	Land Bureau Rwamagana district	0788767091	rubanse@yahoo.fr
13	Pascal Nahimana	Agriculture department Kigali City Council	0788353080	nahipas@yahoo.fr
14	Vicky Ruganzu	Sustainable Land Management Rwanda Agriculture Board	0788562938	rugavicky@yahoo.fr
15	Venant Gasangwa	PAPSTA/KWAMP project Ministry of Agriculture and Animal resources	0788434747	venantg@gmail.com
16	Emmanuel Kayiranga	Post Harvesting Project Rwanda Agriculture Board	0788526573	kayiranga02@yahoo.fr
17	David Kagoro	Partners in Agriculture and Environment	0788599542	kagosw269@yahoo.com
18	Wilfred Muriithi	NRM Rwanda Agriculture Board	0783202928	wmfred2007@yahoo.com
19	Nadia Musaninkindi	Famine Early Warning Systems Network	0788750862	nadiev2002@yohoo.fr

20	Immaculee Nyampinga	National Agriculture Export Board	0788754020	nyampinga9@yahoo.fr
21	Louise Munganyinka	Agronomist / Post Harvest	0788853454	mlmunganyinka@yahoo.fr

Annex III-Technology factsheets-Adaptation sector

Annex III.A Seed and grain storage

Technology: Seed and grain storage	
Technology characteristics	
Introduction	Cereals, pulses, oilseeds etc. are very important grain products for storage. Good storage helps ensure household and community food security until the next harvest and commodities for sale can be held back so that farmers can avoid being forced to sell at low prices during the drop in demand that often follows a harvest. While considerable losses can occur in the field, both before and during harvest, the greatest losses usually occur during storage. Therefore the basic objective of good storage is to create environmental conditions that protect the product and maintain its quality and its quantity, thus reducing product loss and financial loss. Only well-dried seeds should be stored. Seeds with moisture in them become damp, moldy and vulnerable to insect attacks.
Institutional and organizational requirements	In Rwanda, the implementation of efficient seed and grain systems would be facilitated by several institutions/agencies. These include: The Ministry of Agriculture and Animal resources- Rwanda Agriculture Board for technical training, The Ministry of Commerce -Rwanda Bureau of Standards for health and safety regulations and quality control guidelines, local financial institutions-BRD for funds mobilization and farmers' associations who are indeed the first beneficiaries. Health and safety regulations and quality control guidelines should be elaborated by the relevant national authority. Standardized training and inspections may also be undertaken by a government agency.
Size of beneficiaries	1 400 000 households

Operation and maintenance	Requires high initial investments costs, operation and maintenance are simple and easy. However, they require regular monitoring for possible system failure.
Advantages	The establishment of safe, long-term storage facilities ensures that: 1. Grain supplies are available during times of drought (UNEP, 2010). It is important to be able to store food after harvest so as not to be compelled to sell at low prices. 2. Appropriate storing techniques can prolong the life of foodstuffs, and/or protect the quality, thereby preserving stocks year-round.
Disadvantages	1. Difficulties in achieving the desired freedom from excess moisture and foreign matter are frequently encountered. 2. Failure to adequately clean and dry grain can lead to pest infestations. 3. Over-drying of grains can also negatively impact seed quality. 4. Losses of seeds from insects, rodents, birds and moisture uptake can be high in traditional bulk storage systems. 5. Controlling or preventing pest infestation may require chemical sprays. Some markets will not accept seeds and grains treated with these chemicals.
Capital costs	
Cost to implement adaptation options	To install storage capacity of one ton in a good seed and grain storage system with a capacity of 60 000 tons in total with well installed drying space and management offices and other supporting equipments costs 15 $/ ton
Additional cost to implement extra unit	The average cost of one addition unit (ton) is 8 $/ton

Development impacts, indirect benefits	
Economic benefits	
Employment	Jobs are obtained in storage systems installation, operation and maintenance.
Investment	Investments opportunities exist in manufacturing and supply of in storage systems components and spare parts.
Public and private expenditures	A lot can be saved on seeds and grain importations.
Social benefits	
Income	Through the selling of their products at a reasonable price some time after harvest time, farmers earn extra income.
Learning	With this income farmers can send their children to school
Health	Well contained and stored grain would protect humans against storage pests such as insects, fungi etc
Environmental benefits	
Grain storage has been established to prepare for droughts and hunger and malnutrition (UNEP, 2010). Grain storage provides an adaptation strategy for climate change by ensuring feed is available for livestock and seed stock is available in the event of poor harvests due to drought (UNEP, 2010). Efficient harvesting can reduce post-harvest losses and preserve food quantity, quality and the nutritional value of the product (FAO, 2010). Innovations for addressing climate change include technologies for reducing waste of agricultural produce (BIAC, 2009). In fact, the establishment of safe storage for seeds and reserves of food and agricultural inputs are used as indicators of adaptive capacity in the agriculture sector (CARE, 2010)	
Local context	

Opportunities	• Existing storage techniques are fragile and not reliable • Improved storage infrastructures are generally absent and yet producers need them • There is a possibility to keep surplus produce stored away rather than having to sell any extra produce immediately • There is a possibility to sell any extra produce • There is increased profit through improved storage • Already some storage facilities have been installed countrywide which makes available knowledge and skills to implement the new technology • There exist benefits against investment on time, money and effort in improving storage.
Barriers	Produce has to be sold off immediately to pay off debts to landowners or creditors
Market potential	Seed and grain storage systems can be applied from small to large scales. In Rwanda, the technology has potential nationwide.
National status of the technology	Only very few installations (one in the eastern province, one at RAB premises in Kigali city, one at Bakheresa grain milers, two in the northern province) are in place for the whole country
Timeframe	The technology can be implemented immediately
Acceptability to local stakeholders	Well accepted by the local population

Annex III.B Agro forestry

Technology: Agro forestry	
Technology characteristics	
Introduction	Agro-forestry is used in almost the whole world where agriculture is practiced. In Rwanda, it is practiced in the agriculture zones which are found in all the provinces. World Agro forestry Center defines the technology as an integrated approach to the production of trees and of non-tree crops or animals on the same piece of land. The crops can be grown together at the same time, in rotation, or in separate plots when materials from one are used to benefit another. Agro-forestry systems take advantage of trees for many uses: to hold the soil; to increase fertility through nitrogen fixation, or through bringing minerals from deep in the soil and depositing them by leaf-fall; and to provide shade, construction materials, foods and fuel.
Institutional and organizational requirements	Agro forestry development in Rwanda involves government institutions/agencies such as the Ministry of Local Government, the Ministry of Agriculture and Animal Resources, the Ministry of Natural Resources, RAB/NAFA, Rwanda Natural Resources Authority Rwanda Environmental Management Authority, Research institutions like RAB/ISAR, Training institutions – Gako Organic Farming, NGOs such as ICRAF, farmers' associations/cooperatives –Urugaga Imbaraga and the private sector-dealers in seeds.
Size of beneficiaries	1 400 000 households
Operation and maintenance	It requires specialized skills in seedling production. Plantation and maintenance can be made easy by training farmers' representatives. Harvesting can be done using local knowledge.
Advantages	• Agro-forestry is appropriate for all land types and is especially important for hillside farming where

	agriculture may lead to rapid loss of soil. • Agro-forestry systems make maximum use of the land and increase land-use efficiency. • The productivity of the land can be enhanced as the trees provide forage, firewood and other organic materials that are recycled and used as natural fertilizers. • Increased yields. For example, millet and sorghum may increase their yields by 50 to 100 per cent when planted directly under Acacia albida (FAO, 1991). • Agro-forestry promotes year-round and long-term production. • Employment creation – longer production periods require year-round use of labor. • Protection and improvement of soils (especially when legumes are included) and of water sources. • Livelihood diversification. • Provides construction materials and cheaper and more accessible fuel wood • Agro-forestry practices can reduce needs for purchased inputs such as fertilizers
Disadvantages	Agro-forestry systems require substantial management. Incorporating trees and crops into one system can create competition for space, light water and nutrients and can impede the mechanization of agricultural production. Management is necessary to reduce the competition for resources and maximize the ecological and productive benefits. Yields of cultivated crops can also be smaller than in alternative production systems; however agro-forestry can reduce the risk of harvest failure.
Capital costs	

Cost to implement adaptation option	The average cost to put in place 1 ha of agro forestry plantations is 10 000 $ covering land preparation, seedling preparation (seeds purchasing, tubing, shade construction, nursery maintenance) and baby trees plantation.
Additional cost to implement extra unit	Any additional unit (ha) implemented in the same area during close periods is half of the price for the initial unit ($ 5000).
Development impacts, indirect benefits	
Economic benefits	
Employment	Creation of jobs in seedling preparation, land preparation, plantation, maintenance and harvesting
Investment	Can create investment in forestry production inputs, equipments and production transformation industry
Public and private expenditures	Can reduce public expenditure on subsidized fertilizers and irrigation systems
Social benefits	
Income	It increases the income earned and inputs saved through improvements in the farm resource base and products for sale. Through increased yields, it provides significant savings for households on fire wood, forage and fertilizer purchase.
Learning	Agro forestry practices would improve local knowledge about the technology and increased income would increase school attendance.
Health	It can improve medicinal plant conservation, domestication, and propagation, provides nutritious agro forestry foods, including fruits and leaves, promotes changes in ecosystem structure and function that affect disease risk and transmission.
Environmental benefits	
Increasing water infiltration and slowing runoff flow, stabilizing and protecting stream banks	

from erosion, filtering pollutants from runoff water, shading streams for controlling temperature, providing woody debris that promotes good stream habitat, providing habitat for wildlife, providing conduits for wildlife movement, slowing erosive winds and promoting dust deposition, providing visual diversity that improves scenic quality, screening undesirable views	
Local context	
Opportunities	-The technology is well understood by local farmers, -There exist farmers associations/cooperatives which can reduce initial investment costs by sharing the cost of seedling production, -Maintenance can be done by beneficiaries themselves, -Conservation and reforestation are among the country's' priority
Barriers	1. Poor access to agro-forestry inputs/resources including land tenure, tree tenure, water, seeds and germplasm, and credit. 2. Agro-forestry production or management issues relating to knowledge about agro-forestry systems, quality control, storage, processing of products, access to technical outreach services, and upfront costs versus long-term gain. 3. The main benefits of agro-forestry are perceived in the medium term at least five to ten years after establishment; this means that farmers must be prepared to invest in their establishment and management during several years before the main benefits are generated. 4. Marketing of agro-forestry products and services. Lack of access to transport, handling, processing, and marketing infrastructure, bans/restrictions on timber products.
Market potential	The technology has a national wide potential

National status of the technology	Agro forestry plantations only occupy ¼ of the available space to be used for the same purpose.
Timeframe	The implementation can start immediately
Acceptability to local stakeholders	Well accepted by the local population

Annex III.C Rain water harvesting

Technology: Rain water harvesting	
Technology characteristics	
Introduction	Rain water harvesting is a technology used for collecting and storing rainwater from rooftops, the land surface or rock catchments using simple techniques such as jars and pots as well as more complex techniques such as underground check dams. Commonly used systems are constructed of three principal components; namely, the catchment area, the collection device, and the conveyance system.
Institutional and organizational requirements	To implement this technology, the government of Rwanda through the Ministry of Local Government-local governance entities, the Ministry of Agriculture and Animal Resources, Rwanda Agriculture Board would play a key role in providing subsidies for equipment purchases by making the technology accessible to a larger number of farmers, particularly small-scale farmers, who have problems raising capital investment funds. The technology is simple to install and operate and does not imply any specific organizational requirements.
Size of beneficiaries	1 400 000 households
Operation and maintenance	Rain water harvesting systems are easy to operate. However maintenance is required for the cleaning of the tank and inspection of the gutters, pipes, taps and other conveyance systems which typically consist of the removal of dirt, leaves and other accumulated materials. In the Rwandan context, such cleaning should take place twice

	annually before the start of the major rainfall season with regular inspections.
Advantages	Rainwater harvesting technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are also readily available. Rainwater harvesting is convenient in the sense that it provides water at the point of consumption, and family members have full control of their own systems, which greatly reduces operation and maintenance problems. Running costs, also, are almost negligible. Water collected from roof catchments usually is of acceptable quality for domestic purposes. As it is collected using existing structures not specially constructed for the purpose, rainwater harvesting has few negative environmental impacts compared to other water supply project technologies. Although regional or other local factors can modify the local climatic conditions, rainwater can be a continuous source of water supply for both the rural and poor. Depending upon household capacity and needs, both the water collection and storage capacity may be increased as needed within the available catchment area.
Disadvantages	Disadvantages of rainwater harvesting technologies are mainly due to the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source in dry periods or in time of prolonged drought. Low storage capacity will limit rainwater harvesting potential, whereas increasing storage capacity will add to construction and operating costs making the technology less economically viable. The effectiveness of storage can be limited by the evaporation that occurs between rains. Adoption of this technology requires a *bottom up* approach rather than the more usual *top down* approach employed in other water resources development projects.
Capital costs	

Cost to implement adaptation options	Currently, to install one cubic meter in a rooftop rainwater harvesting system costs: 3. With plastic tank: $ 230 4. Stone and concrete tank: $ 220 The installation of one cubic meter in a small sized (240 m^3) runoff pond system costs: $ 15
Additional cost to implement extra unit	To install additional one cubic meter in a rooftop rainwater harvesting system costs: 1. With plastic tank: $ 200 2. Stone and concrete tank: $ 220 The installation of one cubic meter in a small sized (240 m^3) runoff pond system costs: $ 15
Development impacts, indirect benefits	
Economic benefits	
Employment	The implementation of the technology itself does create employment through the installation of the systems' components for both rooftop and runoff pond systems. These opportunities can be more observed in the case of runoff pond system which is labor intensive.
Investment	There are investments opportunities in the manufacturing of commodities needed to put all the component of any rain water harvesting. They include gutters, pipes, pumps, taps, dam sheets etc.
Public and private expenditures	Savings can be made on money spent by the government in supplying food during prolonged draughts and in alternative water infrastructures installation for remote areas.
Social benefits	
Income	With improved water supply through rooftop rain water harvesting and runoff pond systems, households and small-scale farmers are able to not only feed their families better, but also earn extra income from selling their produce at local markets.
Learning	With this income farmers can send their children to school

Health	On the health side, the technology improves water supply conditions which have positive impacts on hygiene. With improved income, people are able to upgrade their living conditions by renovating their shelter.
Environmental benefits	
-Rainwater harvesting removes the need for the energy and chemicals used to produce pure drinking water - unnecessary if all we're going to do is watering the garden, clean the car or flush it down the toilet -It also reduces the need for the pumping of mains water, and the energy use, pollution and CO_2 emissions that go with it -It reduces demand on rivers and groundwater -Using water to wash cloths reduces the amount of detergent used and reduces water pollution from these compounds -Large-scale collection of rainwater can reduce run-off and therefore the risk of flooding	
Local context	
Opportunities	-There exist two separate intensive rainfall seasons/year countrywide which make rain water harvesting optimum. - Increasing the size of irrigated space is one of the country's priorities in the agriculture sector.
Barriers	-The cost of rainwater harvesting systems is relatively high -Lack of national policy on rainwater harvesting -Lack of technical assistance in maintaining communally-owned systems
Market potential	Rain water harvesting systems can be applied from small to large scales. In Rwanda, the technology has potential nationwide.
National status of the technology	Only around 1% of the total number of beneficiaries has rooftop rain water harvesting systems.
Timeframe	Pilots installations have already took place in the eastern province where water is a big issue. This gives the technology the possibility of being implemented immediately.
Acceptability to local stakeholders	The technology is well known by the population and can be easily accepted.

Annex III.D Drip irrigation

Technology: Drip irrigation	
Technology characteristics	
Introduction	Drip irrigation is based on the constant application of a specific and focused quantity of water to soil crops. The system uses pipes, valves and small drippers or emitters transporting water from the sources (i.e. wells, tanks and or reservoirs) to the root area and applying it under particular quantity and pressure specifications. The system should maintain adequate levels of soil moisture in the rooting areas, fostering the best use of available nutrients and a suitable environment for healthy plant roots systems. Managing the exact (or almost) moisture requirement for each plant, the system significantly reduces water wastage and promotes efficient use. Compared to surface irrigation, which can provide 60 per cent, water-use efficiency and sprinklers systems which can provide 75 per cent efficiency, drip irrigation can provide as much as 90 per cent water-use efficiency (FAO, 2002).
Institutional and organizational requirements	The development and use of drip irrigation would involve government institutions/agencies such as the Ministry of Local Government-local governance entities, the Ministry of Agriculture and Animal Resources, Rwanda Agriculture Board/ISAR, Training institutions – Gako Organic Farming, NGOs such as, farmers' associations/cooperatives –Urugaga Imbaraga and local suppliers - Balton company. Organizational requirements involve capacity building for workers in order to accurately manage maintenance and water flow.
Size of beneficiaries	1 200 000 households
Operation and maintenance	The operation and maintenance of the technology requires

	technical skills and relatively high initial investments.
Advantages	Drip irrigation can help use water efficiently. A well-designed drip irrigation system reduces water run-off through deep percolation or evaporation to almost zero. If water consumption is reduced, production costs are lowered. Also, conditions may be less favorable for the onset of diseases including fungus. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality. Agricultural chemicals can be applied more efficiently and precisely with drip irrigation. Since only the crop root zone is irrigated, nitrogen that is already in the soil is less subject to leaching losses. In the case of insecticides, fewer products might be needed. Fertilizer costs and nitrate losses can be reduced. Nutrient applications can be better timed to meet plants' needs. The drip system technology is adaptable to terrains where other systems cannot work well due to climatic or soil conditions. Drip irrigation technology can be adapted to lands with different topographies and crops growing in a wide range of soil characteristics (including salty soils). It has been particularly efficient in sandy areas with permanent crops such as citric, olives, apples and vegetables. A drip irrigation system can be automated to reduce the requirement for labor.
Disadvantages	The initial cost of drip irrigation systems can be higher than other systems. Final costs will depend on terrain characteristics, soil structure, crops and water source. Higher costs are generally associated with the costs of pumps, pipes, tubes, emitters and installation. Unexpected rainfall can affect drip systems either by flooding emitters, moving pipes, or affecting the flow of

	soil salt-content. Drip systems are also exposed to damage by rodents or other animals. It can be difficult to combine drip irrigation with mechanized production as tractors and other farm machinery can damage pipes, tubes or emitters.
Capital costs	
Cost to implement adaptation options	The technology is widely variable, however the cost of a drip irrigation system ranges from US$ 800 to US$ 2,500 per hectare depending on the specific type of technology, automatic devices, and materials used as well as the amount of labor required
Development impacts, indirect benefits	
Economic benefits	
Employment	Creation of jobs in systems installations and maintenance
Investment	Investments in components manufacturing, supply and systems installation.
Public and private expenditures	Could increase yields, contribute to food security and reduce public expenditure on food purchased abroad in case of prolonged droughts.
Social benefits	
Income	In the Rwandan context, the technology would increase farmers' income by increasing the number of harvests from two to four times per annum and by making savings on water, energy and labor costs.
Learning	The use of drip irrigation would improve local knowledge about the technology especially in water resources management. Savings made by adopting the technology and increased income would increase school attendance.
Health	Reduces air pollution and improves air quality because improved plant health promotes plant absorption of air pollutants. Also, water conservation can lead to decreased energy use and associated air pollution associated with pumping and treating less irrigation water.

	Reduces human exposure to hazardous material because controlling the amount of water administered to plants improves plant health, reducing the need for fertilizers and pesticides.
Environmental benefits	
Drip irrigation conserves water as it applies water directly to the roots, which minimizes runoff and evaporation. Rain-shutoff devices minimize over-watering after significant rainfall. It reduces runoff and non-point source pollution because drip irrigation systems and rain-shut off devices control the application rate to meet the plants' need for water, minimizing water and subsequent runoff. Improves groundwater recharge because sub-surface drip irrigation systems and rain-shutoff devices calibrate the rate and amount of water to match the absorption rate of the soil. This will minimize runoff and improve groundwater recharge. Improves soil quality and retards erosion because reducing runoff can prevent degradation of soil structure and reduce erosion, depending on the surrounding landscape. Supports local ecology as it delivers water directly to the plants' roots, which encourages strong root growth. Preserves wildlife habitat because sub-surface drip irrigation systems promote healthy plant life, which contributes to wildlife habitat. Conserves fossil fuels because reduced water usage can lead to decreased energy needed to pump and treat irrigation water.	
Local context	
Opportunities	-There exist reform in water resources management -Existence of good public institution arrangements to implement the technology. -There exist farmers' cooperatives and associations which can facilitate capacity building and medium scale implementation of the technology, increasing economic benefits and reducing initial investment costs.

	- Irrigation is one of the priorities in the agriculture sector -The technology can be employed in conjunction with other adaptation measures such as the establishment of water user boards, multi-cropping and fertilizer management. -Promoting drip irrigation contributes to efficient water use, reduces requirements for fertilizers and increases soil productivity.
Barriers	-Lack of access to finance for the purchase of equipment, -High initial investment, -Presence of steep slopes can increase implementation and maintenance costs or affect drip system efficiency.
Market potential	The technology is small-scale, proven with potentials of harvest time increment per annum. It has market potential nationwide.
National status of the technology	Only very few installations are in place. Agriculture Research Centers, horticulture green houses for flower and tomatoes growing.
Timeframe	The implementation can start immediately after an awareness raising campaign about the functions and benefits of the technology among farmers has been completed
Acceptability to local stakeholders	There is little knowledge of the technology by local stakeholders which can make the acceptance difficult.

Annex III.E Radical terracing

Technology: Radical terracing	
Technology characteristics	
Introduction	Radical terracing refers to a technique of landscaping a pierce of sloped land into a series of successively receding flat surfaces or platforms, which resemble steps, for the purposes of more effective farming. This type of landscaping, therefore, is called terracing. Graduated terrace steps are commonly used to farm on hilly or mountainous terrain. Terraced fields decrease erosion and surface runoff retaining soil nutrients. According to Mupenzi et al. 2012, radical terraces contributed to increase in the farm productivity, fight against erosion and also contributed to poverty reduction in Rwanda.
Institutional and organizational requirements	The implementation of radical terracing would involve government institutions/agencies such as the Ministry of Local Government-local governance entities, the Ministry of Agriculture and Animal Resources, Rwanda Agriculture Board/ISAR, Training institutions – Gako Organic Farming, NGOs such as, farmers' associations/cooperatives –Urugero cooperative and local suppliers. Organizational requirements involve knowledge of terraces design, installation and maintenance, including contouring or leveling techniques as well as knowledge of crops suited to radical terraces. Radical terraces can also be implemented at farm-level without specific institutional and organizational arrangements. Notwithstanding, local government agencies can provide assistance in the form of technology transfer and training and subsidies. In terms of social organization, advantage should be taken of communal work ethics and other mutual cooperation systems for faster installing and more efficient maintenance.
Size of beneficiaries	1 000 000 households

Operation and maintenance	Compared to the old landscape, radical terraces are simple and easy to operate, cheap to maintain in terms of money and allocated time.
Advantages	Radical terraces allow for the development of larger areas of arable land in rugged terrain and can facilitate modern cropping techniques such as mechanization, irrigation and transportation on sloping land. They increase the moisture content of the soil by retaining a larger quantity of water. They capture run-off which can be diverted through irrigation channels at a controlled speed to prevent soil erosion. They increase soil exposure to the sun and they replenish the soil and maintain its fertility as the sediments are deposited in each level, increasing the content of organic matter and preserving biodiversity. Radical terraces have also been shown to increase crop productivity.
Disadvantages	In terms of limitations, an economic analysis of terrace investments in the Peruvian Andes has shown that if implemented on a regional-scale, terraces can produce varied and sometimes limited returns. Where farmers must pay the full costs of investments, returns can be as low as 10 per cent (Antle et al, 2004). Profitability will depend on additional factors such as interest rates, investment costs and maintenance costs. Cost-benefit analysis should, however, take account of other factors including increased soil productivity and conservation benefits.
Capital costs	
Cost to implement adaptation option	The average cost to establish on hectare of radical terraces in Rwanda including manpower and basic tools such as picks, shovels is $ 1000 tax exclusive.
Additional cost to implement extra unit	The cost for any additional unit (ha) of radical terraces would cost the same amount as the initial unit.
Development impacts, indirect benefits	
Economic benefits	

Employment	The implementation radical terraces are a labor intensive exercise which provides jobs to the local population.
Investment	There are investments opportunities in tools manufacturing. These include picks, shovels, tridents etc
Public and private expenditures	With its potential in soil fertility restoration, the technology would significantly reduce the amount of money spent by the government of Rwanda on subsidized fertilizers.
Social benefits	
Income	By increasing arable surface, soil fertility as well as permanent moisture content, radical terraces contribute to the improvement of yields in both quality and quantity. For example potato yields would increase up to 140% on terraced spaces compared to non terraced ones which generate more income to the farmer.
Learning	Radical terracing technology would add something on the Rwandese farmers' skills and increase family members' opportunities to attend school.
Health	Minimize the number of accidents and causalities as a result of farm operations on steep slopes and landslides.
Environmental benefits	
Well studied and installed radical terraces have several environmental benefits which include; -Soil erosion control -Soil moisture improvement and maintenance -Soil fertility improvement and maintenance -Biodiversity conservation -Natural hazards (land slide) prevention	
Local context	
Opportunities	-The technology has proven being suitable locally, -Can be implemented by the local population, -It provides an opportunity for improvements in soil, crop and water management practices
Barriers	-Difficult access to credit by local farmers,

	- The technology takes time to give returns which can lead to farmers abandoning the technology if long-term benefits are not fully understood.
Timeframe	There are already some actions to promote and implement the technology and it can continue where it has already been started. For new places, it can start immediately.
Acceptability to local stakeholders	The technology is accepted by Rwandan farmers

Annex IV-Technology factsheets-Mitigation sector

Annex IV.A. Large Grid Connected Solar Photovoltaic Technology

1. Introduction	
1.1. Historical	- The first steps of PV technology proved that special material of semiconductors convert directly the sunlight into electricity. - Process of preparing such materials require about 1 400 °C, this is why, and among others, that PV systems are expensive - Worldwide production was only 5 MW in year 1982 and substantially increased to 385 MW in year 2001 - Above trends are regarding mainly small-scale solar PV - In fact, large grid-connected solar PV technology is relatively new, but highly promising
1.2. Location of Resources	- Whole country
1.3. Variability of Resources	- Stable , equatorial zone
2. Brief Description	
2.1. Conditions	- Solar radiation: globally about 5 kWh every day and per one square meter of a receiver surface - Conditions for a proper production of electric power directly connected to national grid, or any mini-grid, are complex due to required agreements between EWSA and private sector expected to invest in large-scale PV such as 5 MW or more
2.2. Characteristics	- Below description of characteristics of

	a 5 MW solar PV plant is based on a modular unit of 73 kW [http://www.caddet.org] ✓ PV area: 532 m^2 ✓ PV efficiency: 14% ✓ Inverter efficiency: 85% (DC to AC) ✓ Total incident radiation: 526 MWh/year ✓ Total incident: 55 MWh/year - Such a modular unit can result in a larger PV plant once about 70 units are assembled and provide 5 MW - Connection to the national grid is more appropriate for reducing the cost by avoidance of use of batteries; thus the capacity factor equals the daily sunshine duration (in Rwanda about 6 hours) - Lifespan of main components: 25 years - Best materials: Crystalline silicon - Remark: Optional scenario for reduction of cost = concentrating solar in order to use less size of solar modules (Requirements of about 5 kWh/m^2 for the beam direct normal solar component)
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Based on lessons and experience for grid-connected solar PV in USA, in Europe and in North Africa, applications of large-scale PV is feasible in Rwanda

3.2. Potentialities	- Over the whole year, the incident solar radiation is, as average, about 5 kWh/m^2 - Particularly during the two rainy seasons, the solar radiation remains sufficient due to the fact that the solar declination is almost matching the latitudes in Rwanda (Duffie et al, 1988)
3.3. Limitations	- The main constraint to the deployment of solar PV systems in Rwanda is due to initial cost of investment which is very high in addition to the fact that the payment of acquisition is cash instead of loans from Banks
4. Status of the Technology in Rwanda	
4.1. Local Production	- Access to commercial solar PV modules is made easy due to the maturity of such technology in Europe, USA, China and Japan - Assembly of solar calls resulting in such modules locally in Rwanda is possible but not yet done; but in year 1993, a small workshop in actual Muhanga District was assembling cells resulting themselves in small modules
4.2. Shared Power Plants	- NA
4.3. Projects	- EWSA presented recently in February 2012 at Kigali an opportunity of investing in large-scale solar PV and an alternative of grid-connected expected for short term
5. Benefits to Development	

5.1. Social	- Especially, rural population will be more committed to join the Umudugudu policy and settlements - Facilities like charging phones, iinternet and TV access are thus becoming more popular
5.2. Economic	- Promotion of exploitation of local natural resources for electric power generation - Reduction of exodus from rural to urban areas - Small scale business and factories are more promoted and increased towards a better GDP and incomes - Increases rate of access to electricity services and thus to good growth of economy - Creation of jobs
5.3. Environmental	- Decrease of use of wood and charcoal fuels, of petroleum for lighting - Increase of promotion of electric vehicles through wider available battery stations
6. Climate Change Mitigation Benefits	
6.1. Reduction of GHG Emissions	- Solar PV is a non carbon technology - Batteries are not required in case of grid-connected solar option - In case of replacing the existing thermal oil power plants by large solar PV , the rate of contributing to the reduction of GHG emissions is about 79%. - In fact the emission factor of solar PV

	grid is about 155 kg / MWh against 750 kg/MWh and 1075 kg/MWh respectively by the oil and peat use.
6.2. Low Carbon Credits	- Grid-Connected Solar PV, being a non-carbon resource, will hence contribute in carbon market
6.3. Specific Sectors of Health	- Air and water quality are conserved due to use of such a clean source of electricity - Pollution is limited or avoided
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- Even Solar PV systems, there are popular in Rwanda; therefore private investors can be attracted by the approach of grid-connected solar power. Such a scenario is today planned by EWASA and MININFRA in Bugesera District
7.2. Capital Cost	- For instance a 5 MW of PV had its initial capital cost of 7 060 USD/kW - Projection for the year 2015: about 4500 to 5 500 USD/Kw
7.3. Generating Costs	- Projections for the year 2015: total energy generation cost is in the range of 25 to 33 US cents/kWh - Total levelized cost in year 2005: 42 US cents/kWh - The O & M costs are negligible
7.4. GHG Emissions	Slight emissions are associated to the process of preparation and transformation at high temperature before reaching the finished solar cells
7.5. Capability Building	- Small solar PV systems are often

	installed in Rwanda and technicians became sufficiently skilled - But, it is not the large and grid-connected solar power technology; such a new scenario in Rwanda requires more skilled staff technicians

Annex IV.B. Small Hydropower Technology

1. Introduction	
1.1. Historical	- All over the World, hydropower sector is playing a great role in economic development since the last decades of the 20th century - In Rwanda, hydropower development started mainly with harnessing water from Lakes Bulera and Ruhondo but also the River Sebeya - Before 1980's local production of hydropower was very small
1.2. Location of Resources	- Rich Hydrography covered by the upper Nile and Congo river basins with many streams - High lands in Northern, Western and Southern Provinces for hydropower development - Reforestation is welcomed for stability of water resources - Rainfall is enough along the two main wet seasons - A Rwanda hydropower atlas has been recently established and about 333 potential sites for small hydro development have been characterized and recommended for exploitation
1.3. Variability of Resources	- It is important to highlight that, by now and then, rainfall resources for recharging the aquifers towards the baseline flow are affected by the ENSO phenomenon - Eastern Province is characterized by a

	specific geology resulting in poor potentialities for micro hydropower
2. Main Characteristics	
2.1. Conditions	- Usual no need of water storage - Reservoir in case of need of storage of water (use of dams and spillways) to avoid seasonal impact - Enough head and water levels - Option of in-stream turbine for pico-hydro - Control of river flow by crested weirs - Permissible head, turbine and generator
2.2. Characteristics	- Efficiency of converting hydraulic energy into electric power is high, about 60% - Use of Manning equation for designing small hydroelectric power systems drivers by water flowing through closed conduits (steel or PVC or concrete penstocks) - For capacity less than 600 kW, installed transformers can be very small - Hydraulic turbines (efficiency: 80%), Generators: 90% and Transformers: 90% - Option of in-stream turbine is appropriate for low lands like in Western Province of Rwanda - Design: Kaplan or Francis Turbine; self excited induction for picohydropower - Amount of electric power is

	proportional to the head drop and the water flow discharged on turbine - Pico-hydro: lifespan is about 15 years - Micro-hydro: lifespan is about 30 years - The capacity factor i.e. operational time duration per day: about 30% - Power capacity: less than 50 kW for a pico-hydro system and less than 1 000 kW for a micro-hydro plant - Electric output is linked to seasonal variations of water flow
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Illustrative example: For a head drop of 2 m, any stream flow of 0.3 m^3/s can generate an electric power of 3 kW; such a stream cross-section is 25 cm x 30 cm if v = 2 m/s - Pico-hydropower systems (for lowest capacity i.e. less than 10 kW) are yet to be introduced - Also in-stream turbine alternative is not used in Rwanda, but it is quite applicable and recommended especially for Akanyaru, Nyabarongo and Akagera rivers in low lands in Eastern areas - Remark: Micro-hydropower systems are popular in Rwanda and got a great acceptability by all kinds of stakeholders
3.2. Potentialities	- Important water resources and sites presenting head drops in Northern, Western and Southern Provinces

	- During the year, apart from the underground base flow towards the rivers and streams, rainfall trends are stable in the two main rain seasons
3.3. Limitations	- Eastern Province: Not proper for Micro-hydropower - Seasonal variations affected for instance the hydro sector in 2000-2003 during the drought linked to El Nino/La Niña events - Hydrological risk is thus to be considered for a proper design and sustainability of the project
4. Status of the Technology in Rwanda	
4.1. Local Production	- Domestic hydropower productions: 44 MW in year 2006, with supply to industrial sector (40%) and to services (20%) - These above 44 MW represent 56% of the total electric production (against 44% by oil-fired thermal power plants) - Rate of access to electricity services to population: 6% in year 2006 - Tariff: 22 US cents/kWh
4.2. Shared Power Plants	- Hydropower resources in Rwanda are shared with neighbouring countries - Thus, Rusizi river power plants and coming Rusumo project are among examples of share
4.3. Projects	- Pico and Micro-hydropower sectors are expected to generate above 20 MW of electric capacity against for instance 27.5 MW by the Nyabarongo

	Hydropower Project
5. Benefits to Development	
5.1. Social	- Especially, rural population will be more committed to join the Umudugudu policy and settlements - Facilities like charging phones, internet and TV access are thus becoming more popular
5.2. Economic	- Promotion of exploitation of local natural resources for electric power generation - Reduction of exodus from rural to urban areas - Small scale business and factories are more promoted and increased towards a better GDP and incomes - Increases rate of access to electricity services and thus to good growth of economy - Creation of jobs
5.3. Environmental	- Decrease of use of wood and charcoal fuels, of petroleum for lighting - Increase of promotion of electric vehicles through wider available battery stations
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	- Progressive replacement of diesel engine power generators and of wood fuels(at some extent) will result in a significant decrease in GHG emissions - The total annual CO_2 emissions by energy sector in Rwanda in year 2002 (MIINITERE, 2005) was 6 948 gig

	grams (4% by petroleum, 11% by charcoal and 85% by wood fuel) - Only 43 kg/MWh are emitted by a hydro plant; thus the rate of contribution to reduction of GHG emissions is very high(94%),compared to the use of oil in thermal power plants(emission factor : about 750 kg/MWh)
6.2. Low Carbon Credits	- Promotion of pico/micro hydropower sector will contribute in reducing CO_2 and CH_4 emissions as far as the projections predicted that electricity will be also used for cooking and of course for industrial purposes; therefore wood fuel and charcoal will be partially replaced - Given the importance of sequestration of carbon emissions by the forests, any reduction in use of wood fuel and charcoal results in increase of carbon credits opportunity
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- Development, as wider scale, of pico/micro hydropower systems will require more involvement of private sector in close partnership with among others the districts - In fact, off grid scenario is widely applicable in different areas of Rwanda and potential of pico-hydro is high
7.2. Capital Cost	- Probable capital cost of pico/micro

	hydro systems in year 2015 (Ref.: ESMAP, 2007) is 1 470 USD/kW, 2 550 USD/kW and 2 450 USD/kW respectively for the capacity of 300 W, 1 kW and 100 kW; these, against 1 560 USD/kW, 2 680 USD/kW and 2 600 USD/kW in year 2005 - Comparison to a mini hydroelectric power system of 5 MW: cost of 2 370 USD/kW in year 2005 and 2 250 USD/kW in year 2015
7.3. Generating Costs	- Probable generating costs for a 100 kW power plant is, in year 2015, about 11 US cents/kWh (with 13% for O & M costs and 87% for levelized capital cost) in coming year 2015 [Ref.: ESMAP, 2007] - Compared to a 5 MW mini hydropower (7 US cents), the generation cost is higher for the pico/micro hydro
7.4. GHG Emissions	- Externalities are not considered, the pico/micro hydro is a friendly environmental
7.5. Capability Building	- There is a great need in enhancing the capacity building for further skilled staff and technicians for design, operation and maintenance once the technology is widely deployed in Rwanda

Annex IV.C. The PHEV technology

1. Introduction	
1.1. Historical	- The concept of PHEV option is well known in transport sector but its diffusion and deployment have not been characterized by a high speed of penetration in the market
1.2. Location of Resources	- Recharging batteries requires a set of stations providing electric energy preferably generated through use of renewable resources
1.3. Variability of Resources	- Renewable energy sources of electric power expected can be mainly the solar based options, geothermal and hydropower ; - Such sources are stable in Rwanda
2. Brief Description	
2.1. Conditions	- Large campaigns - Installation of appropriate stations for recharging the batteries running the electric motors of vehicles
2.2. Characteristics	- Any PHEV is mainly equipped with a combination of a classic efficient gasoline engine, a conventional electric motor and rechargeable batteries - Recharging batteries through a station connected to electric grid - Efficiency of internal combustion is 25% in urban areas - Efficiency of battery electric motor to wheels a conversion of chemical energy into rotation energy is about 75%

3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- PHEV can largely work in Rwanda as far as power projects for electric generation through renewable option are part priority at short and medium terms - PHEV technology and its components are commercially proven and ca be applied in Rwanda road transport market - PHEV is a potentially promising technology for mitigation purposes
3.2. Potentialities	- Opportunities and potentialities for PHEV technology are important especially within the current context of regular increase in the costs of importation of vehicles and gasoline and diesel fuels
3.3. Limitations	- Rechargeable batteries require a special maintenance and recharges with a relatively high frequency of returning to the station - A lot of second hand vehicles are available on the local market
4. Status of the Technology in Rwanda	
4.1. Local Production	- Not yet introduced in Rwanda - Both batteries, electric motors, internal combustion engines and other spare-parts are imported
4.2. Shared Power Plants	- NA
4.3. Projects	- PHEV option is still a project idea in Rwanda - Goals and visionary aims for efficient

	inclusive integrated transport system - fully secure domestic energy supply, multi-modal transport based efficient technologies) are projected up to 2050
5. Benefits to Development	
5.1. Social	- Introduction to the new vehicles on local market can induce an interest in setting up local units for manufacturing components of PHEV and hence for creating new jobs
5.2. Economic	- Benefits from increasing use of renewable resources and decreasing importation of gasoline and diesel for vehicles - Potential manufactures and industry of PHEV components - Cost of electricity is lower than the cost of fossil petroleum fuels
5.3. Environmental	- Using such vehicles based on a mixed «electric and liquid fuel» contribute in a significant decrease in GHG emissions
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	- The amount of CO_2 emissions is about 0.11 kg/km for PHEV against about 0.44 kg/km by usual non efficient gasoline vehicles in urban areas; - In rural areas and highways, CO_2 emission are respectively 0.09 kg/km and 0.26 kg/km respectively by PHEV and usual gasoline vehicles
6.2. Low Carbon Credits	- Carbon market is really recommended for such road transport option.

	- Once made available such a special incentive can result in a wide diffusion of PHEV in Rwanda
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- Once promoted and commercially available, the PHEV will greatly interest the private sector
7.2. Capital Cost	- The initial cost of a PHEV is higher than the conventional vehicles ; - In fact the PHEV, are still limited on international market
7.3. Generating Costs	- Cost of «gasoline-electric» fuel is 2 times lower than the cost of liquid fuel for classic gasoline vehicles; - The maintenance cost for classic gasoline vehicles is about 1.5 times more important than the PHEV maintenance

Annex IV. D. Concentrated Solar Power (CSP) with Storage System

1. Introduction	
1.1. Historical	- CSP is a high temperature solar power technology - First solar concentrator and steam engine, in Egypt in year 1913 - USA, in 1991, an area of mirrors and receivers generate 384 MW of electric power and are today still working properly - Spain, followed the example of USA and constructed - Options: parabolic through is more reliable
1.2. Location of Resources	- Solar radiation in Rwanda is available the whole year and even during rainy seasons - CSP utilizes only the sunlight tracking component (direct normal solar) and Eastern Province is more favourable while high lands in North or West are favourable only in absence of cloudy periods - Inter seasonal variability is low
1.3. Variability of Resources	- Direct normal solar irradiation component(DNI)of the global solar radiation (direct plus diffuse)is proportional to duration of sun shine: average of six hours per day in Rwandan sunny regions
2. Brief Description	
2.1. Conditions	- Need of information of spatial and daily distribution of solar energy,

	especially its beam component which can be tracked (DNI = 0, i.e. Direct Normal Solar Radiation) - Need of enough land for installation of field area of collectors/mirrors - Need of agreement between the owner of the power plant and EWASA for an alternative of direct connection to the national grid instead of installation the system for thermal output storage
2.2. Characteristics	- Direct perpendicular component of solar radiation on a mirror (parabolic, spherical) is tracked by a mechanical tracking system from 06h00 to 17h00 - Then such a flux of solar energy is focused and concentrated on a small absorber (black painted) - Via a system of pipes containing a thermal working fluid, such a fluid is heated by the absorber - Step of transfer of heat to water becoming a steam with high temperature and high pressure - Finally, a steam turbine and an alternator are rotated by such a steam - Option of a thermal storage molten salt system (higher cost) - Option of direct connection to an available grid network without any thermal storage
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- A proper design and pre-feasibility studies are required before any

	conclusion regarding the level of applicability in Rwanda - Only indicative preliminary studies on DNI variability are available but not yet validated (Museruka, 2011)
3.2. Potentialities	- Preliminary studies prove that area Rwanda are characterized a stable DNI resources: about five kWh/m^2 per day; in fact the elevation constant angle is about 0.5; there is also an opportunity of permanently tracking the DNI incident on ground surface
3.3. Limitations	- For some months, the DNI component equals and even exceeds the global solar radiation
4. Status of the Technology in Rwanda	
4.1. Local Production	- NA
4.2. Shared Power Plants	- NA
4.3. Projects	- NA
5. Benefits to Development	
5.1. Social	Refer to above other technology options
5.2. Economic	Idem /ditto
5.3. Environmental	Idem /ditto
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	Refer to above other clean technology options
6.2. Low Carbon Credits	Such a new technology is highly eligible to carbon credits; it is a short term option, in fact it already commercial in leading countries(USA, Spain)
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	Special incentives, subsidies and particular studies for design are both required for

	motivating the involvement of private sector in such a technology
7.2. Capital Cost	- Capital cost for a typical 30 MW: - In year 2005, about 2 480 USD/kW and 4 850 USD/kW respectively for option without storage and option having a molten salt storage tanks system - Projection to year 2015: about 2 000 USD/kW and 4 000 USD/kW - Compared to a solar photovoltaic, the capital cost of the latter is 3 to 2.5 times more higher This CSP technology of concentrating and tracking incident direct normal solar radiation is becoming very attractive and promising
7.3. Generating Costs	- CSP without storage (i.e. directly connected to national grid): 18% of total generation cost which was 13 US cents/kWh in year 2005 and projected to 11 US cents/kWh in year 2015 CSP with a thermal storage: 22% of total generating cost (18 US cents/kWh in year 2005)
7.4. GHG Emissions	CSP technology is mainly based on solar fuel and optical parabolic mirrors; thus it is a very low carbon emission The emission factor(about 43 kg/MWh) is lower than the case of solar PV
7.5. Capability Building	Local expertise is to be trained for handling such a promising new technology requiring, in its design, additional components(heat storage, backup system, optional connection to national electric grid)

Annex IV. E. Wind Turbine

1. Introduction	
1.1. Historical	- Wind power technology is proven option for generating electricity and become very popular where resources area available and sufficient enough [Velocity>5 m/s] like coastal regions - By the year 2003, capacity commercial wind turbines ranges between 600 kW to 2.5 MW against only 25 kW twenty years ago (The Power Guide, 1994, and ESMAP, 2000)
1.2. Location of Resources	- Ares more flat, such as the Lake Kivu water surface or the tops on mountains characterized with a morphology favourable to the wind flow - Average for stations with datasets records is about 2 m/s above ground - Vertical gradient is increased at about 100 m above ground - Periods for which velocity is higher than 5 m/s are mainly the afternoons
1.3. Variability of Resources	- Wind resources are very limited in Rwanda(being spatial distribution, velocity of air, frequency, duration)
2. Brief Description	
2.1. Conditions	- Wind atlas is required before any exploitation; frequency and variability of wind velocity - Identification of potential sites and preliminary design and pre-feasibility studies
2.2. Characteristics	- Wind is captured by the blades of the

	of the rotor of the turbine - Rotor to alternator, through a transmission shaft - Induction alternator (more flexible, direct connection to the grid, power electronics control) or synchronous alternator (gearboxes, revolution of rotor is increased with wind speed - Typical commercial turbine = 600 kW to 2 500 kW - Wind tower: 65 m to 100 m; lattice (bolted structure) or tubular (more withstanding vibrations, easy access to the nacelle); the yaw control (for orienting the rotor in wind direction) - Option of batteries, mini-grid for villages via a DC – AC inverter
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Refer to the about paragraph n° 1.2 and 2.1
3.2. Potentialities	- At the top of mountains - Along the Lake Kivu - Locations: Historically known for rich resource of wind flow
3.3. Limitations	- Wind speed variation - Frequency and duration of acceptable value of wind speed - Mountainous topography and morphology limiting the wind - Location of a country vis-à-vis large oceans
4. Status of the Technology in Rwanda	
4.1. Local Production	- NA

4.2. Shared Power Plants	- NA
4.3. Projects	- Wind atlas project is being implemented; preliminary measurements proved that wind velocity at 40m above ground surface is in the range of 2.3 m/s to 4m/s
5. Benefits to Development	
5.1. Social	Opportunity of setting up hybrid wind/ solar at small scale in selected rural areas
5.2. Economic	Remote areas can develop non-agricultural incomes based on among others water pumping systems, in fact, wind resources in Rwanda are more eligible to running pumps instead of generating electric power
5.3. Environmental	- No GHG emissions - But, impact of noise, bird death, land acquisition, aesthetic and visual consideration location – specific impacts and mitigation
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	Wind is a clean and renewable energy
6.2. Low Carbon Credits	Wind is highly eligible to carbon credits
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	Small scale wind solar hybrid systems and water pumping by wind are relatively affordable and thus a private sector involvement has to be initiated and promoted
7.2. Capital Cost	- Up to 2 300 USD/kW for a typical 100 kW - About 1 100 USD/kW for a 10 MW capacity
7.3. Generating Costs	- 31% of the total generation cost for a 100 kW

	- 12% of the total generation cost for a 10 MW - Generation cost is 19 and 6 US cents/kWh respectively for a 100 kW and a 10 MW - Thus, the higher the power capacity, the lower the cost
7.4. GHG Emissions	Wind is a non-carbon emissions Its emission factor is very low: 43kg/MWh
7.5. Capability Building	Training for design of wind options is highly recommended especially due to the intermittent behaviour of wind distribution in Rwanda

Annex IV. F. Geothermal Power Technology

1. Introduction	
1.1. Historical	- By the year 1870: discovery of the role of radiogenic heat generated by long-lived radioactive isotopes of Uranium, Thorium and Potassium - In 1942, installed capacity of worldwide geothermal -electricity reached 127 MW against 9 028 MW in year 2003
1.2. Location of Resources	- With reference to hydrothermal manifestations on ground surface mainly along the lake Kivu, it is considered that main reservoirs of underground hot water are expected in parts of Rwanda belonging to the Rift Valley Branch (Kivu, Tanganyika)
1.3. Variability of Resources	- In Rubavu District, near the breweries of BRALIRWA for instance, and in Rusizi District mainly in Bugarama low lands, hydrothermal manifestations [hot springs of about 70° C) prove that geothermal resources in Rwanda are a promising option
2. Brief Description	
2.1. Conditions	- Geothermal exploitation follows a substantial investigation and exploration before concluding on the type of technology - 2 types: Engineering Geothermal System (Hot Dry Rocks) or Naturally Hydrothermal Resources (Wet Rock Technology)

	- We hereby present only the option called Binary Hydrothermal Electric Power System
2.2. Characteristics	- Binary Hydrothermal Electric Power Technology is based on 2 fluids (Geothermal steam and brine), hydrocarbon working fluid) - Working Fluid: Kalina water-ammonia mixture; butane; n-pentane - Capacity range: 200 kW to 20 MW (Remark: a flash hydrothermal technology can generate up to 50 MW) - Temperature required for the geothermal water brine is about 120 °C to 170 °C for 200 kW up to 20 MW - Flow of fluids: mode of a closed-loop in order to minimize GHG emissions - Modern drilling can reach a depth of 10 km underground - Average geothermal gradient: 3 °C/100 m - Conventional steam turbines require about 150 °C - Binary plants are elaborated for commercial purposes in small modular units (small mobile plants) which can be, hence, assembled for higher capacity up to about 110 MW - For instance in Ethiopia, the installed geothermal-electric power was 8.5 MW in year 2003 against 45 for Kenya; up to now, leading countries are mainly USA (2 800 MW),

	Philippines (1 905 MW), Italy (862 MW), etc. - In case of geothermal resources reaching a temperature of 180 °C and a pressure equals to 8 atmospheres or more, the steam can be directly passed through the turbine; then condensed and re-injected in deep layers of ground for recharging the source - Such avoidance of use of heat exchanger and hydrocarbon working fluid makes the geothermal technology more cleaner without emission of GHG; in fact for lower temperatures and pressures, steam is still containing brine, thus: need of an exchanger
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Wet rock-based binary geothermal electric power technology is applicable in Rwanda, due to key parameters (hot springs, volcanoes area) and preliminary investigations (capacity potentially up to 340 MW)
3.2. Potentialities	- Wider geological exploration covering the overall scenarios of geothermal options (binary direct transmission to turbine, non use of heat exchanger, mapped temperatures, flash in expansion vessel, hot dry rock, wet rock technology
3.3. Limitations	- Drilling can be expensive in case of deeper wells for both extraction and re-injection

4. Status of the Technology in Rwanda	
4.1. Local Production	- Geo thermo electric power technology is not yet introduced in Rwanda - Only preliminary technical studies have been conducted and resulted in an estimated potential capacity of up to 320 MW (REMA, 2009)
4.2. Shared Power Plants	- N/A
4.3. Projects	- Rwanda is greatly committed in exploration of geothermal resources and in planning for an electrical production of about 300 MW from such a resource
5. Benefits to Development	
5.1. Social	- Especially, rural population will be more committed to join the Umudugudu policy and settlements - Facilities like charging phones, internet and TV access are thus becoming more popular
5.2. Economic	- Promotion of exploitation of local natural resources for electric power generation - Reduction of exodus from rural to urban areas - Small scale business and factories are more promoted and increased towards a better GDP and incomes - Increases rate of access to electricity services and thus to good growth of economy - Creation of jobs
5.3. Environmental	- Decrease of use of wood and charcoal

	fuels, of petroleum for lighting - Increase of promotion of electric vehicles through wider available battery stations
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	- Geothermal technology systems emit very small amount of GHG, just due to use of hydrocarbon working fluids for use of heat exchanger - Thus with its GHG emission factor of about 197kg/MWh, replacing oil thermal power plants by geothermal plants can result in a reduction rate of 74%.
6.2. Low Carbon Credits	- Geothermal, being a non-carbon resource, will hence contribute in carbon market
6.3. Specific Sectors of Health	- Air and water quality are conserved due to use of such a clean source of electricity - Pollution is limited or avoided
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- Promotion of small plants and modular units of geo thermoelectric power systems (up to 200 kW or even 1 MW) is possible in Rwanda - For such a small scale of production, moderate private business companies can participate under the partnership with EWSA among others
7.2. Capital Cost	- For a 200 kW binary unit, cost was 7220 USD/kW in 2005 and projected to about a probable value of 6 410

	USD/kW (ESMAP, 2007) - In case of a binary 20 MW plant, cost was 4 100 USD/kW in 2005 and expected to about 3 730 USD/kW in 2015 (ESMAP, 2007) against 2 510 USD/kW and 2 290 USD/kW respectively in 2005 and 2015 for a flash 50 MW plant - Installed capital cost is influenced by an optimal design of an atmospheric exhaust plant instead of a condensing plant (UNESCO, 2003)
7.3. Generating Costs	- A binary 200 kW unit: O & M costs were 3 US cents/kWh (19% of total average levelized cost) in 2005 - For a binary 20 MW power plant: O & M costs were 1.7 UC cents/kWh (28%) for the flash geo thermoelectric 50 MW - Regarding the projection for the total average levelized cost (energy generation cost) in year 2025, expectations are 14.2 US cents/kWh, 6.3 US cents/kWh and 4 US cents/kWh respectively for a binary 200 kW, a binary 20 MW and a flash 50 MW (ESMAP, 2007)
7.4. Environmental	- Environmental impacts associated with the geo thermoelectric power production are very small for the matter of GHG emissions - But small amount of CO_2 and H_2S gases are emitted and thus a closed cycle is more recommended instead

	emission towards atmophere - In fact, geothermal plant can emit up to 0.4 gigagrams of CO_2 per kWh against 1.1 by a coal-fired plant, and 0.45 by a natural gas-fired plant (Fridleifsson[i], 2001)
7.5. Capability Building	- Given that the expected introduction of such a new technology and deployment in Rwanda will require specific studies, exploration, installation and skills for operation and maintenance, the cost for training and capacity building has to be considered in financial and economic analysis

Annex IV. G. Biomass-Steam Power Technology

1. Introduction	
1.1. Historical	- Photosynthesis by vegetal and forests: absorption of CO_2 and solar heat flux and production of biomass fuel and oxygen - Combustion: Release of energy and CO_2 - Traditional source of energy (wood fire and charcoal) - Emission of CO_2 (116 g/kWh of electricity)
1.2. Location of Resources	- Biomass fuel resources are mainly available over the whole rural areas - One ton of mass can generate 18 000 MJ, i. e. 0.25 t.e.p (heat capacity) - Solid waste in urban areas
1.3. Variability of Resources	- Biomass fuels are limited in Rwanda; large deforestation has been also recorded; pressure on forest ecosystems is in fact the most factor of decrease in availability of biomass
2. Brief Description	
2.1. Conditions	- Granular form of biomass fuel is recommended - Mixing with oxygen from air - Avoidance of temperatures resulting in NO_x emissions - Direct firing in a steam boiler
2.2. Characteristics	- Biomass fuel (wood, waste) is directly fired in a combustion boiler - Through a heat exchange, water in pipes is heated and resulting steam

	reaches a conventional steam turbine connected to a generator - Remark: emission of NO_x is avoided due to the injection of air and oxygen in the boiler and thus the temperature of combustion becomes lower than that of emitting the NO_x - About 1.5 kg of biomass fuel can result in an electric generation of 1 kWh (i.e. 4 000 kcal/kg) - Capacity: Commercial type up to 50 MW - CF = 80% - 1.5 kg/kWh of electricity
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Biomass-Steam is a proven technology and 1.2 tons of dry biomass produce 1MWh of electricity
3.2. Potentialities	- Wood, forests, wood waste and vegetal residues can be collected accordingly - Municipal solid waste in urban areas - Benefit from external experience like for the case of the Netherlands - Reforestation of national dry lands: in fact about 90% of them are not yet afforested (REMA, 2011)
3.3. Limitations	- Biomass steam power can just be applicable for small scale capacity; among others demand covered by biomass is large
4. Status of the Technology in Rwanda	
4.1. Local Production	- Technology based on Direct-fired

	Biomass Combustion for generation of electricity via a steam turbine is not yet applied in Rwanda
4.2. Shared Power Plants	
4.3. Projects	- Not yet, apart from the strategies and policies towards Biogas-steam at small scale
5. Benefits to Development	
5.1. Social	- Small scale biomass- steam technology is quite feasible in rural and sub-urban areas
5.2. Economic	- Promotion of artisanal industry and non-agricultural incomes
5.3. Environmental	- Sequestration of CO_2 being possible and NO_x being avoidable, this technology is considered as non-pollutant
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	- We consider that Biomass-steam technology can be associated to carbon capture and sequestration for minimizing the CO_2 emissions - GHG emission factor: not more than 58 kg/MWh - Contribution rate in reduction of emissions: 92%, compared to oil used for power generation
6.2. Low Carbon Credits	- Eligible to carbon credits if above conditions (paragraph 6.1) are fulfilled
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- Investment in small scale options of biomass can be facilitated by microfinance institutions; cooperatives

	can also be involved
7.2. Capital Cost	- About 1 700 USD/kW in year 2005 and 1520 USD/kW - Generation cost: about 6 US cents/kWh
7.3. Generating Costs	- 50% of above generating cost
7.4. Environmental,	- Biomass technology can be easily a low carbon emissions - Natural sequestration is playing a key role and huge amount of CO2 are absorbed by the forests
7.5. Capability Building	- Demonstrative pilot projects are expected to greatly contribute in practical «training by doing ».

Annex IV. H. Combined Cycle Gas Turbine (Kivu Methane – Combustion Turbine Power Technology), CCGT[18]

1. Introduction	
1.1. Historical	- Kivu methane Gas: extraction of small amount since 1950^s for heat purposes of the brewery BRALIRWA in North-West at Gisenyi City in Rubavu District - Annual supply: about 1.5 million cubic meters - Properties of the gas: mix of CO_2 and CH_4 - CCGT is not yet applied in Rwanda - CCGT is a combined use of sets of components: combustor of gas, gas turbine, heat recovery boiler, steam turbine and is a reliable technology and is commercial
1.2. Location of Resources	- Lake Kivu
1.3. Variability of Resources	- Where the depth of water in lake Kivu is greater than 300m, the concentration of dissolved gases is high enough - The speed of renewing methane resources is relatively limited - The planned speed of extraction can be adjusted to such a process of transformation resulting in renewability of methane(CH_4 associated to CO_2 and H_2S
2. Brief Description	

[18] CCGT technology is hereby recommended for replacing the current conventional internal combustion option in use by the actual pilot project generating electricity; to fulfill the conditions of mitigation scenario, al types of GHG emissions have to be treated accordingly: CO2 neutral scenario is possible(reinjection into the lake; storage), H_2S can be transformed into sulfuric acid

2.1. Conditions	- Extraction of mixture of gas from the lake - Separation and collect the CH_4 combustible, re-injection of CO_2 into the lake or use it for industrial purposes - Opportunity of liquefaction for the transfer to the end-users far from the Lake Kivu
2.2. Characteristics	- CT and CCGT can be taken together so that the CT branch can cover the demand linked to the peak load periods while the CCGT cover the base load demand - Modular units of CT: 1 MW to 10 MW - New option: Gas-fired Micro Turbine technology with electric capacity ranging between 25 kW and 250 kW - How CCGT is working with both CT and ST? ✓ The methane gas is injected into a combustion chamber ✓ Then burned gases drive a gas turbine (CT) combined to a generator for producing electric energy ✓ The waste heat is extracted from this gas turbine and sent to a boiler in charge of producing steam (Heat Recovery Steam – Gas Turbine) ✓ Such a steam, in turn, rotate a steam turbine (ST) combined to a generator - Specific parameters for a CCGT

	system: ✓ Thermal efficiency: 34% for a CT system and 51% in case of a CCGT ✓ ST inlet temperature: 538 °C ✓ CT inlet temperature: 1 300 °C ✓ Capacity factor: 80% (i.e. 19 hours) ✓ Life span: 25 years
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Already: 1st steps of exploitation - Heat for domestic and industrial - Electrical option is set us s priority at national scale
3.2. Potentialities	- Potential extractions of 10^9 Nm^3/year - Potential electric power generation of 700 MW during about 50 years (MININFRA, 2009)
3.3. Limitations	- Refer to paragraph 3.1
4. Status of the Technology in Rwanda	
4.1. Local Production	- Referring to above paragraph. 1.1. the Kivu methane gas is exploited at very small scale
4.2. Shared Power Plants	- Probably shared option is expected between Rep. Dem. Congo and Rwanda, lake Kivu basin is covering parts of two countries
4.3. Projects	- The generation of electric energy and heat for industrial and domestic purposes is one of the high priority of Rwanda in energy sector (MININFRA, 2003)
5. Benefits to Development	

5.1. Social	Potentially high
5.2. Economic	Potential important at industrial sector and energy supply levels
5.3. Environmental	- The CCGT system produces GHG emissions relatively significant for NO_x (about 110 mg/Nm^3 while the emission standard is 125 mg/Nm^3 and for CO_2 (400 mg/kWh against 600 mg in case of a CT system taken alone
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	Requirements: application of appropriate techniques[regarding carbon sinks, capture, sequestration, storage /underwater]; Associated with the CCS, the CCGT can contribute to GHG mitigation at rate of about 79% with comparison to the oil thermal power plants characterized by an emission of 750kg/MWh
6.2. Low Carbon Credits	Given that both CCGT option and carbon capture systems are expected to result in a low carbon technology of Kivu methane, this technology (highly prioritized at national level) is eligible to carbon credits
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	Financial support to private investors is required especially for those who are intending to be involved both in electric power production and in liquefaction (-168°C)of methane gas towards long -distance –distribution for use by households and industries(progressive replacement of fossil fuels and

	wood/charcoal fuels by methane gas associated with measures for low carbon emissions)
7.2. Capital Cost	- Costs for CCGT (up to 300 MW) - Capital cost: 650 USD/kW and 560 USD/kW respectively for the years 2005 and 2015 [Equipment: 74%] - Gene ration costs: 5.6 and 5.2 US Cents/kWh respectively for the years 2005 and 2015
7.3. Generating Costs	- O & M Cost: 9%; Fuel cost: 74% - Comparison to a simple CT system: ✓ Given that, and among others, the heat associated to the rotation of gas turbine is regularly extracted, CCGT gas a high efficiency (51% against 34% for a CT system) and higher capacity factor (19 hours); in addition, the generating cost is 2 times more important for a CT system
7.4. GHG Emissions	CCGT, if associated with techniques for carbon sequestration and for use of H_2S, is considered as a low carbon technology; it can therefore become the case for development of the Kivu methane projects Taken alone, conventional Gas Turbine technology can result in an emission factor of about 630 kg/MWh against 750 kg/MWh by the oil thermal power plants
7.5. Capability Building	Training and expertise regarding both the combustion/gas/steam turbines,

	thermoelectric processes , distribution of liquid methane, techniques for carbon sequestration are recommended for any sustainable diffusion of such a CCGT new technology in Rwanda

Annex IV.I. Peat-based IGCC (Integrated Gasification Combine Cycle)

1. Introduction	
1.1. Historical	- Technology based on combustion on coal for electric energy generation is the most ancient and had played a great role in early steps of industrial development in Europe among others - Up to now, this technology is highly competitive - Peat resource is similar to coal resource as a combustible
1.2. Location of Resources	- Important resources of peat are located in marshlands of Akanyaru and Akagera river basins - Potential available and commercially extractable peat resources are about 50 millions of tons - Both electricity and heat are expected as outputs, according to EWSA strategies (MININFRA, 2006)
1.3. Variability of Resources	- This is a non-renewable resource; but spatial distribution is interesting and dense in low lands along Nyabarongo and Akanyaru rivers but also in Bugarama in SouthernWest of the country alon the Rusizi river
2. Brief Description	
2.1. Conditions	- Detailed environmental studies are required before any wider exploitation of peat resources
2.2. Characteristics	- Peat resource fuel is pulverized in typical peat or coal pulveriser - The boiler, into which combustion of

	peat is done, produces a steam (T < or = 565 °C; P > or = 17 megapascals) - Then the steam expansion results in a rotation - Capacity factor: 80% (i.e. 19 hours) - Efficiency of the system: 40% - Lifespan: 30 years - Remark: above data are adapted from databank on coal-steam technology
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Very high for heat energy and electricity supply
3.2. Potentialities	- Important; exploration proved that large amount of reserves are available
3.3. Limitations	- Risks of conflict with land use for agriculture; - Low applicability of carbon sinks/sequestration in case of use of peat by small scale industries and households
4. Status of the Technology in Rwanda	
4.1. Local Production	- Extraction of peat is currently done at small scale for heat output purposes
4.2. Shared Power Plants	- NA
4.3. Projects	- A project on peat-steam to electric power is aiming at generating 100 MW by the year 2015; site for exploitation mainly in District of Nyanza in Southern Province
5. Benefits to Development	
5.1. Social	- Energy security
5.2. Economic	- Reduced use of wood and charcoal - Replacement of imported fossil fuels

5.3. Environmental	Reduction of pressure to forests and ecosystems
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	- Measures for carbon sequestration are undertaken before any wider exploitation of the peat resources - Given that important reserves of peat are those which are located along the main big rivers in Rwanda, technique of storing GHG underground and under water is quite feasible - Particular new options(IGCC...) are recommended - Compared to classic peat based technologies, IGCC with CCS can result in a GHG emission decrease of 74%; in fact the conventional peat to steam emits up to 1075 kg/MWh
6.2. Low Carbon Credits	- Not eligible - Unless above described measures for transforming
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	-
7.2. Capital Cost	- Below costs are estimated and adapted with similarities to coal as far as in Rwanda the project of Peat-to-electric power is still in its early steps of implementation - Capital cost: 1 190 USD/kW and 1060 USD/kW respectively for the years 2005 and 2015 (equipment: 65%) - Generation cost: 4.5 US cents/kWh in year 2005 against 4.2 US cents/kWh

	projected for year 2015 (O & M costs: 16.5%; fuel cost: 44%); Remark: such above costs are indicative and require more investigations for such a coming peat-to-power project in Rwanda. It is also important to remind that such a technology, if we refer to above paragraphs is the cheapest of the ten selected technologies for this TNA Project
7.3. Generating Costs	-
7.4. GHG Emissions	- Within the option of IGCC, the use of peat for generating energy can result in reduction of GHG emissions and these can be lower than the acceptable standards - Combination to the CCS is quite recommended - Without such above required improvements, this technology results in very high GHG emissions reaching more than one tonne per MWh generated - Peat based IGCC with CCS option can replace the imported fossil fuels especially covering almost the half of electricity generation in Rwanda
7.5. Capability Building	- Identical to other technologies based on the gas/steam turbines and related exploitation of the peat, a GHG component - Great capacity in carbon sinks/sequestration is required also

	- Capacity in environmental assessment and with reference to coal options in specific countries is also required in Rwanda; in fact steps reached in process of installation the peat industry are advanced and a power capacity of 100 MW is awaited at short term.

Annex IV.J. Biodiesel / Internal Combustion Technology

1. Introduction	
1.1. Historical	- Due to the discovery of petroleum resources and their thermal and fuel characteristics or properties, electric generators driven by an engine based on internal combustion became popular just after the coal-based technologies - Thus, since the first decades of the 20th century, internal combustion and steam boiler started to play role in industrial development - This technology became more and more popular when fuels like ethanol, methane and biogas were found suitable for use in the Internal Combustion Engines
1.2. Location of Resources	- Up to now, oil is imported by Rwanda - Alternatives of replacing oil/petroleum in IC engines by biofuels, biodiesel
1.3. Variability of Resources	- Fossil fuels are imported - But biodiesel based among others on vegetal oils can be locally produced
2. Brief Description	
2.1. Conditions	- Considering the option of replacing Gasoline/diesel by vegetable oils for driving engines generators; - Production of vegetable oils and bio-fuels without any competition susceptible of affecting food security and agriculture sector
2.2. Characteristics	- Fuels for a diesel engine: oil

	(light/residual) palm , coconut oils (biodiesel), - Internal combustion results in rotation of the electrical generator in fact driven by a shaft output of the gasoline/diesel engine - Range of power capacity: 2 kW up to 20 MW - Electrical efficiency (up to 45%) is higher than the case of gas-fired combustion turbine (34%) - Capacity factor: 80% for the high capacity - Lifespan = 20 years for a range of 100 kW to 20 MW; 10 years for lower capacity
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- This technology is already operational at very small scale for demonstration at IRST (National Institute of Research, Science and Technology) in Huye district.
3.2. Potentialities	Limited due to low availability of land for cultivating appropriate trees for generating vegetal oils/biodiesel
3.3. Limitations	- biodiesel fuel is facing a serious constraint of lack of large lands for its potential plantation and sustainability
4. Status of the Technology in Rwanda	
4.1. Local Production	- Still at preliminary steps
4.2. Shared Power Plants	- NA
4.3. Projects	- NA
5. Benefits to Development	

5.1. Social	Energy security at different scales
5.2. Economic	-Promotion of artisanal industry, non-agricultural incomes, -Option of hybrid systems with solar, wind and biomass
5.3. Environmental	-Application of techniques for lowering the carbon emissions is a prerequisite condition for environmental benefit -In case of biodiesel fuel, mitigation and environmental requirements are fulfilled
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	Optional biodiesel and blends diesel are expected to contribute in mitigation scenario Its emission factor is quite low and hence it can result in an important rate of decreasing GHG emissions: 94% compared to the oil power plants
6.2. Low Carbon Credits	Development of options based on engine driven by biodiesel fuels is suitable for benefitting from the carbon credits
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- It is obvious that specific funds for supporting private sector interested in developing technologies based on biodiesel and on techniques of lowering carbon emissions can result in wider involvement of smaller companies
7.2. Capital Cost	- For a 5 MW: about 600 USD/kW and 550 USD/kW respectively in years 2005 and 2015
7.3. Generating Costs	- For the case of a 5 MW base-load, the

	generating cost (the sum of levelized capital cost, O & M costs and fuel cost) is 9.25 US cents/kWh and 17.7 US cents/kWh respectively in the years 2005 and 2015 with 38% for the O & M costs and 53% for the fuel cost
7.4. GHG Emissions	- Emission factor of biodiesel: only about 43 kg/MWh - Replacing the gasoline and diesel fuels by the biodiesel can contribute in avoiding the below emissions; - Gasoline engine: ✓ Very small emission of SO_2 ✓ High emission of CO_2: about up to 1900 kg/net MWh ✓ High emission of NO_x: about 1 400 mg/Nm^3, while the standard acceptable NO_x is 460 mg/Nm^3 in case of oil fuel (ESMAP, 2007)[19] - Diesel Engine: ✓ Up to 2 000 mg/Nm^3 of NO_x ✓ Up to 4 700 mg/Nm^3 of SO_x while 2000 mg/Nm^3 are acceptable standard ✓ Up to 650 kg/net MWh of CO_2 -Compared to above scenarios of diesel/gasoline, biodiesel and vegetal oils are renewable and very low-carbon fuels
7.5. Capability Building	- Given that such a technology is requiring a large diffusion within both rural areas and urban cities, a high

[19] ESMAP is a World Bank Program

	number of skilled technicians is recommended

Annex IV.K. Enhanced Peat /Coal-bed methane recovery (ECBM)[20]

1. Introduction	
1.1 Historical	-Technology of producing methane from coal /peat seams is operational mainly in countries like USA since 1980s
1.1. Location of Resources	In low lands of Bugesera, Nyanza, Gisagara and Rusizi districts
1.2. Variability of Resources	None renewable
2. Brief Description	
2.1. Conditions	- Exploration, prefeasibility studies - Design for a proper drilling, injection of CO_2 for displacing methane from the seams
2.2. Characteristics	- Extraction of the combustible CH_4 - Combustion of CH_4 (directly fired in a boiler for driving a steam turbine and generating electricity) - Or, after an appropriate treatment of this CH_4 gas, running a gas engine for further electricity production - Or, directly burned for heat and cooking but also for any industrial purposes - Liquefaction of methane for cooking

[20] Refer to: Schroeder K, Ozdemir E. and Morsi B.I (2002); Sequestration of Carbon Dioxide in Coal Seams. Journal of Energy and Environment Research.Vol.2(1).pp54-63; and to Gale J. and Freund P(2001) Coal-bed methane enhancement with co_2 sequestration worldwide potential; Environmental Geosciences, vol 8 (3), pp 210-217

	and thermal application in industries
3. Applicability and Potentialities in Rwanda	
3.1. Applicability	- Applicable at small scale in rural areas near peat reserves
3.3. Potentialities	- Limited to peat resources
3.4. Limitations	- Cost of technology
4. Status of the Technology in Rwanda	
4.1. Local Production	NA
4.2. Shared Power Plants	NA
4.3. Projects	NA
5. Benefits to Development	
5.1. Social	- Refer to above technologies
5.2. Economic	- Idem
5.3. Environmental	- The CO_2 is captured and injected into the seams and rocks - The CH_4 is collected as an output product
6. Climate Change Mitigation Benefits	
6.1. Reduction GHG Emissions	Replacement of wood fuel and of fossil fuels ECBM results in methane products and, once combined to the CCS systems, can widely contribute in GHG mitigation: About 79% of reductions can be achieved
6.2. Low Carbon Credits	Highly recommended especially because of potential large diffusion of such a technology at small scale for rural communities
7. Financing Requirements and Costs	
7.1. Private Sector Involvement	- Small funds and loans for promoting

	the use of methane gas
7.2. Capital Cost	- about 3 250 USD/kW
7.3. O & M Costs	- Generation cost: about 8.5 US cents/kWh in year 2005 and projection to 7 US cents/kWh in year 2015; O & M cost: 22% of above generating cost;
7.4. GHG Emissions	- Refer to above CCGT technology - ECBM combined to CCS is in fact similar to CCGT with CCS
7.5. Capability Building	- Idem

Annex IV.L. The biogas thermal applications (BTA)

1.Introduction	
Historical	Use of biomass is well implemented in Rwanda, Biogas is becoming popular
Location of Resources	Over the whole country, but forests are mainly in the highlands in West and North
Variability of Resources	Most of forests are affected by use related to wood and charcoal; Variability is in line with reforestation
2Brief Description	
7.6. Conditions	- Availability of biomass resources - Production of biogas
7.7. Characteristics	- Organic materials, [solid urban and domestic waste, leafy plant materials/animal dung/human excreta] can be compacted, after selection and collection, and then covered in appropriate landfills, bio digesters - Mixing materials with water - Anaerobic digestion process: ✓ Decomposition of such materials by bacteria ✓ Production of a gas (main components are: CH_4, CO_2) ✓ The gas CO_2 can be solved into water present in the bio digesters - Extraction of the combustible CH_4 directly burned for heat and cooking but also for any industrial purposes
8. Applicability and Potentialities in Rwanda	
8.1. Applicability	- Limited to urban areas for the case of solid waste

	- Applicable at small scale in rural areas where among other biogas can be generated from the dung of cows in the context of the One Cow per Family program
3.5. Potentialities	- High
3.6. Limitations	- Limited to small scale
4.Status of the Technology in Rwanda	
4.1.Local Production	Biogas is just produced by mainly schools, health centres, prisons; this is for heat direct consumption
4.2.Shared Power Plants	NA
4.3.Projects	NA
5.Benefits to Development	
5.1.Social	- Refer to above solar and small hydro
8.2. Economic	- Idem
8.3. Environmental	- The CO_2 is captured as it is soluble in water filled in the landfill - The CH_4 is collected as an output product - Only traces of H_2S are polluting
9. Climate Change Mitigation Benefits	
9.1. Reduction GHG Emissions	Replacement of wood fuel and of fossil fuels used in lighting is a great alternative
9.2. Low Carbon Credits	Highly recommended especially because of potential large diffusion of such a technology at small scale for rural communities
10. Financing Requirements and Costs	
10.1. Private Sector Involvement	- Small loans are available from the banks
10.2. Capital Cost	- Refer to above biomass-based technologies

10.3.	O & M Costs	- Refer to above biomass-based technologies
10.4.	GHG Emissions	- Refer to above biomass-based technologies - Emission factor ranges between 40 and 60 kg per MWh of heat generated
10.5.	Capability Building	- At communities level, a training related to the whole network of the biomass technology management is required

Annex IV.M. The carbon capture and sequestration (CCS) technology

1. Introduction	
1.1 Historical	- Early 1970s, in Texas(USA) and in Canada, non- anthropogenic CO_2 were injected underground for the purposes of recovering oil fuel from geological reservoirs - In 1996, in North Sea, the first large unit of CO_2 storage was installed by the Sleipner Gas Field (Norway). - In 1998 and 2003, the Alberta Research Council(ARC) installed a CCS pilot project respectively in Canada and Chine - In Algeria some industrial projects are developing a program of CO_2 as a mitigation option, it is the case for the in Salah project
1.2 Location of Resources	- Significant sources of CO_2 emissions to be captured and sent to geological storage are manufacturing units in Kigali, thermal oil power plants, and cement factories in Rusizi district. - Small and mobile sources of GHG emissions are not included in this context of potential CCS deployment
1.3 Variability of Resources	- An important increase of flue gases in expected due to current promotion of industrial sector and energy sector
2. Brief Description	
2.1 Conditions	- Applying CCS required a high support

	through the promotion of carbon credit market - Development of large units of Kivu methane CCGT - CCS can be justified by the coming extraction of peat resources at large scale for power generation
2.2 Characteristics	- The first step is the capture of CO_2 from flue gases - Before transportation to storage unit, removal of moisture to avoid corrosion of pipelines and compression process are required - Transport of compressed and dry CO_2 is done through a network of pipelines - Location of geological formations can be far from the source of CO_2; - Efficiency of capture and storage: about 85% - The post-combustion capture is commercially feasible - Depth of injection is up to 1km - Geological storage plays the double role of CO_2 sequestration and extraction of methane fuel through recovery like ECBM (Enhanced oil recovery);
3. Applicability and Potentialities in Rwanda	
3.1 Applicability	- Development of electric power generation by Kivu methane gas and by peat-based technologies can consider the feasible options of CCS such as the post-combustion capture and

	geological storage
3.2 Potentialities	- Industrial thermal oil power plants in Kigali - Coming power projects based on Kivu methane and peat resources - Existing cement factories in rural areas of Bugarama in Southern West of Rwanda, Rusizi district
3.3 Limitations	- Distance between potential geological formations appropriate for storage and location of industrial sources of CO_2 emission .
4. Status of the Technology in Rwanda	
4.1 Local Production	- NA
4.2 Shared Power Plants	- NA
4.3 Projects	- NA
5. Benefits to Development	
5.1 Social	- Creation of jobs especially for installation and maintenance of the CCS components
5.2 Economic	- Generation of additional revenues due to the recovery of methane from the geological peat-based seams - Benefits from the carbon credit market
5.3 Environmental	- GHG emissions to atmosphere are avoided - Combine to natural sequestration by forests, the CCS deployment in Rwanda can secure future scenario of fully green country
6. Climate Change Mitigation Benefits	
6.1 Reduction GHG Emissions	- In case of CCS combined to Kivu CCGT, at least 360 kg of CO_2 are

	captured from flue gases per each MWh generated; i.e. about 300 kg of CO_2 emission are avoided. For the case of peat-based IGCC with CCS, at least 670 kg of CO_2 are captured and hence 590 kg of CO_2 per MWh are avoided
6.2 Low Carbon Credits	- Application and deployment of the CCS in the energy sector are expected to be given priority to access of carbon credit finances
7. Financing Requirements and Costs	
7.1 Private Sector Involvement	- Investment in CCS technology for further deployment on local market is possible if private companies are given loans and incentives or access to carbon credits funds
7.2 Capital Cost	- Unless the CCS is developed for both mitigation purposes and extraction of methane (ECBM) from deep peat steams , the capital cost of a post-combustion capture system and geological storage of CO_2 emissions from IGCC or ECBM or CCGT plants is an additional non affordable cost.
7.3 Generating Costs	- Cost of electric energy ranges between about 4 and 8 USD cents per kWh for the case of methane CCGT combined with the CCCS against about 3 to 5 USD cents per kWh generated by a CCGT without a CCS option. - Therefore applying CCS to CCGT results in cost increase of about 37 to

	85%