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Agriculture Sector Working Paper

Appendix B

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Executive Summary

This paper is one of nine sector working papers written as part of the process of developing a National Strategy on Climate Change and Low Carbon Development for Rwanda. It follows on from the Baseline Report produced in February 2011 which provides the local context for each sector, including current programmes and development plans. This paper focuses on Agriculture while the other working papers cover Energy, Water, Land, Forestry, Transport, Built Environment, Mining and Finance. The paper should be read in conjunction with the 'thinkpiece' which proposes the Strategic Framework including a vision for 2050, objectives, guiding principles and enabling pillars. The aim of each paper is to identify the vulnerabilities and opportunities facing the sector, to review global best practice and relevant case studies, and to propose an action plan for addressing climate change and low carbon development in the short, medium and long term. This action plan is put forward to stakeholders in Rwanda for review and comment. As the title suggests, the working papers are aimed at prompting discussion with stakeholders, rather than being the final word.

In this Agriculture Sector Working Paper, options to mainstream climate-smart agriculture are discussed and proposed as a component of the National Strategy on Climate Change and Low Carbon Development for Rwanda. Consequently, the paper identifies a range of climatic, demographic and economic hazards that are likely to increase the vulnerability of the agricultural sector in Rwanda, and the wider region, over the next four decades, these include:

- Increased rainfall variability
- Increased temperatures
- Rising oil prices
- Rising food prices
- Peak phosphorus resulting in steep rises to inorganic fertilizer costs
- Population growth resulting in high demand for food, land, & water

Any of these hazards has the potential to directly impact the agricultural sector, but a combination of climatic, demographic and economic hazards from multiple sources is likely to substantially increase agricultural vulnerability leading to a decline in food production and losses in agricultural export revenue with grave consequences for food security. The current agricultural intensification programmes being implemented by the Ministry of Agriculture and Animal Resources are not designed for climate change adaptation and mitigation, rather they depend on external inputs such as inorganic fertilizer, small-scale machinery, exotic cattle breeds and improved seed varieties, much of which remains carbon intensive. In addition many of these programmes have yet to be evaluated and tested under extreme environmental and economic conditions. The current increases in crop productivity are a direct result of improving farming systems due to increased access to inorganic fertilizer however the maintenance of this growth and performance over the long term, 2030-2050, is unlikely as a result of the unfavourable climatic, demographic and economic forecasts listed above. The recommendations in this paper are aimed at countering these risks and mitigating future agriculture vulnerability by developing climate-smart agriculture that should form the core component of the agricultural intensification programme.

Each of the main agricultural intensification programmes, namely the Land husbandry, Water harvesting and Hillside irrigation Project (LWH), Integrated Water Resource Management (IWRM) (irrigated rice production) and the One Cow Program offer a range of opportunities to mainstream climate-smart agriculture through the introduction of adaptation and mitigation measures. For example, long-term objectives of such approaches should include the reduction of inorganic fertilizers through efficient soil fertility management, so that external inputs, such as NPK-based inputs, are used through precision application and only as a final component of an integrated soil fertility management approach. Such strategies would also allow the development of agricultural infrastructure to support organic production in niche market cash crops such as tea pyrethrum, tea, coffee, and sericulture thus adding value to current practices.

A range of adaptation and mitigation strategies are proposed to counter the potential impacts from climate change and carbon dependency. Consequently within the agricultural sector two broad programmes of action have been identified which provide the overall strategic for intervention. Under each programme of action, a range of individual actions each with specific aims and objectives have been identified to provide an operational framework for implementation:

- Programme 1: Sustainable intensification of small-scale farming
    - Action 1: Mainstreaming of agroecology (climate-smart agriculture)
    - Action 2: Resource recovery and reuse
    - Action 3: Fertiliser enriched products
    - Action4: Mainstreaming of "Push-Pull" Strategies (IPM)
- Programme 2: Agricultural diversity in local and export markets
    - Action 1: Expansion of Crop Varieties
    - Action 2: Expansion of Local Markets
    - Action 3: Expansion of Manufacturing
    - Action 4: Expansion of Exports

These programmes of action will allow the mainstreaming of climate-smart agriculture in the current agricultural intensification programmes consisting of Land husbandry, Water harvesting and Hillside irrigation Project (LWH), Integrated Water Resource Management (IWRM) (irrigated rice production) and the One Cow Program; thereby maximising appropriate nutrient recycling and water conservation techniques, and ensuring that agricultural landscapes are not only productive but also sequestrate terrestrial carbon thus improving both adaptation and mitigation capacity.

Finally, the National Strategy on Climate Change and Low Carbon Development for Rwanda identified a number of Big Wins, defined as large scale economy-wide programmes designed to make significant impacts on mitigation, adaptation and economic development. In the context of agriculture, three Big Wins are included:

- Reduced dependency on inorganic fertilisers
- Irrigation infrastructure
- Agroforestry

Agriculture

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Acronyms and Abbreviations

AMSL above mean sea level

CDCF Community Development Carbon Fund

CDM Clean Development Mechanism

CH_4 methane

CO_2 carbon dioxide

COMESA Common Market of East and Southern Africa

EDPRS Economic Development and Poverty Reduction Strategy

FDP fertiliser deep placement GHG greenhouse gas

GOFTC Gako Organic Farming Training Centre

GoR Government of Rwanda

ha hectare

IPM Integrated Pest Management

ISAR Rwanda Agricultural Research Instititute

IWRM Integrated Water Resource Management

kcal kilocalorie

kg kilogram

LWH Land husbandry, Water harvesting and Hillside irrigation Project

MDG Millennium Development Goals

MINAGRI Ministry of Agriculture

MININFRA Ministry of Infrastructure

N_2O nitrogen dioxide

NAPA Nationally Appropriate Plans of Action

NEMA National Environment Management Authority of Uganda

NGO non-governmental organisation

REMA Rwanda Environmental Management Authority

RSSP Rural Sector Support Project

TNA Techincal Needs Assessment

UNDP United Nations Development Programme

USD United States dollar

VUP Vision 2020 Umurenge Programme

Introduction

This paper is one of eight sector working papers written as part of the process of developing a National Strategy on Climate Change and Low Carbon Development for Rwanda. It follows on from the Baseline Report produced in February 2011 which provides the local context for each sector, including current programmes and development plans. This paper focuses on Agriculture while the other working papers cover Energy, Water, Land, Forestry, Transport, Built Environment and Mining. Finance and Education are incorporated into the working papers rather than standing alone. The paper should be read in conjunction with the 'thinkpiece' which proposes the Strategic Framework including a vision for 2050, objectives, guiding principles and enabling pillars. The aim of each paper is to identify the vulnerabilities and opportunities facing the sector, to review global best practice and relevant case studies, and to propose an action plan for addressing climate change and low carbon development in the short, medium and long term. This action plan is put forward to stakeholders in Rwanda for review and comment. As the title suggests, the working papers are aimed at prompting discussion with stakeholders, rather than being the final word.

1.1 Agricultural Growth

Agricultural growth features in several key poverty reduction and climate change related strategy policies that have been implemented by the Government of Rwanda (GoR). In addition, the agricultural sector is also covered as a key component in a range of regional and international climate change strategies (see Figure 1). Central to the GoR's agricultural strategy are Vision 2020, National Adaptation Programmes of Action to Climate Change (NAPA), the Economic Development and Poverty Reduction Strategy (EDPRS), and the Strategic Plan for the Transformation of Agricultural in Rwanda – Phase II. In this section relevant elements from these strategies will be briefly presented to highlight the context and scope of current agricultural development.

1.2 Vision 2020 and Related Planning and Development Strategies

The Rwanda Vision 2020 is the central development vision for the GoR, which identifies the key development priorities and methods to achieve those desired goals. Vision 2020 has direct influence and relevance in all agricultural policy including the Strategic Plan for the Transformation of Agricultural in Rwanda – Phase II, and the Economic Development and Poverty Reduction Strategy (EDPRS), which provide guidance and implementation details for achieving Vision 2020. For example, the document Vision 2020 Umurenge (2007), provides strategic policy guidelines for poverty eradication, rural growth and social protection through the transformation of the agricultural sector (see Table 1). Also contained in Vision 2020, is a range of ambitious targets linked to the agriculture sector, of relevance here are:

- Decrease in agricultural population from the 90% in 2000 to 50% in 2020.
- Modernization of agricultural land from 3% in 2000 to 50% in 2020.

2000 – Vision 2020
2002 – Poverty Reduction Strategy Paper (PRSP)
2004 – Strategic Plan for Agricultural Transformation in Rwanda
2005 – Initial National Communication to UNFCCC
2006 – National Adaptation Programmes of Action to Climate Change (NAPA)
2007 – Economic Development and Poverty Reduction Strategy (EDPRS)
2008 – UNIDO-UNEP Resource Efficiency and Cleaner Production
2009 – Strategic Plan for the Transformation of Agricultural in Rwanda – Phase II
2009 – Economics of Climate Change report
2009 – UN PEI Environmental Mainstreaming
2010 – Copenhagen Accord association
2010 – Draft Second National Communication and Mitigation Options
2010 – Draft National Carbon Policy
2010 – East Africa Climate Change Policy
2011 – UNEP Technical Needs Assessment (TNA)
2011 – East Africa Climate Change Master Plan
2011 – InfoDev Climate Innovation Centre
2011 – Preparations for Third National Communication

Figure 1: Planning and development policies relevant to agriculture and climate change

- Use of fertilizers from 0.5 Kg/ha/year in 2000 to 15 Kg/ha/year in 2020.
- Financial credits to the agricultural sector from 1% in 2000 to 20% in 2020.
- Agricultural production from 1612 kcal/day/person in 2000 to 2200 kcal/day/person.

Currently these indicators drive the agriculture planning in attempts to intensify crop production through 'modernization' programmes that will then allow an increase in labour availability for off-farm employment by 2020, although it is not so clear what employment or livelihoods will be adopted by this target 40% of the population. Also not discussed are the long-term implications of a crop intensification programme based around inorganic fertilizers as this strategy then places the agriculture sector dependent on external inputs. The

Table 1. Summary of the Vision 2020 Umurenge Program (VUP)

Program components ("focus")	Additional benefits ("externalities")	Areas where changes need to be instigated in a systematic fashion
Public works	Creation of off-farm employment opportunities	Assist local government to coordinate the implementation of national sector ministries strategies
Credit packages	Monetisation & formalisation of the economy	Instill the notion of interconnectedness of services across sector ministries
Direct supports	Effectiveness of social protection	Change attitudes through pro-active interventions of all sector ministries to accelerate the rate of poverty reduction in Rwanda

agricultural intensification programme includes a range of sub-programmes including the Rural Sector Support Project (RSSP) consisting of Land husbandry, Water harvesting and Hillside irrigation Project (LWH), Integrated Water Resource Management (IWRM) (irrigated rice production) and the One Cow Program. Other agricultural commodities that are currently being developed include pyrethrum, tea, coffee, sericulture, and aquaculture. In regards to climate change, each of these programmes provides risks and opportunities depending on how natural resources and external inputs are used and managed, for example methane emissions from rice production can be mitigated through improved irrigation management, and soil fertility and structure can be improved through the composting and application of organic waste. Many of these agricultural intensification programmes are yet to be fully evaluated although it is critical now that monitoring is implemented to ensure uptake-opportunities for climate-smart agriculture and increasing adaptation capacity are maximised.

It is worth highlighting the integrated approach of Vision 2020 and its Umurenge Program (VUP). which addresses a range of social, health and environmental issues at the village level. Poverty reduction is a central feature thus giving priority to the extreme poor but matching a range of economic 'clients' with 'adapted solutions' allowing for a holistic development and economic approach (see Table 2).

1.3 National Adaptation Programmes of Action to Climate Change (NAPA)

NAPA prioritizes high vulnerability areas to climate change in the wider context of population, agriculture, water resources and energy 'due to mutual influences and cumulative impacts' of:

- High degradation of arable land due to erosion, following torrential regime of rains in Northern regions (Gisenyi, Ruhengeri and Byumba), centre/west (Gitarama, Kibuye, Gikongoro) and floods in their downhill slope.
- Desertification trend in agro-bioclimate regions of the east and South-east.
- Lowering of level of lakes and water flows due to pluviometric deficit and prolonged droughts
- Degradation of forests.

The NAPA response strategy is based on six priority adaptation options which include:

1. Integrated Water Resource Management – IWRM
2. Setting up information systems to early warning of hydro-agro metrological system and rapid intervention mechanisms.

Table 2. VUP intervention points

Clients	Adapted Solutions
Land owners	Agriculture / livestock productivity solutions implemented through public works (e.g. terracing, watershed, irrigation) or credit packages (e.g. seeds, fertilizers, livestock purchase)
Landless able to work on-farm	Labour / HIMO productivity solutions implemented through public works (e.g. community assets, village settlement), credit packages (e.g. on/off-farm skills, households/business assets), or direct supports (e.g. access health and education)
Landless able to work off-farm	
Unable to work	Social assistance solutions implemented through direct supports (e.g. access to social services) or credit packages (e.g. appropriate skills, handicraft)
Above poverty	Entrepreneurship solutions implemented through credit packages (e.g. business assets, supply-chain upgrades, exports)

3. Promotion of non agricultural income generating activities.
4. Promotion of intensive agro-pastoral activities.
5. Introduction of species resisting to environmental conditions.
6. Development of firewood alternative sources of energy.

From these priority options, seven high priority projects have been selected including:

1. Land conservation and protection against erosion and floods at the level of districts of vulnerable regions to climate change.
2. Establish the mastering hydro meteorological information and early warning systems to control extreme phenomena due to climate change. Installation and rehabilitation of hydrological and meteorological stations.
3. Development of irrigated areas by gravity water systems from perennial streams and rivers in often vulnerable zones to prolonged droughts.
4. Support districts of vulnerable regions to climate change in planning and implementing measures and techniques related to conservation and water harvesting and intensive agriculture, and promoting existing and new resistant varieties if crops adapted to different bioclimatic soil.
5. Increase adaptive capacity of grouped habitat “Imidugudu” located in vulnerable regions to climate change by the improvement of drinking water, sanitation and alternative energy services, and the promotion of non agriculture jobs.
6. Increase food and medicine modes of distribution to respond to extreme climate change and sensitize to stocking and conservation of agricultural products.
7. Preparation and implementation of woody combustible substitution national strategy to combat deforestation and erosion as well.

In theory the practices from the agricultural intensification programmes may seem incompatible with NAPA objectives but over time and with good project monitoring any potential environmental problems will be observed and recorded allowing for mitigation or remedial action, as the quality of implemented programmes will ultimately govern the environmental impacts from the respective agricultural intensification programmes. Likewise it will be sometime before the impacts from the recently introduced environmental mainstreaming programme will be realized, and again these programmes will need to be fully evaluated so that lessons can be learnt for future programme planning and design. The following sections of the working paper now add additional context and perspectives to agriculture, climate change and low carbon development by identifying and detailing further vulnerabilities and also proposing a range of short, medium and long term interventions to mitigate the negative impacts of climate change and also the dependency on externally-sourced carbon intensive resources thus building wider resilience in the agricultural and food security sector.

Vulnerabilities

In the agriculture sector there are two main areas that require attention in the context of vulnerability, although overlap exists between the two areas. The first dimension is the dependency on externally-sourced carbon-based commodities and technologies, including agro-chemicals, fuel, equipment, seeds and imported food stuffs. The second dimension is directly related to the impacts of climate change, including increased rainfall variability leading to droughts and/or rain storms potentially resulting in crop failures, rising temperatures leading to increased crop and/or livestock pests and disease again potentially resulting in crop failures, and other cultivation problems associated with salinisation, soil drying and weed infestation[1-3]. In such cases these problems can then be exacerbated through inappropriate land management techniques[3].

2.1 Dependency on Carbon-based Agricultural Inputs

In the context of agriculture this dependency has to be viewed in two very closely related aspects, first the fuel and energy requirement in operating 'modern' food production systems, which includes energy and fuel for transportation of raw materials and harvested food products, and processing and storage of food products. For example in cases of geographically centralised food production systems, for example regional locations of commodity-based items such as rice, cassava or maize in locations that suit the agroecological conditions, then effective harvest, storage and transportation systems are paramount to ensure efficient national distribution of the specific commodities. Such systems bring a level of dependency as opposed to locally based food production systems using district-based markets.

The second aspect of carbon dependency that creates vulnerability in food production systems is the application and use of agricultural inputs largely in the form of agricultural chemicals such as inorganic fertilizers, pesticides, herbicides and fungicides. Of particular concern are dependencies on inorganic fertilizers which, following a very short period of application and usage, can bring marked increases in crop production but if continued without other important soil management interventions can contribute to the degradation of soil structure as valuable carbon matter is not returned to the soils. Furthermore, due to the focus on a limited range of inorganic fertilizers the necessity to address other micro-nutrient requirements that are essential for plant growth may consequently be neglected. In these crop production systems, inorganic fertilizers become the main input to crop production resulting in a linear nutrient pathway, moreover ever increasing application of fertilizers are required overtime to meet the original high achieving yields. During this process natural soil fertility is lost, including a range of micro-nutrients which are not supplied in NPK-based fertilizer products, and thus overtime soils lacking organic matter become exhausted. Dependency on imported fertilizers also brings a degree of vulnerability due to rising oil prices which impact on fertilizer production and transportation, and the inevitable price rise of fertilizers themselves as we approach peak-phosphorus which Cordell et al.[4] predicts will be as early as 2030.

2.2 Climate Change Impacts on Agriculture

The challenges and risks to agriculture from climate change are multi-dimensional and complex. The obvious and frequently discussed is 'increased rainfall variability' which can directly affect agricultural production by the shortening of seasonal rains thus reducing crop productivity, particularly if such conditions occur towards the end of a crop cycle when water demand is higher. Increased rainfall variability also reduces the planning capacity of farmers particularly during the loss of early rains which often provide traditional markers and indicators for crop planting. In addition to droughts and erratic rainfall conditions, another problem stems from too much rainfall in too short a time period, leading to heavy rain storms and flash floods, which again directly affect crop production due to extensive crop damage and high levels of soil erosion. During recovery from these scenarios farmers may well look for alternative methods to swiftly build soil fertility back to productive levels thus using inorganic fertilizers as a primary soil treatment. With the removal and loss of topsoil the remaining underlying soils often contain low levels of humus and organic matter thus accelerating the dependency on chemical-based agricultural inputs in attempts to make quick returns[1-3, 5].

In addition to increased rainfall variability, rising temperatures also impact on crop and livestock production through potential crop failure and increased diseases and pests. This problem is particularly relevant in highland agriculture where farming systems are more susceptible to rising temperatures as this allows pests, such as tsetse fly and cattle ticks, to survive at higher altitudes where conditions were previously too cold for their survival[1-3, 5]. Recent studies in Kenya have shown that temperature rise would increase the optimum altitude for growing tea from between 1,500 and 2,100 metres above mean sea level (AMSL) to between 2,000 and 2,300 metres AMSL[6]. A temperature rise would thus result in a reduction of suitable land for tea production, and alternative horticultural crops, such as maize, cabbage, peas and passion fruit, would have to be grown on land formerly used for tea. Coffee could not be an alternative crop as it requires similar conditions to tea. Finally, crop and fodder production may also be affected by other cultivation problems associated with salinisation, soil drying and soil carbon loss, and weed infestation from pervasive and parasitical weeds such as striga infestations.

Many of these problems are also interrelated thus requiring well designed adaptation and mitigation strategies (as presented and discussed in the following section addressing opportunities). In any given context the degree of vulnerability also varies depending on a range of factors directly linked to local conditions and practices, along with external economic and political dimensions, for example international commodity markets, climate change, population growth, and not least land management, all of which remain dynamic but in some cases may have marked degrees of change thus exponentially effecting, or impacting on, vulnerability overtime[1-3, 5]. In Table 3, many of the

Table 3. Possible progression of vulnerability over time

LOW	Progression of vulnerability →	HIGH
2012	**2030**	**2050**
Increased rainfall variability →	→	→
Increased temperatures →	→	→
Rising oil prices →	→	→
Rising food prices →	→	→
	Peak phosphorus expected steep rises to inorganic fertilizer costs →	
	Population growth resulting in high demand for food, land, & water →	

Table 4. Examples of vulnerability and food insecurity cause and effect relationships

Trigger	Primary impact	Secondary impact	Net result
Increased rainfall variability →	Decline in food production →	Crop failure →	Food insecurity
Increased temperatures →	Increased diseases and pests →	Decline in food production →	Food insecurity
Rising oil prices →	Increase in biofuels →	Decline in crop acreage →	Food insecurity
Rising food prices →	Increase costs of staples →	Limited food access →	Food insecurity
Peak phosphorus →	Limited inorganic fertilizer →	Decline in food production →	Food insecurity
Population growth →	Increasing resource demand →	Resource depletion →	Food insecurity

problems listed in the progression of vulnerability are directly related though cause and effect relationships to other response strategies that can then exacerbate the negative impacts thus reinforcing the progression of vulnerability as illustrated in Table 4[7]. Further details is given in Table 5.

Table 5. Agriculture priorities assessment framework – key vulnerabilities and opportunities

	Economic/ Finance	Social/ Capacity	Technology/ R&D	Political	Legal/ Institutional	Environment/ Climate	Communication / Information
Vulnerabilities	i) Economic insecurity ii) Increasing demands from other sectors for land / water / resources iii) Rising prices for external commodities: agro-chemicals, fuel, equipment, seeds, imported foods etc	i) Food insecurity, ii) Increasing unemployment / poverty	i) Introduction of inappropriate technologies ii) Dependency on capital intensive technologies e.g. agro-chemicals	i) Limited access to resources may exacerbate political / ethnic divisions / tensions	i) Failure to reinforce environmental / agricultural bylaws / policies	i) Increased rainfall variability leading to droughts / rain storms, crop failures ii) Rising temperatures leading to increased crop / livestock pests & disease, soil drying, weed infestation	i) Lack of appropriate information, miss-information
Opportunities	i) Intensification of small-scale production ii) Growth of agro-industries, export commodities iii) Regional food supplier	i) Food security ii) Livelihood generation iii) Poverty reduction	i) Development of knowledge based agro-sector ii) Development of indigenous knowledge iii) Regional hub for biotechnology	i) National political stability ii) Regional security	i) Mainstreaming of environmental policies across all sectors e.g. waste recycling, water conservation ii) Development of organic& fair-trade policies	i) Photosynthesis / crop production ii) Soil and water conservation iii) Integrated nutrient management iv) Integrated pest management	i) Enhancement of cross-sector communication and development
Sectoral overlaps	i) Energy / water/ land demands across all sectors	i) Off-farm livelihood generation	i) Decentralised energy / waste management	i) Mutually reinforcing across all sectors	i) Energy / water/ land management and policies	i) Energy / water/ land management and policies	i) Inter sector communication crucial

Opportunities

The planning and design for climate-smart agriculture brings a range of economic and environmental opportunities to the farmer and agricultural entrepreneur. For each of the problems identified in the previous section there are adaptation, mitigation and development options that can be designed and implemented to counter the negative impacts of carbon-dependency and climate change thus building resilience into agricultural ecosystems. In the context of small-scale agriculture and small-holdings, as in the case of Rwanda where average farm sizes are 0.7 of a hectare, this is particularly relative, because the aggregate benefit of small-holdings can be considerable, particularly when small-scale production is intensified and agricultural biodiversity is increased through agroecology techniques using agroforestry, kitchen gardens, nutrient recycling and water conservation to maximise sustainable food production[8]. In such cases small-scale agriculture can also bring wider aggregate benefits including food security, improved environmental sanitation, disaster risk reduction (slope stabilization/flood mitigation) leading to climate compatible development[9-11]. In this section a range of adaption, mitigation and low-carbon development options that are relevant in developing sustainable and resilient agricultural systems are presented and discussed.

3.1 Adaptation

Agricultural adaptation strategies for climate change (and carbon-dependency as often these problems are synonymous) are based on building resilience within the agricultural eco-system, primarily through soil and water conservation, and applying integrated approaches to nutrient and pest management. Such measures are best implemented at the landscape level and consequently designed to provide a holistic approach in tackling a range of problems and impacts that may stem from climate change. Hence overall planning and implementation needs to be conducted at the watershed level adopting an integrated watershed management approach. As Gregersen et al.[12] highlight "water flows downstream, ignoring all political boundaries en route" and "most of the things that people do to their land and water upstream affects the water quantity, timing of flow and quality downstream and, as a consequence, downstream land productivity in its various forms". An integrated watershed management approach ensures that measures and practices can be implemented to effectively manage watersheds particularly in reducing risks from flash floods and soil erosion using a range of interventions including cross-sector issues such as forest management in the upper watershed. Coupled with sustainable land management practices, rainfall infiltration can be maximised and surface run-off minimised to reduce erosion and flooding risks.

Such strategies at the farm level draw on a range, and combination, of tried and tested indigenous farming techniques coupled with the application of state-of-the-art scientific knowledge aimed at improving a range of related crop and livestock productivity aspects including biotechnologies that enhance photosynthesis, maximising sustainable soil management and tackling plant and livestock parasites and pathogens. For example, integrated approaches to soil nutrition and pest management build resilience through the application of a range of techniques which are based on cultural and biological interventions before relying on chemical treatments which become interventions of the last resort, rather than single solution-based approaches such as the application and dependency of inorganic fertilizer and/or pesticides. Many of these interventions are closely related, for example improving soil structure through the addition of organic inputs, such as composts and manures, increase soil fertility and mycorrizal activity, and the water retention capacity of the soils, which combined improves major and micro nutrient uptake within the crop[8, 13], thus also improving crop susceptibility to diseases and pests; examples of adaptation interventions are listed in Table 6.

3.2 Mitigation

In the context of mitigating greenhouse gas emissions, firstly many of the adaptation techniques listed in Table 6 also provide additional benefits by reducing greenhouse gas emissions (see Table 7). Consequently such approaches can also be planned and designed to maximise carbon sequestration and potentially benefit from carbon credit funding schemes. Further reduction of greenhouse gas emissions can also be achieved by restructuring agricultural markets by expanding crop varieties, local markets and manufactured products and exports in support of the sustainable intensification of small-scale farming. This will involve diversifying agricultural production and enhancing the agriculture value chain, as improving the agriculture value chain also reduces the sectors dependency on external inputs (fertilizers/food/fuel), while building an agricultural market economy based on added value and import substitution. Furthermore becoming more self-sufficient by expanding crop varieties will also add value to those crops through processing to meet its own market demand. This approach will create employment through the development of small and medium enterprises, thus converting a subsistence-based agriculture sector into a bio-diverse and sustainable agricultural market economy[8, 13].

Table 6. Selection of adaptation interventions

Broad function	Adaptation techniques	Benefits
Integrated nutrient management	Compost / farm yard manure application	Improve soil structure / water holding capacity
	Biodigester waste application	Improve soil structure / provides NPK /micro nutrient levels
	Use of nitrogen fixing plants	Soil nitrogen fixation / fodder provision, slope stabilization
	Appropriate crop rotation	Reduces build-up of soil pests and pathogens
Water conservation	Contour bunding /swales	Reduces soil erosion / maximises rainfall infiltration
	Mulching	Retains soil moisture / reduces weeds
Integrated pest management	Monitoring & forecasting strategies	Holistic approach to farm management
	Biopesticides application (e.g. neem)	Low cost / sustainable pest treatments
	Companying cropping	Trap crops / root secretion

Table 7. Proposed measures for mitigating GHG emissions from agricultural ecosystems[14]

		Mitigation effects			Net mitigation (confidence)	
Measure	Examples	CO_2	CH_4	N_2O	Agreement	Evidence
Cropland management	Agronomy	+		+/-	***	**
	Nutrient Management	+		+	***	**
	Tillage/residue management	+		+/-	**	**
	Water management (irrigation, drainage)	+/-		+	*	*
	Rice management	+/-	+	+/-	**	**
	Agro-forestry	+		+/-	***	*
	Set-aside, land use change	+	+	+	***	***
Grazing land management / pasture improvement	Grazing intensity Increased productivity (e.g. fertilization) Nutrient management	+/- + +	+/-	+/- +/- +/-	* ** **	* * **
	Fire management	+	+	+/-	*	*
	Species introduction (including legumes)	+		+/-	*	**
Management of organic soils	Avoid drainage of wetlands	+	-	+/-	**	**
Restoration of degraded lands	Erosion control, organic amendments, nutrient amendments	+		+/-	***	**
Livestock management	Improved feeding practices		+	+	***	***
	Specific agents and dietary additives		+		**	***
	Longer term structural and management changes and animal breeding		+	+	**	*
Manure/biosolid management	Improved storage and handling Anaerobic digestion		+ +	+/- +/-	*** ***	** *
	More efficient use a nutrient source	+		+	***	**
Bio-energy	Energy crops, solid, liquid, biogas, residues	+	+/-	+/-	***	**

Note: '+' denotes reduced emissions; - denotes increased emissions; '+/-' denotes uncertain or variable response

3.3 Options for Low Carbon Development

The planning, design and implementation of agroecology allows for a holistic approach to farm management that incorporates a range of adaptation and mitigation strategies that enhance agriculture ecosystems. Crucial to the process of building resilient agriculture ecosystems is the implementation of a combination of activities that are designed to bring a range of solutions each with multiple benefits to reduce negative climatic impacts and carbon-dependency. Some examples of appropriate interventions for the development of climate-smart agriculture are listed in Table 8. In Figure 2, a strategy to reduce external inputs in soil fertility management is illustrated. This is achieved by ensuring a range of additional soil fertility inventions and measures are implemented so that

Table 8. Some options for low carbon and climate resilience development

Option	Capital cost	Operating cost	Time to delivery	Ease of use	Development benefit	Climate benefit
Mainstreaming of agroecology	Low	Low	Immediate	Requires capacity building, extension & research & development	Improves productivity & income generation, reduces dependency on external inputs	Improves resilience of farming systems, mitigates GHG emissions
Resource recovery and reuse	Medium	Low	Immediate	Requires capacity building, trained operators & public awareness campaigns	Creates off-farm employment, improves environmental sanitation & reduces landfill inputs	Conserves water & soil nutrients, reduces GHG (methane) emissions from waste dumps
Fertilizer enriched products	Low	Low	Immediate	Requires capacity building, production plant & extension	Creates micro-enterprises, improves environmental sanitation & reduces landfill inputs	Conserves water, soil nutrients & fertilizers, reduces GHG emissions from waste dumps
Mainstreaming of “Push-Pull” Strategies (IPM)	Low	Low	Immediate	Requires capacity building, extension, research & development	Improves productivity & income generation, reduces dependency on external inputs	Improves resilience of farming systems, reduces pesticide inputs, improves fodder
Expansion of crop varieties	Low	Low	Immediate	Requires capacity building, extension, research & development	Increases agricultural biodiversity, reduces crop failure risk due to diversification	Improves resilience of farming systems, reduces food imports & food miles
Expansion of local markets	Low	Low	Immediate	Requires capacity building, minor infrastructure & public awareness campaigns	Provides economic opportunities, creates demand for local products	Reduces food imports & food miles, reduces GHG emissions
Expansion of manufactured products	Low	Low	Immediate	Requires capacity building & production facilities	Creates off-farm employment, creates demand for variety of locally grown produce	Reduces food imports & food miles, reduces GHG emissions
Expansion of exports	Low	Low	Immediate	Requires capacity building, extension, research & development	Provides foreign revenue, Fairtrade niche bring environmental & social benefits	Organic production improves resilience of farming systems, mitigates GHG emissions

farming systems are not dependent on single nutrient sources particularly when such inputs are externally sourced. Each level of intervention in the soil fertility triangle provides additional opportunities for designing interventions that can be implemented as components of adaptation and/or mitigation strategies. Such strategies should be implemented as a gradual and transformative process with the initial aim of reducing rather than replacing or restricting external inputs such as inorganic fertilizers. The listed interventions are discussed further in Section 5 Focus Areas, Section 7 Analysis of Options and Section 8 Strategic Framework.

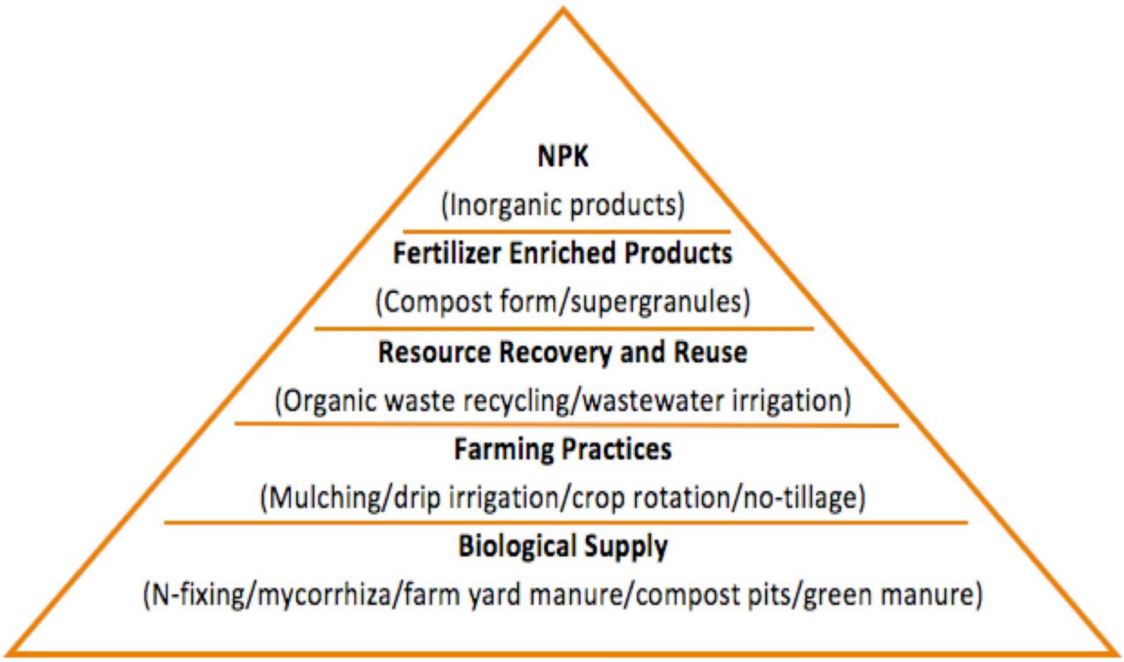

Figure 2: Practical interventions to achieve integrated soil fertility management

Sectoral Overlaps

The agriculture sector overlaps with most sectors including disaster management, energy, health, national resources (forestry / land / water), transport and even urban planning In this section some of the commonly occurring sectoral overlaps are identified, followed with some brief guidelines to address the management of these overlaps with the aim of building linkages and maximising the potential synergies that can be found between the different sectors (see Table 9).

Table 9. Sectoral overlaps for agriculture illustrating the multiple linkages, synergies and benefits

i) End goal	ii) Objectives	iii) Outputs	iv) Some techniques	v) Some benefits
ECOSYSTEM RESILIENCE (Disaster risk reduction)	Environmental Protection	Flood prevention / mitigation	Riparian buffer zones for seasonal rainfall	Flood plain protection
			Reforestation of watershed	Reduced runoff
			Small dams in upper watershed	Rainfall / runoff capture and retention
		Agricultural biodiversity and habitat conservation	Agroforestry	Indigenous crop utilisation
				Reduction in urban heat island effect
			Agroforestry in wetlands (canopy closure)	Reduction in Anopheles breeding
		Slope stabilization	Agroforestry	Soil binding from plant root interaction
			Swales (ditch on contour)	Increased rainfall / runoff infiltration
				Formation of strong mounds on contour
	Environmental Sanitation	Solid waste utilization	Biogas production	Local energy creation
			Community-based composting	Also engages non-farming households
			Household-based composting	Direct home garden application
		Wastewater irrigation	Agroforestry	Livelihood creation (e.g. silk production)
				Reduced health risk from pathogens
			Vegetable production	Increased dry-season food availability
	Food Security	Food production	Aquaculture	Increased protein productivity
			Cultivation	Low-external input (e.g. micro-gardens)
			Livestock husbandry	Increased meat and dairy productivity
		Income generation	Creation of local food markets along urban-rural continuum	Employment creation
				Reduced dependency on external food
			Livelihood diversification	Increased resilience to economic shocks

4.1 Sectoral Overlaps

4.1.1 Disaster Management

Agriculture overlaps with disaster management primarily through land management and economic development. Impacts from agriculture can play a role in disaster risk reduction through reduction in physical vulnerability, such as effective land zoning tool in fragile ecological locations such as steep slopes, flood prone areas and wetland systems. In this context, secure farming-tenancy prevents the informal and illegal settlement in vulnerable locations. The implementation of sustainable farming practices, such as agroforestry, swales on contour and rock bunding, can improve water infiltration and reduce overland water flow thus reducing flooding risks during heavy storms. Also improvements in economic development at the household level ensures households are more resilient to external shocks and it allows farmers to take risk reduction measures such as purchasing crop insurance.

4.1.2 Energy

There is a clear two-way relationship between agriculture and energy that can be exploited to maximize potential synergies. Agriculture requires energy in crop production, harvesting, processing, storage and distribution. The energy demands in the agriculture sector are dependent on the scale of operation and the technologies that are being used in the sector. Energy is also an important component required to transform subsistence agriculture into a market-based economy as energy is required in most production methods that add value through crop processing. Such energy demands can be met through small-scale and off-grid energy plants that can be implemented at the village level to develop village-level agricultural processing plants using appropriate technology. The other dimension to agriculture and energy is the use of agricultural wastes and other farm by-products for energy production using methods such as biogas digesters or biochar production. When considering the best applications in a waste reuse programme all options should be evaluated and designed to bring 'best resource recovery and reuse' in terms of nutrient value and energy produced, for example certain organic wastes may bring higher value when composted and used for improving soil fertility and structure rather than being incinerated in a waste-to-energy plant.

4.1.3 Health

Health clearly overlaps with agriculture through physiological, nutritional, psychological and economic benefits Agriculture is pivotal to public health strategies and maintaining food security through the production of food so that all citizens have access a well-balanced nutritional diet regardless of social-economic status. In addition to rural food production, urban and peri-urban agriculture can also contribute to food security, and kitchen gardens can be promoted in all urban, peri-urban and rural areas to contribute to food security at the household level (see Table 10 and Figure 3).

Figure 3: Kitchen garden with mushroom production shed in the background in Kigali

Table 10. Key potential benefits from kitchen gardens[15-18]

Benefit Type	Health, Economic and Wellbeing Benefits
Physiological	Multi-muscular exercise – improving cardiovascular function
	Controlled load bearing – reduced osteoporosis
	Bending and stretching – increased general muscle tone
	Outdoor exercise – 'fresh' air, sunshine
Nutritional	Diets rich in micronutrients and antioxidants strongly recommended to supplement medicinal therapy in fighting HIV/AIDS
	Increased availability of dietary antioxidants, including flavonoids, carotenoids, vitamin C and tocopherols
	Fresh produce rich in vitamins and trace elements
	Spinach and green leafy vegetables high in calcium, folic acid, iron and ascorbic acid
	Okra for calcium – good to strengthen bones of the weak
	Tomatoes and African eggplant (type of aubergine) for vitamin C
	Chinese cabbage for vitamin A
	Amaranthus for iron and vitamin A
	Artemisia for malaria treatment and implicated in preventing cancers (used in teas)
	Brassicas (cabbage, cauliflower, broccoli, brussels sprouts, curly kale) rich in glucosinolates - implicated in preventing cancers
	Legumes (peas, beans) key components of the health protecting 'Mediterranean diet'
	Berry fruits rich in anthocyanins, flavonoids and vitamin C
	Apples rich in anti-oxidants implicated in cancer prevention
	Sunlight exposure – leading to increased vitamin D synthesis in skin
Psychological	Sunlight exposure – increased serotonin (less winter-depression)
	Sense of achievement and well-being – improved psychological health
	Empowerment – independence/self sufficiency
	Nature and green space interaction-increased well-being
	Enhanced social networks and community interaction-increased well-being
	Sense of community and belonging-increased well-being
	Reduced stigmas that are associated with HIV/AIDS
Economic	Income generation through sales of surplus garden produce
	Income generation through reduced expenditure on household food purchasing
	Livelihood diversification and strengthening of household resilience
	Establishment/strengthening of local markets
	Contribution to the urban economy and markets

4.1.4 Natural Resources

Agricultural land is often perceived as being in competition with a range for other land use demands such as forestry and urban development. In urban areas, water demand also increases with industrialization and urban development placing further restrictions on agricultural production in peri-urban areas. Planning and design at a wider watershed scale have the potential to resolve some of these issues in addition to bringing 'macro' scale benefits, including disaster risk reduction through enhanced flood management and slope stabilization of steep hillsides; protection and rehabilitation of fragile and vulnerable habitats including riverbanks and wetlands which act as natural sponges and wildlife havens; and reductions in the urban heat island effect. The ecosystems services approach is another analytical tool suited to the management of natural resources, which may also be applied to manage competing demands[15]. Four categories of ecosystem services are commonly used: provisioning services (e.g., food/water/minerals/pharmaceuticals/energy); regulating services (e.g., carbon sequestration/waste decomposition and detoxification/purification of water and air/crop pollination/pest and disease control); habitat services (e.g., nutrient dispersal and cycling/seed dispersal/primary production) and; cultural services (e.g., cultural, intellectual and spiritual inspiration/recreational experiences/ecotourism/scientific discovery)[16].

4.1.5 Transportation

Transport networks and logistical facilities are important for developing rural areas and improving important agriculture value chains and markets that then bring added value to rural production. Effective transport networks are also required in the development of village-based industries such as small-scale agricultural processing plants using appropriate technology. Without good market linkages via well planned and implemented transport networks rural development programmes are likely to fail, which is why road construction and upgrading are often featured in integrated rural development programmes.

4.1.6 Urban Planning

There are multiple linkages between urban planning and agriculture. As illustrated in Table 9, agriculture can be planned and designed for environmental protection, environmental sanitation and food security, and each of these objectives equally apply in urban and peri-urban areas. In the context of climate change, urban and peri-urban agriculture can reduce food miles as food is produced closer to urban populations where food demands are higher[21].

4.2 Management of Sector Overlaps

Effective management of sector overlaps is crucial to maximise resource efficiency through the enhancement of productive synergies. For example in the context of a low carbon strategy the safe utilization of urban and rural wastes is an important synergy that can bring a range of benefits to agricultural production through the application of composted organic wastes to agricultural plots. To effective manage sector overlaps the key stakeholders must be identified and included to ensure a participatory approach in the development of appropriate policies and guidelines. Local community participation, public-private partnerships and a participatory approach are all crucial in the development and implementation of polices that cover a combination of sectors. Such approaches are crucial in developing local ownership to multi-faceted and complex development issues.

Focus Areas

In the agriculture sector a range of adaptation and mitigation strategies are proposed to counter the potential impacts from climate change and carbon dependency. Consequently within the agricultural sector two broad programmes of action have been identified which provide the overall strategy for intervention. Under each programme of action, a range of individual actions each with specific aims and objectives have been identified to provide an operational framework for implementation:

- Programme 1: Sustainable intensification of farming
  - Action 1: Mainstreaming of agroecology (climate-smart agriculture)
  - Action 2: Resource recovery and reuse
  - Action 3: Fertiliser enriched products
  - Action 4: Mainstreaming of "Push-Pull" Strategies (IPM)
- Programme 2: Agricultural diversity in local and export markets
  - Action 1: Expansion of Crop Varieties
  - Action 2: Expansion of Local Markets
  - Action 3: Expansion of Manufacturing
  - Action 4: Expansion of Exports

Also of relevance are Programme 12 Sustainable Forestry, Agroforestry and Biomass Energy, which is covered in more detail in the Forestry Sector Working Paper, and Programme 3: Integrated Water Resource Management and Planning, which is covered in detail in the Water Sector Working Paper.

These programmes of action will allow the mainstreaming of climate-smart agriculture in the current agricultural intensification programmes consisting of Land husbandry, Water harvesting and Hillside irrigation Project (LWH), Integrated Water Resource Management (IWRM) (irrigated rice production) and the One Cow Program; thereby maximising appropriate nutrient recycling and water conservation techniques, and ensuring that agricultural landscapes are not only productive but also sequestrate terrestrial carbon thus improving both adaptation and mitigation capacity. The two programmes for agriculture are based on developing low-carbon development and climate resilience across the sector through mainstreaming or small-scale intensification (agroecology); the closure of nutrient recycling loops (organic waste recycling); the application and development of biotechnologies such as push & pull technology; the development of agriculture value chains across local, national and export markets; and building capacity at a range of scales and across a variety of crop and livestock production systems. Examples of practical interventions are given in Table 11.

Finally, the National Strategy on Climate Change and Low Carbon Development for Rwanda identified a number of Big Wins, defined as large scale economy-wide programmes designed to make significant impacts on mitigation, adaptation and economic development. In the context of agriculture, three Big Wins are included:

- Reduced dependency on inorganic fertilisers
- Irrigation infrastructure
- Agroforestry

Table 11. Focus areas and options for intervention

Focus area	Option 1	Option 2	Option 3
Mainstreaming of agroecology	Integrated nutrient management, including N-fixing mycorrhiza, farm yard manure, compost pits, green manure	Improved farming practices, mulching, drip irrigation, crop rotation, no-tillage	Mainstreaming of agroforestry approaches, including use of border trees, fruit orchards, mixed coffee systems
Resource recovery and reuse	Establishment of decentralised composting plants	Establishment of organic waste recycling at household level	Development of Kigali landfill site into municipal composting station
Fertilizer enriched products	Establishment of 'Comlizer' production plant (public-private partnership)	Establishment of decentralised 'Comlizer' pilot projects in crop production	Establishment of fertilizer deep placement (FDP) supergranules projects in rice production
Mainstreaming of "Push-Pull" Strategies (IPM)	Establishment of demonstration sites (innovation centres)	Building capacity in research & development of push & pull technologies	Establishment of push & pull farmer field schools, training of extension workers in push & pull
Expansion of crop varieties	Establishment of innovation centres to introduce vanilla seeds, apricot saplings, macadamia plants	Use of innovation centres to promote underutilized crops such as Russian comfrey & indigenous African vegetables	Use of innovation centres as bioregional centres for germplasm collection e.g. seed banks, nurseries & small woodlots
Expansion of local markets	Construction of covered market facilities in towns and settlements	Construction & upgrading of road networks	Public awareness campaigns in nutrition & preparation of exotic and underutilised crops
Expansion of manufactured products	Training for cooperatives in the development of agricultural processing technologies	Establishment of small-scale and off-grid energy plants using appropriate technology	Establishment of decentralized village-based agricultural processing centres
Expansion of exports	Greening of export crop processes that are energy & biomass intensive such as tea production	Development & promotion of Fairtrade market products	Development & promotion of organic market products

5.1 Integrated Soil Fertility Management

The agricultural intensification programme in Rwanda is currently dependent on the application of inorganic fertiliser to increase crop yields, although these external inputs produce a significant proportion of Rwanda's GHG emissions through the fertiliser manufacturing process and the transportation of fertiliser products. However demand for inorganic fertilisers can be reduced by applying an integrated approach to soil fertility and nutrient management, which employs agroecology, resource recovery and reuse, and fertiliser enriched products. An integrated approach will significantly lower inorganic fertiliser demand, reduce dependence on oil, reduce GHG emissions and increase farm profitability due to reduced input costs for farmers. Such approaches also improve soil structure and the water retention capacity of soils leading to resilient agricultural ecosystems and sustainable food security, consequently climate-smart agriculture.

5.2 Climate-Smart Agriculture

The mainstreaming of agroecological into extension and development programme design is to ensure the long term and sustainable management of small-scale agriculture using a range of strategies that enhance the agricultural ecosystems. Such an approach allows for the gradual reduction of carbon-based farm inputs such as inorganic fertilizer and pesticides as more holistic approaches to soil fertility management are adopted. In regards to agroecological there are a host of possible entry points and interventions, three of which are listed in Table 10. Each of these options can be broken further down into specific techniques, and the skills and training required for effective demonstration and extension (many of the techniques are already covered in Section 3). In the context of MINAGRI's three main agricultural intensification programmes each component offers the opportunity of mainstreaming agroecology and thus developing climate-smart agriculture particularly as this would integrate sub-components of the agricultural intensification programme:

- Land husbandry, Water harvesting and Hillside irrigation Project (LWH)
  - Integration of kitchen garden at household level
  - Increasing crop diversity at plot and landscape levels
  - Adoption of the soil nutrient triangle principles (see Figure 1)
  - Incorporation of agroforestry strips/swales on contour as extreme runoff/erosion checks
  - Introduction of fodder crops, such as Napier grass and desmodium, on plot boundaries and as intercrop to provide fodder yield and push-pull pest control
- Integrated Water Resource Management (IWRM) (irrigated rice production)
  - Improved biodiversity in silt trap areas
  - Integration of kitchen garden at household level
  - Regulated irrigation control to reduce standing water
  - Improved bio-diverse agroforestry in upper watershed areas
  - Establishment of fertilizer deep placement (FDP) supergranules projects in rice production
- One Cow Program
  - Integration of kitchen garden at household level
  - Use of multipurpose fodder crops such as Napier grass and desmodium
  - Introduction of improved farm-yard-manure (FYM) techniques to maximise FYM quality
  - Improved use of underutilised crops with high fodder potential such as Russian comfrey (local name Mbogagifu)

Other agricultural programmes such as the BTC integrated pest management (IPM) Farmer Field School provide ideal platforms and models for the extension and uptake of related technologies including agroecology, integrated soil fertility management and push-pull pest control technologies (see Figure 4).

Figure 4: BTC Farmer Field School in Rwanda

5.3 Other Relevant Resilience/Adaptation Big Wins

5.3.1 Irrigation infrastructure

Rwanda has high annual rainfall which it has traditionally been able to exploit for seasonal agriculture. However, seasonal agriculture is vulnerable to climate change and population pressure, as even slight changes in rainfall patterns and air temperatures can have significant impacts on crop and livestock production, likewise, a rapidly growing population places serious pressure on food security. Consequently, the development of irrigation infrastructure is required to maximise efficient land and water usage in Rwanda, and to adapt seasonal farming systems into climate-smart agriculture thereby building resilience to potential future shocks. The implementation of irrigation infrastructure forms a crucial component of Integrated Water Resource Management as improved watershed management allows for increased water efficiency in other sectors including domestic and industrial sectors, while also reducing disaster risks through the mitigation of floods and landslides.

5.3.2 Agroforestry

Rwanda does not have the land available to expand its forests and plantations, yet the majority of the population depends on wood for cooking and will continue to do so until electricity is available and affordable for all. Agroforestry will provide wood for fuel and social protection while avoiding deforestation. It also reduces soil erosion, improves slope stability and increases resilience to heavy rains. Different tree species will be used in agroforestry to provide construction materials and livestock fodder and food (fruit and nuts) which both improve food security.

Review of Best Practice

In this section three 'best practices' that provide use insights and lessons relevant to a low carbon development and climate resilient strategy are discussed. The first briefly introduces sustainable agriculture and food security in an era of oil scarcity in Cuba as experienced during the 1990s with the aim of reflecting on low-carbon models as implemented in Cuba during the American blockade. The second 'best practices' presents the Gako Organic Farming Training Centre outside Kigali which promotes a range of agroecology practices, and the third 'best practices' examines Send a Cow's organic agriculture programme as practised and implemented in Rwanda.

6.1 Sustainable Agriculture and Food Security in an Era of Oil Scarcity in Cuba

The sustainable agriculture and food security lessons that were learnt in Cuba during the early 1990s' era of oil scarcity provide the classic example of this phenomenon. Following the collapse of the Soviet Union and subsequent cessation of Soviet imported oil and oil-based agrochemicals coupled with the American trade embargo, Cuban farmers could no longer irrigate and fertilize their fields as previous practised during the subsided Soviet era[22]. These two agricultural constraints, or rather their effects, mimic climatic-induced events, for example the effects of limited irrigation are similar to that of increased rainwater variability (no longer having the right amount of water at the right time on the field). In relation to soil fertility, the effects of a sudden lack of fertilizers are similar to those likely to emerge during warmer climatic conditions, including increased soil degradation and a higher carbon decomposition rate in soils, ultimately leaving agricultural plots nutrient deficient and prone to erosion[14]. In response, Cuban underwent a major readjustment in agriculture and strongly supported urban and peri-urban agriculture, organic farming and resource recovery and reuse. All organic wastes were diverted to compost production as organic farming practices were adopted from necessity rather than commercial reasons. Other approaches that could maximise organic methods such as integrated pest management and the use of biological plants for pest control were adopted. The Cuba experience provided a clear example to the potentials of adopting a low-carbon approach through the adoption of agroecology and the recycling of organic wastes in farming systems[22].

6.2 Gako Organic Farming Training Centre

The Gako Organic Farming Training Centre (GOFTC) is located on the outskirts of Kigali. At GOFTC they run training worships that run from one day to 30 days, although the majority of courses in recent times have been on average around one week duration. Since 2002 they have trained over 3000 farmers in organic agriculture techniques. The training at GOFTC consists of a combination of class room sessions and hands-on practical work sessions as students engage with the demonstration systems well established at the training centre. Examples of the agricultural intentions are livestock production (poultry, pig, small ruminants, and rabbits). All liquid slurry from the livestock enclosures is collected and used as a biofertilizer, likewise the manure is collected and used either as farmyard manure or is deposited in the methane digester for energy production. The waste product from the methane digester is applied to the fruit trees. Other biofertilizer options include comfrey production which is used as mulch and also to make liquid comfrey, a very effective and nutrient rich biofertilizer. Comfrey leaves are also used as fodder for poultry and pig production (see Figure 5). Cropping systems on display include kitchen gardens, agroforestry, growing vegetables in containers, and feature the use of underutilised crops. The use of composting is very evident at the site as such practices and inputs must be maintained to ensure the fertility of soils under organic production systems are not depleted of their nutrients (see Figure 6).

6.3 Send a Cow Organic Farming

Send a Cow's organic agriculture programme as practised and implemented in Rwanda is a good example of agroecology. The programme is aimed at balancing people, livestock and the environment with the whole training process taking 18-months but the results are sustainable with good adoption and satisfaction from the participating framers. The organic farming programme uses a range of sustainable framing techniques:

Figure 5: Russian comfrey at Gako

Figure 6: On-farm composting demonstration at Gako

- Composting of animal manure to improve soil structure and rejuvenate tired land, resulting in the improvement and diversification of crops.
- Building of keyhole gardens and bag gardens, techniques that encourage the micro-climates necessary for year-round production of vegetables.
- Use of animal urine and manure to produce natural pesticides and plant food.

Additional training in natural resource management is also provided including:

- Introduction of agroforestry practices, such as the planting of a sustainable source of fast growing trees for firewood, building materials and animal fodder.
- Building of fuel-efficient stoves, significantly reducing the amount of wood required for cooking.
- Introduction of simple water harvesting techniques, such as the capturing of rain water, the building of wells and the digging of trenches.

The Send a Cow programmes illustrates the importance of an holistic approach to rural development that integrates all elements of natural resource management, including people, livestock, water, land and soil fertility management, as all form crucial components of climate-smart agriculture.

Analysis of Options

The following section provides additional analyses for the multiple components of the two selected Programmes of Action as detailed in Section 5. To consolidate the background and operational information and thus provide a clear analysis for each of the eight actions a strengths weakness, opportunities and threats (SWOT) analysis for each of the actions listed in Table 11 is now given.

Programme 1: Sustainable intensification of small-scale farming

Action 1: Mainstreaming of agroecology (climate-smart agriculture)

Strengths

- Low operating cost
- Low cost capital cost
- Immediate time to delivery
- Maintenance of soil fertility
- Improves productivity and income generation
- Reduces dependency on external farm inputs
- Mixed farming systems brings dairy and meat products

Weaknesses

- Labour intensive
- Lower quantity of cash crop production
- Livestock component require feed and veterinary inputs
- Zoonosis and public health risk if livestock manure not managed

Opportunities

- Diversify crop production
- High impact for climate resilience
- Suitable for Farmer Field School approaches
- Recovery and reuse of organic on-farm wastes/ by-products
- Use of livestock for animal traction and livestock by-products

Threats

- Requires effective extension services
- Requires capacity building in research and development

Action 2: Resource recovery and reuse

Strengths

- Low operating cost
- Medium capital cost
- Immediate time to delivery
- Conserves water and soil nutrients
- Creates off-farm employment and micro-enterprises
- Reduces waste volumes at landfill and open dump sites
- Composting at household level provides compost input for kitchen gardens

Weaknesses

- Requires land space for plant facilities
- If not correctly practised can attracts rats/flies
- Requires start-up resources to construct plants and operator training

- Household composting requires containers if practised near to dwellings

Opportunities

- High impact for climate resilience
- Improves environmental sanitation
- Closes nutrient recycling loop with organic wastes
- Development of compost-based products/ markets
- Development of Kigali landfill site into municipal composting station
- Medium impact on GHG emissions reduction (particularly methane emissions)

Threats

- Requires public awareness campaigns
- Risks from using contaminated organic waste inputs
- Requires capacity building in research and development
- Compost plant breakdown if equipment/ machinery not maintained

Action 3: Fertiliser enriched products

Strengths

- Low cost capital cost
- Immediate time to delivery

Weaknesses

- Degree of dependency on external inputs

Opportunities

- High impact for climate resilience

Threats

- Subsidised agricultural pesticides
- Requires effective extension services
- Requires capacity building in research and development

Action 4: Mainstreaming of "Push-Pull" Strategies (IPM)

Strengths

- Low operating cost
- Low cost capital cost
- Immediate time to delivery
- High impact for climate resilience
- Builds local biotechnology capacity
- Can link into current farmer field schools (FFS)
- Improves livestock fodder availability and quality
- Provides important catalyst for improved farm management
- Reduces dependency on external inputs such as agricultural pesticides
- Can combine with integrated nutrient management for agroecology approach

Weaknesses

- Requires effective extension services
- Extension process and roll-out slow
- Requires repeated farmer contact and farm visits
- Without correct farmer support uptake discouraged
- Requires capacity building in research and development

Opportunities

- High impact for climate resilience
- Suitable for Farmer Field School approaches
- Develop Rwanda as a regional hub in biotechnology
- Establishment of demonstration sites (innovation centres)

Threats

- Subsidised agricultural pesticides
- Immediate time to delivery

Programme 2: Agricultural Diversity in Local and Export Markets

Action 1: Expansion of Crop Varieties

Strengths

- Low operating cost
- Low cost capital cost

- Immediate time to delivery
- Increases agricultural biodiversity
- Crop diversification improves farm resilience

Weaknesses

- May increase labour intensity

Opportunities

- Improves local economic markets
- High impact for climate resilience
- Reduces food imports and food miles

Threats

- Requires public awareness campaigns
- Requires effective extension services
- Requires capacity building in research and development

Action 2: Expansion of Local Markets

Strengths

- Low operating cost
- Low cost capital cost
- Immediate time to delivery
- Reduces food imports and food miles

Weaknesses

- Requires infrastructure such as covered market facilities in towns and settlements

Opportunities

- High impact for climate resilience
- Creates demand for local products
- Medium impact on GHG emissions reduction

Threats

- Requires public awareness campaigns
- Requires capacity building in research and development

Action 3: Expansion of Manufactured Products

Strengths

- Low operating cost
- Low cost capital cost
- Immediate time to delivery
- Reduces food imports and food miles

Weaknesses

- Requires energy provision
- Requires infrastructure such as village-based crop processing plants

Opportunities

- Creates off-farm employment
- High impact for climate resilience
- Reduces food imports and food miles
- Creates demand for locally grown produce
- Medium impact on GHG emissions reduction

Threats

- Requires capacity building in research and development

Action 4: Expansion of Exports

Strengths

- Low operating cost
- Low cost capital cost
- Immediate time to delivery
- Fairtrade brings social and environmental benefits
- Organic production improves resilience of farming system
- Greening export crop processes tea processing reduces energy and biomass demands

Weaknesses

- Organic production is labour intensive

Opportunities

- Generates foreign revenue
- High impact for climate resilience
- Development of niche organic markets
- Development of niche Fairtrade markets
- Organic production mitigates GHG emissions

Threats

- Requires effective extension services
- Requires capacity building in research and development

Strategic Framework

Table 12. Focus areas and options for intervention

Focus area WHY	Policies and Actions WHAT	Stakeholders WHO	Timescale WHEN	Measurables HOW	Sources of Finance
Mainstreaming of agroecology	Extension strategy; Innovation centres; Research & development	MINAGRI; District agronomists; NGOs; Farmers, ISAR	Immediate initiation and then ongoing roll-out programmes	Number of innovation centres established; Farmer participation	Donor (see Section 8.1)
Resource recovery and reuse	Extension strategy; Training programmes; Establishment of composting plants	Local authorities; MINAGRI; MININFRA; NGOs; Farmers; District agronomists	Immediate initiation and 3-year development	Number of compost plants established; Quantity of compost produced	Private sector; Public-private partnership; Donor (see Section 8.1)
Fertilizer enriched products	Extension strategy; Innovation centres; Research & development	Private sector; MINAGRI; MININFRA; NGOs; Farmers; District agronomists, ISAR	Immediate initiation and then ongoing roll-out programmes	Number of innovation centres established; Farmer participation	Private sector; Donor (see Section 8.1)
Mainstreaming of “Push-Pull” Strategies (IPM)	Extension strategy; Innovation centres; Research & development	MINAGRI; District agronomists; NGOs; Farmers, ISAR	Immediate initiation and then ongoing roll-out programmes	Number of innovation centres established; Farmer participation	Donor (see Section 8.1)
Expansion of crop varieties	Extension strategy; Innovation centres; Research & development	MINAGRI; District agronomists; NGOs; Farmers, ISAR	Immediate initiation and then ongoing roll-out programmes	Number of innovation centres established; Farmer participation	Donor (see Section 8.1)
Expansion of local markets	Covered markets; public awareness campaigns in nutrition/food	MINAGRI; MININFRA; NGOs; Farmers	Immediate initiation and then ongoing roll-out programmes	Number of covered markets constructed; Media campaigns	Donor (see Section 8.1)
Expansion of manufactured products	Village-based processing centres; Innovation centres; Research & development	MINAGRI; Private sector; NGOs; Farmers, ISAR	Immediate initiation and then ongoing roll-out programmes	Number of processing centres established; Innovation centres; Farmer participation	Private sector; Donor (see Section 8.1)
Expansion of exports	Extension polices; Training programmes; Innovation centres	MINAGRI; District agronomists; NGOs; Farmers	Immediate initiation and then ongoing roll-out programmes	Number of innovation centres established; Farmer participation	Donor (see Section 8.1)

Climate Finance

9.1 International Climate Funds

Agriculture featured prominently in Rwanda's National Adaptation Plan of Action (NAPA). As such, there should be significant opportunities to receive grants from multilateral climate funds. A few of the funds that offer support for NAPA implementation are the Adaptation Fund, the Least Developed Country Fund, the Global Environmental Facility, the Global Facility for Disaster Reduction and Recovery, and the Global Climate Change Alliance. Other multilateral funds that might support Rwanda's agriculture adaptation and mitigation initiatives include the International Climate Initiative, the Special Climate Change Fund, UNDP/Spain MDG Achievement Fund, The Hatoyama Initiative, the International Development Association, World Bank Group's Catastrophic Risk Management Facility, the UNDP Green Commodities Facility, the ClimDev-Africa Special Fund, the Nordic Climate Facility, and KfW Development & Climate Finance. Each fund has its own mandate, institutional requirements, and application and monitoring procedures which are outlined on the website www.climatefinanceoptions.org. Public funds could also come from Rwanda's future environmental fund, FONERWA, which will in turn be capitalized by bilateral development partners and environmental fiscal sources.

9.2 Crop Index Insurance

An innovative tool to manage increasingly stochastic weather conditions is index insurance in which payments are linked to meteorological indices such as rainfall, temperature, wind speed, etc. The most common index insurance model is crop insurance linked to rainfall. Payments are made to a farmer if it rains less than a predetermined amount over a given period of time. Index insurance has a number of advantages over traditional crop insurance. Because it is based on centrally controlled weather data, there are less transaction costs. Employees need not visit farms to determine losses. As a result, there is less susceptibility to moral hazard and benefits can be paid more rapidly, when they are needed most. The GoR has already supported two pilot crop index insurance programmes – a small one implemented by a company called Sonarwa, and another by MicroEnsure. The MicroEnsure project is operating in six districts, and offers an insurance product linked with microloans provided by Vision Microfinance and Urwego Opportunity Bank to farmers planting maize and rice. The insurance premiums are subsidized 100 percent through funds provided by COMESA, and the coverage is limited to the principle of the loan.

Index insurance can build adaptive capacity to climate change in a number of ways. Most directly, it spreads weather-related risks over large populations and geographical areas. Thus, if there is a drought, farmers will have a safety net in place to ease the economic burden. Perhaps more importantly, crop index insurance can build adaptive capacity by unlocking investment. Creditors are more willing to lend to those with insured assets as it reduces the risk of defaults. Furthermore, in the absence of safety nets, farmers are hesitant to invest scarce assets in technology and other inputs that could increase productivity and resilience such as drought resistant seeds, irrigation, and transport to access markets. By enabling farmers to take such risks, index insurance can allow farmers to escape climate-related poverty traps to become more resilient to the effects of climate change. It is important to note that increased weather-related resilience in the short-term does not necessarily translate into resilience to long-term climate change. If the climate changes drastically – for example, a drought that formerly occurred once every ten years, begins to occur bi-annually – then crop insurance premiums will increase to the point where the scheme is no longer functional. To overcome this issue, a crop insurance scheme could be designed to incentivize physical adaptation measures through price signals and risk management stipulations. For example, it might stipulate that a farmer adopt drought tolerant crops in order to be covered. Such adaptation promoting incentive structures remain theoretical at this point, but are an area that pilot programmes should explore.

Another example of crop index insurance promoting physical adaptation is the joint World Food Programme-Oxfam America drought insurance project in Ethiopia, which allows cash-constrained farmers to pay premiums through labour on adaptation projects, such as the construction of irrigation systems or water harvesting structures. Such work-for-insurance and work-for-food programmes are called "productive safety nets," and are a tool to reach the lowest-income clients without traditional unproductive subsidies. Crop index insurance programmes rely on data from weather stations that are in close proximity to farmers. The stations should generally be at most 20 kilometres from client. The further the weather station is from a farm, the greater the issue of what is known as "basis risk" – that a drought experienced by a farm will not be registered in the weather station's data. If this occurs, there is a chance that the farmer will unfairly lose out. Basis risk is particularly relevant to Rwanda due to its numerous microclimates. There are a number of ways to address this problem. Remote sensing data from satellites can be used to supplement weather data and increase its accuracy. A system could also be set up to identify victims of basis risk, and a portion of the premiums could be put into a fund to compensate them. Most importantly however, the GoR will need to invest in increasing the coverage of weather stations and in employing and training permanent staff to collect weather data for the MET. It has already invested in installing 90 new stations to improve coverage. To promote the index insurance industry, the GoR could also invest in marketing programmes and training employees of financial institutions that have a presence in rural areas. At the initial stages, it will also likely be necessary to continue the subsidies of the premiums, though these subsidies should be phased out as the product becomes popular.

9.3 Clean Development Mechanism Programme for Organic Waste Composting

Appropriate land husbandry techniques results in significant reductions in greenhouse gas (GHG) emissions. Unfortunately, offsets from land-use management changes are not yet eligible for carbon credits through the Clean Development Mechanism (CDM), which is described in detail in the Finance Sector Working Paper. However, there are significant opportunities for Rwanda to generate CDM carbon revenues through organic waste management projects. The vast majority of the waste sent to Rwanda's landfills is organic, the resulting anaerobic decomposition of which leads to emissions of methane gas. Methane's global warming potential is 21 times stronger than that of carbon dioxide. Hence, abating these emissions through appropriate aerobic composting will prevent potent GHG emissions from contributing to climate change and could yield 21 times the number of carbon credits as a project reducing an equal amount of CO_2. Furthermore, the compost produced could be certified and sold to farmers as organic fertilizer to enhance plant growth.

One example of such a project comes from Uganda, where 80 percent of the waste sent to the landfill is organic. In 2010, the Uganda's Municipal Waste Compost Programme was set up as a countrywide CDM programme to eliminate these methane emissions by recovering and composting the organic matter. The resulting compost is sold to farmers. Municipalities either set up and operate the composting facilities on their own, or contract the service out to the private sector. The implementing entity, the National Environment Management Authority (NEMA), provides financial and technical assistance during implementation of the composting facilities, and then monitors their operation. To finance the initial costs of the project, the Government of Uganda has taken a loan from the World Bank. The municipalities then transfer their carbon credit rights to the NEMA in repayment for the initial investment. NEMA, in turn, sells the carbon credits directly to the Community Development Carbon Fund (CDCF) of the World Bank. On average, each municipality handles 70 tonnes of waste per day (between 50 and 200 tonnes), and 25,550 tons per annum. The average yield of compost for each municipality is about 5,000 tonnes, which at the predicted price of USD 13 per tonne, is worth USD 65,000. The predicted emission offset for the whole programme during the first seven-year crediting period is 8,370 tonnes of CO_2 equivalent per year from 2010 to 2017. Priced at USD 15 per offset, this offset is worth USD 125,550 annually.

A similar CDM programme could be implemented in Rwanda with the Ministry of Infrastructure (MININFRA) as the implementing entity, and could include both rural and urban organic waste. Private companies and cooperative could be contracted to set up the composting plants. Funds and technical support could be obtained the Public Private Infrastructure Advisory Facility, the World Bank Community Development Carbon Fund and BioCarbon Fund, the UNDP/MDG Carbon Facility or the European Investment Bank Post-2012 Carbon Facility.

Summary of Programmes of Action

10.1 Programme 1: Sustainable Intensification of Small-scale Farming

10.1.1 Responsible Stakeholders (lead in bold)

MINAGRI, MININFRA, Municipal Authorities, ISAR, Private Sector, NGO's, REMA

10.1.2 Summary of Programme

In Rwanda, average farm size is small at 0.7 of a hectare. The sustainable intensification of small-scale agriculture is a key component in building a low carbon and climate resilient agricultural sector. Adaptation, mitigation and agricultural development options can be designed and implemented to counter the negative impacts from climate change and reduce the sectors dependency on fossil-fuels, thus building resilience into agricultural ecosystems[5, 9, 11]. When small-scale production is intensified through agroecology techniques including agroforestry, kitchen gardens, nutrient recycling and water conservation to maximise sustainable food production, the aggregate benefit of small-holdings can be considerable and substantially contribute to national food security. Additional aggregate benefits include improved environmental sanitation, and disaster risk reduction (slope stabilization/flood mitigation) all leading to climate compatible development[9-11].

10.1.3 Action 1: Mainstreaming of Agroecology

Rwanda will mainstream agroecology in the agriculture intensification programme and other natural resource-based livelihood programmers. This action will focus particularly on the Land husbandry, Water harvesting and Hillside irrigation Project (LWH); Integrated Water Resource Management (IWRM) (irrigated rice production); and the One Cow Program to maximise adaptation and mitigation capacity, and build agricultural diversity in current farming systems through an integrated approach to farm design using biologically enhancing practices including agroforestry, N-fixing crops, mycorrhiza enhancement, farm yard manure, compost pits and green manures, along with improved farming practices including mulching, drip irrigation, crop rotation and no-tillage[8, 9, 11, 13].

10.1.4 Action 2: Resource Recovery and Reuse

Rwanda will promote recovery and reuse of both organic waste and wastewater. Recycling organic waste is a critical adaptation and mitigation strategy. It improves soil fertility and structure, as compost increases soil water retention and nutrition supply to crops; and it diverts organic waste from waste dumps and landfill sites reducing methane emissions. Wastewater irrigation allows increased food production in urban and peri-urban agriculture during periods of rainfall scarcity. Consequently, urban-regional planning is required to ensure suitable peri-urban areas are identified and maintained as potential agricultural sites for implementation of wastewater irrigation during possible periods of food insecurity due to rainfall scarcity[21, 22].

10.1.5 Action 3: Fertiliser Enriched Products

The agricultural intensification programme in Rwanda is currently dependent on the application of inorganic fertiliser to increase crop yields, although these external inputs produce GHG emissions through the fertiliser manufacturing process and the transportation of fertiliser products. However demand for inorganic fertilisers can be reduced by applying an integrated approach to soil fertility and nutrient management, which employs agroecology, resource recovery and reuse, and fertiliser enriched products. An integrated approach can significantly lower inorganic fertiliser demand, reduce GHG emissions and increase farm profitability due to reduced input costs for farmers. Such approaches also improve soil structure and the water retention capacity of soils leading to resilient agricultural ecosystems and sustainable food security. Rwanda will promote the use of fertiliser enriched products. This technique will ensure a more efficient use of inorganic fertilisers, and will add valuable organic matter to soils, which also maximises terrestrial carbon in farm soils[23, 24].

10.1.6 Action 4: Mainstreaming of "Push-Pull" Strategies (IPM)

"Push-pull" strategy is a sustainable pest management technique that incorporates a cropping system based on producing multiple crop and fodder yields but which is also designed to control plant parasites and pathogens such as stemborers and striga weed. Rwanda will implement a push-pull system using Napier grass and desmodium legume to manage pests in fields of maize, sorghum, millets and rainfed rice. "Push-pull" strategies increase maize yield, fix nitrogen into farm soils and provide a continuous supply of cattle fodder from the harvest of Napier grass and desmodium, which improves milk yields of cattle while also reducing methane emissions due to improved fodder regimes[25, 26].

10.2 Programme 2: Agricultural Diversity in Local and Export Markets

10.2.1 Responsible Stakeholders (lead in bold)

MINAGRI, MININFRA, Municipal Authorities, ISAR, Private Sector, NGO's, REMA

10.2.2 Summary of Programme

Rwanda will expand crop varieties, local markets and manufactured products and exports in support of the sustainable intensification of small-scale farming. This will involve diversifying agricultural production and enhancing the agriculture value chain. Improving the agriculture value chain reduces the sectors dependency on external inputs (fertilizers/food/fuel), while building an agricultural market economy based on added value and import substitution. Rwanda will become more self-sufficient by expanding crop varieties, and will add value to those crops through processing to meet its own market demand. This approach will create employment through the development of small and medium enterprises, thus converting a subsistence-based agriculture sector into a biodiverse and sustainable agricultural market economy. Other opportunities to add value along the agriculture value chain include the development of niche export crops under organic and fair-trade branding.

10.2.3 Action 1: Expansion of Crop Varieties

Rwanda will become more self-sufficient by expanding crop varieties to meet its own market demand for food stuffs that are currently imported from regional and international markets. Examples include the introduction of vanilla seeds, apricot saplings, and macadamia plants to the north-central region of Rwanda. Other potential products include underutilised crops such as the high-yielding fodder crop Russian comfrey, and indigenous African vegetables, which are in high demand and are particularly suited to small-scale farms, as they require low external inputs and are resistant to local pest and climatic conditions[8, 9, 11, 27].

10.2.4 Action 2: Expansion of Local Markets

In order to meet its own market demand, Rwanda will expand local markets by constructing market infrastructure, including roofed market facilities, serviceable road and transport networks, developing decentralised village-based agricultural processing centres that incorporate low-carbon sources of energy, such as biogas-digesters and solar driers, and decentralised compost plants. It will thereby form a conduit for agricultural-based trade based on less food miles for regionally and internationally imported food products. Strengthening local markets will also build economic resilience in rural areas that is less dependent on linear commodity flows of raw goods leaving rural areas unprocessed and without added value.

10.2.5 Action 3: Expansion of Manufactured Products

Rwanda will add value to food stuffs through the processing of agricultural products to supply the market demand of a growing population with an increasingly wider demand for processed food items, much of which is currently imported from regional and international suppliers. Processing agricultural products also reduces post-harvest loss due to insufficient storage or cold-chain facilities, particularly with high value and perishable fruits and vegetable crops. Expansion of manufactured products will best be achieved through the development of decentralised village-based agriculture processing centres using a range of appropriate technologies that incorporate low-carbon sources of energy, such as biogas-digesters and solar driers. Manufacturing products at home can reduce the national GHG emissions by reducing transport costs. It also creates employment, develops skills and builds the economy by spending money domestically instead of abroad.

10.2.6 Action 4: Expansion of Exports

To create additional export opportunities, Rwanda will develop niche export crops under organic and fair-trade branding, such as organic and fair-trade tea, coffee and sugar. Such initiatives, including 'Greening the Tea' initiative will increase adaptive capacity while reducing greenhouse gas emissions (mitigation) by addressing not only crop production, but also processing technologies that are currently energy and biomass intensive. Developing adaptation capacity in the export crop sector will also increase resilience to future temperature changes which are already impacting on coffee production in Kenya[6].

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