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Contents

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Nevertheless, the analyses and interpretations in this paper, as well as any errors and omissions, are those of the authors alone and do not necessarily reflect the views of DFID, LEI, ODI, or Oxford Brookes University.

Abbreviations

BAU	Business-as-usual
CGE	Computable General Equilibrium
DNEAP	National Directorate of Studies and Policy Analysis, Mozambique
GHG	Greenhouse Gas
IIAM	Instituto de Investigação Agraria de Mocambique/Mozambique Institute of Agricultural Research
IITA	International Institute for Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
LSU	Livestock unit
MICOA	Ministry for the Coordination of Environmental Affairs, Mozambique
MPD	Ministry of Planning and Development, Mozambique
SAM	Social Accounting Matrix
STAGE	Static Applied General Equilibrium
UNFCCC	UN Framework Convention on Climate Change
US EPA	US Environmental Protection Agency

Chemical formulae

CH_4	Methane
CO_2	Carbon Dioxide
CO_2Eq	Carbon Dioxide equivalent [of GHG]
NO_X	Mono-Nitrous Oxides, nitric oxide & nitrogen dioxide
N_2O	Nitrous Oxide

Units of measurement

k	Thousand
M	Million
Pg	Petagram [10^15 gram] = Gigatonne = 10^9 tonne, i.e. billion tonne
Gt	Gigatonne = 10^9 tonne, i.e. billion tonne
Gg	Gigagram = 10^3 tonne, i.e. thousand tonne
km	Kilometre
kg	Kilogram
t	Metric ton, tonne
ha	Hectare

Summary

Issues, questions and methods

If global warming is to be held to no more than two degrees centigrade this century, then greenhouse gas [GHG] emissions will need to be reduced. Agriculture is currently responsible for between 11% and 35% of total emissions of GHG, the higher figure applying when taking high-side estimates and including the effects of converting forest, peat and wet lands to farming. Technically there are ways to reduce emissions from agriculture and forestry at relatively low cost. Indeed, through carbon capture, agriculture could — for at least some time — drastically reduce its net emissions, perhaps close to zero.

Yet by 2050 it is expected that the world population will rise to 9 billion. Feeding them will require expanding agricultural output by 70% or more. Given limited land that can be used, then much of the increase will have to come from intensified production, with the danger of increased GHG emissions. Agriculture may thus face a stiff challenge if it is to produce considerably more with lower emissions.

This study addresses the issue of what may happen to agricultural production and the welfare of farmers, especially small farmers in developing countries, if agricultural systems are changed to reduce emissions and capture carbon. Since there are so many variables that might be considered, with complex interactions amongst them, this research restricted the detailed analysis to a single country, and used a quantitative model capable of capturing the many potential interactions of major changes to an important economic sector. Mozambique was proposed partly since it is a low income country heavily dependent on agriculture for livelihoods, and partly since there was an existing model available that could be adapted to address the issues.

The research questions addressed comprise:

- What might be done to move Mozambican farming to significantly lower net emissions? What are the technical challenges and options?
- If such a change were to be made, what would happen to the economy as whole in output, employment, and above all, incomes of the different groups of poor people in Mozambique? What would be the implications for food security?
- What are the implications for policy-makers trying to mitigate emissions in agriculture, while promoting agricultural development to relieve poverty and hunger in Mozambique?

The study proceeded in three stages. First, apparently feasible technical options for mitigation of emissions from farms were examined, estimating how their implementation in selected farming systems would affect use of factors of production, costs, and yields. Options were developed for Mozambique that would be applicable to the main farm enterprises and systems of that country. Second, an existing Computable General Equilibrium model, Static Applied General Equilibrium (STAGE), was adapted to model changes in agricultural practice for the case of Mozambique and generate results to show the likely impacts on overall economic activity, agricultural output, returns to factors of production, incomes to defined groups of households including the poor and vulnerable, and effects on trade. Third, the modelling results were assessed for impacts on poverty and food security, and policy implications considered.

Mozambique and its farming systems

Since peace was restored in 1992, the economy of Mozambique has been growing rapidly, often at rates of more than 6% a year. Most of the growth, however, comes from minerals and energy where

large-scale enterprises have developed the potential of the country's natural resources. Yet these developments have not created many jobs and linkages to the rest of the economy have been quite weak.

The majority of Mozambicans live rurally and work on the land, farming smallholdings: three-quarters or more of the workforce are engaged in agriculture for at least part of the time. Productivity both per hectare and per worker remains low: agriculture contributes just 25–30% to the gross domestic product.

Economic growth in Mozambique is thus not the problem: the issue is the pattern of growth, however, and its failure to create large numbers of reasonably well-paid jobs. That results in high levels of poverty and hunger. A 2008/09 national survey showed that 55% of the population live in poverty: a share that may have even risen since the previous assessment in 2002/03. Some 46% of the children under five are stunted, a percentage that has hardly fallen at all since the mid-1990s. Economic inequality is high, with the Gini coefficient calculated at 0.46.

Agriculture

In a large country, there is much variation in the farming systems: one classification identifies no less than ten distinct agro-ecological zones. Small farms dominate agriculture: some 3M smallholding occupy 95% of the land, the other 5% divided between medium and large-scale farms. Small farms produce food crops — maize, sorghum, rice, millet, potatoes, sweet potatoes, cassava and beans — first and foremost, with low yields. Some produce crops for sale, including copra, cashew nut, cotton, sesame, sugar beans, sunflower and sugar cane. Smallholders often use fallowing to recover fertility: shifting agriculture is common.

Most of the growth in agricultural production since the early 1990s has come from expanding the cultivated area, rather than from raising yields per hectare.

Emissions and climate change

Estimates of emissions from agriculture are broad, but show a pronounced pattern: 69% of GHG, in the equivalent warming potential of CO_2 come from burning savannah, and almost all the rest, 26%, comes from conversion of forest and grassland to fields.

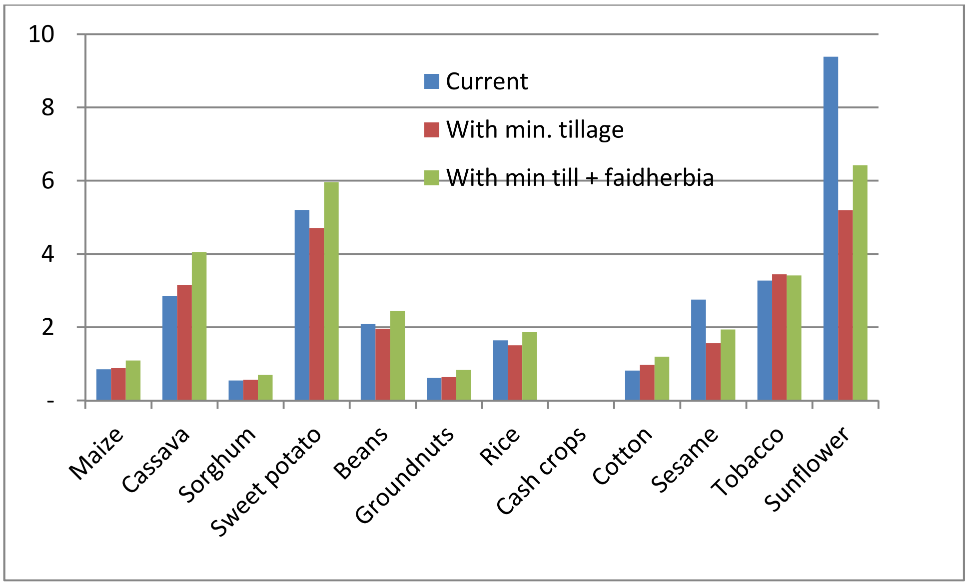
Future climate change for Mozambique is expected to produce higher temperatures, increased rains in several parts of the country, higher seas levels, and, above all, more variable weather with higher risks of cyclones and droughts. Models of future crop yields show minor yield reductions for some crops — 11% for maize — and little significant impact for others. The issue, then, is not the average levels, but the probable increased variations in harvests resulting from more variable weather in the growing seasons, compounded in some areas by damage from storms and floods.

Options for reducing agricultural emissions

Given the importance of savannah burning and clearance of forests and grasslands in emissions, strategies are required that avoid land clearance: that is, strategies that intensify production on existing land. Three approaches are indicated. One, intensify production on existing land, using more intercropping, and reduced ploughing by zero tillage. Two, bring more trees onto fields to capture carbon and help recycle nutrients. Faidherbia albida is a tree that can be grown across much of Mozambique: planted at around one hundred trees per hectare, it has been shown to fix nitrogen and raise yields without the need for external fertilisation. The trees themselves become carbon stores. Three, manage grasslands with more intensive grazing for short periods, encourage a wide range of species and look to reduce the incidence of burning.

The economics of the cropping proposals has been examined through gross margins, looking at costs and returns to cultivation of a typical hectare of the main smallholder crops. The new system may save labour in land preparation, especially in cases where previously the soil was ploughed. This may not, however, apply in manual cultivation. Here there can be heavy costs in preparing the land when making planting pits, and in additional weeding, especially in the early years. There may also be extra labour in managing the Faidherbia trees, such as recommended practices in pruning low branches. Although the additional labour is costly, the gross margin per day worked increases, showing that the extra effort will repay farmers: see Figure A.

Figure A Implicit returns to family labour, US$ a day



Hence it should be possible to encourage farmers to make the conversion on purely financial benefits, without having to appeal to environmental gains.

There are public costs as well, mainly a large-scale extension effort to explain the systems, demonstrate and adapt to local circumstances. As an incentive to convert their fields, farmers might receive planting material in Faidherbia seedlings for free. For switching to conservation farming, they could be rewarded with the value of their additional investment. While a cash payment would be ideal, in practice this would be administratively difficult and risky in the opportunities for corruption. A grant of seed and tools, on the other hand, could be made more transparently.

A tentative timetable with one fifth of farmers being reached every year, and each cohort converting their land over five years, gives a 12-year period including start-up; with public costs reaching a maximum of around US$74M half-way through.

The greatest challenge in making a transition, however, would not be in carrying out a programme of extension backed by incentives; but rather in deterring farmers from further clearance of grass, scrub or forest, and in burning the savannah. Land is currently cleared partly to accommodate the demand for land from a rising rural population, partly since it is usually easier to expand production by expanding the area rather than intensifying production on existing fields, and partly owing the need to recuperate fertility through fallowing. Burning of the savannah in Mozambique arises from several motives: to clear areas to farm, either to accommodate new farmers or new fields; to burn off old grass before the rains and thus encourage growth of fresh grass when the rains arrive, so that herders will have better pasture for their stock; and to drive game from their cover and make them easier to hunt.

Modelling agriculture and changed practice

To examine what might be the results of measures to mitigate agricultural emissions, a computable general equilibrium (CGE) model was used, run for twenty years for a baseline, business-as-usual scenario, and for the simulated changes to reduce emissions. CGE models have the advantage that they can show the full range of interactions in an economy, as changes work their way through the system. The model used here, STAGE (Static Applied General Equilibrium), draws on a social accounting matrix of the Mozambique economy for 2002, the most recent available,. This includes 51 commodities of which 19 are agricultural and 5 are food, 48 activities with 18 agricultural and 5 food, 9 factors accounts of which 6 are labour distinguished by skill and rural versus urban, 7 tax accounts, and 10 types of household — rural and urban, each divided into five quintiles by income.

The model was used to generate two sets of results: a baseline of what would happen over 20 years if recent trends were unchanged; and a projection of what would happen if policies to mitigate emissions from agriculture were adopted.

Key assumptions in the baseline run include:

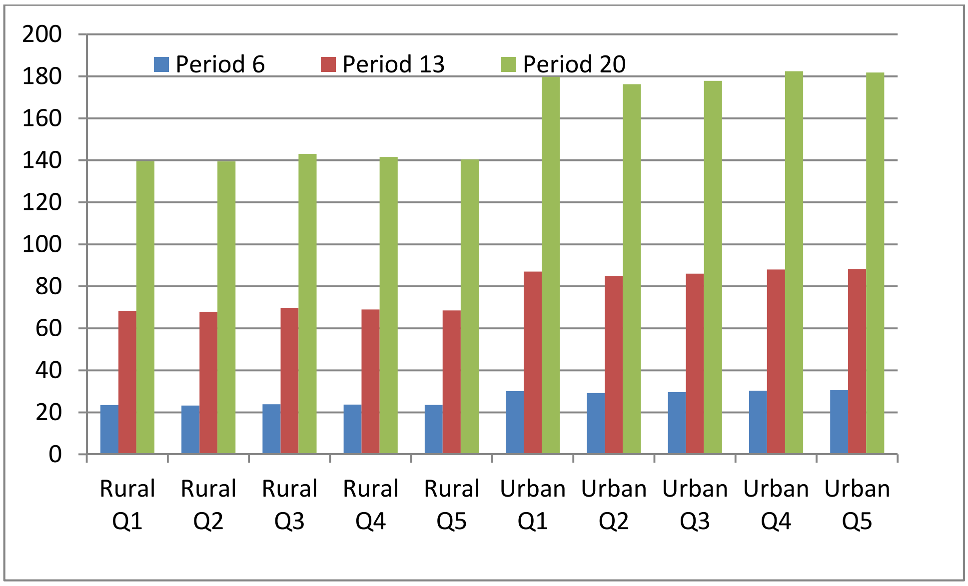
- That on international markets agricultural commodity prices decline by 3% per period and that manufactured commodity prices decline by 2% per period. This means that for Mozambique to remain internationally competitive it must achieve efficiency gains that reduce its costs of production by that amount each year;
- That the productivity of land declines at a rate of 1% per period as a consequence of climate change; and,
- That productivity of capital and labour rises by 2% a period.

The baseline results show that over 20 years, the economy grows by 4% a year. Growth however would further widen the rural-urban divide while benefiting disproportionately the owners of land at the expense of labour and capital employed in agriculture. Only the fact that land incomes are relatively widespread across rural households mitigates the impact on household incomes. Not only will the incomes of the poor be adversely affected, but they will also be affected by the changes in prices: typically food prices will rise appreciably and consequently poor households are likely to bear a disproportionate share of the burden.

In modelling the changes proposed for agriculture, it was not possible to include the detail discussed above. Instead, it was assumed the changes would reverse declines in land productivity; with land productivity rising at 1.5% a year through to year 6, then by 2% to year 13, and finally by 2.5% a year. Labour and capital productivity is allowed to increase by 1% per period. It was further assumed that there may be a temporary increase in agro-chemical use to offset any loss of yields as farmers change their systems. Costs would be funded by aid transfers.

The resulting projections show that the economy grows more strongly, with a 13% increase after 20 years, and higher exports. The most dramatic differences, however, arise in the effects of the new pattern of growth on households. In the baseline, by far the largest increases in welfare and incomes accrued to urban households. With these changes, urban households still get larger increases in their incomes, but the gap has been very much reduced since the changes confer additional gains disproportionately to rural households, see Figure B.

Figure B: Changes in disposable household incomes when changes are made



Moreover, while agricultural prices still rise, this has been much mitigated in degree. All told, the changes deliver more growth, and more equitable growth.

Conclusions

What are the expected effects of the proposed changes on poverty and food security? The clear conclusion from modelling the suggested changes to reduce emissions is that economic growth can increaser, with gains to the poor in both rural and urban areas, and especially so for rural households.

In income terms, then, the interventions must reduce poverty over and above what would have happened given business as usual. Moreover the interventions mitigate the expected rise in staple food prices, limiting these to 13% or less. Given that incomes rises by 140% or more, it is clear that entitlements to food will improve. Hence the interventions proposed should reduce both poverty and hunger, for both urban and rural poor, with slightly greater effect in rural areas.

Policy implications

Modeling confirms the expectation that in a country where almost two-thirds of the population live in rural areas, most with farming as a major activity, measures to improve the productivity of agriculture have broad benefits — and benefits that feed across from rural to urban areas. This suggests that further public investment in agricultural development may be justified. Mozambique in recent years has been spending about half of the 10% of its public budget to support farming, the target adopted by the African Union in 2003 meeting in Maputo. Spending on agricultural research is particularly low. This is a critical limitation: for lower emissions agriculture, much needs to be done to develop and test farming systems — potentially a more complex endeavour than, for example, producing higher yielding seeds and animals.

Another policy challenge, however, will be to find ways not only to encourage lower emissions agriculture, but also to discourage conversion of forest and bush. Bans and regulations alone are unlikely to be respected. Compensating land users for not converting land would be prohibitively costly. Progress here probably lies with entrusting local communities to control conversion, but with some flexibility to accommodate expansion by farmers with little land and by new farmers. Similarly, bush burning might be allowed on a limited scale and early, when burning can apparently be controlled and is less likely to cause wildfires. There may be other options: the point being that debate on these should begin.

Further analysis

Step changes to agricultural technologies present a challenge for economic evaluation. Input and cost structures change in ways that are not that well understood, relations between inputs and outputs are less clear, transitions from trial plots to field scale are depend heavily on farmers and their skills, who are often being urged to depart radically from their own experience.

Analyses of agricultural system changes cannot rely on single dimension economic tools. Analyses are needed at several levels: the farm and village, the regional markets, national economy, and international markets. Farm and village studies are the priority, to understand better the input-output relations, risks, and the interaction with farmers' factors of production and preferences. These would then provide more precise information for modelling at higher levels.

How relevant are these results for other countries?

Mozambique is typical of countries that have relatively abundant land of at least medium potential, with low input agriculture with low yields per hectare. This would apply to several other countries in Sub-Saharan Africa, parts of Latin America and Southeast Asia. It would not reflect conditions in many the more densely-settled parts of Asia.

The most important results from this work are that there would appear to be few trade-offs between reducing agricultural emissions and raising production and productivity. This may surprise some readers, so why is this? The answer lies in the very low yields per unit area in much of Mozambican farming, while there is the potential to raise these by large fractions.

Where farming is carried out at such low intensity, when the time comes to give reducing emissions high priority, there will not necessarily be a threat either to the livelihoods of farming households, many of them currently poor, or to goals of raising agricultural output. Which is not to say that it will easy to achieve a double win. On the contrary, more detailed agricultural research will be required, backed up by appropriate policies to encourage changes, and implemented with determination based on a long-term vision shared by governments, citizens and farmers.

1. Introduction

1.1 The issue

If global warming is to be held to no more than two degrees this century, then greenhouse gas [GHG] emissions will need to be reduced. Agriculture is currently responsible for between 11% and 35% of total emissions of GHG, see Table 1.1, the higher figure applying when taking high-side estimates including the effects of converting forest, peat and wet lands to farming.

Table 1.1 Estimates of emissions from agriculture, c 2005

Activity	Pg/Gt CO_2Eq	Source
Agriculture	5.1–6.1	Bellarby et al. 2008
Land use change	5.9 +/- 2.9	
Production and distribution of agro-chemicals	0.3–0.7	
Farm machinery operation, including irrigation	0.1–0.9	
Total	***8.5–16.5***	
Agriculture	7.4	McKinsey 2009
Forestry	6.2	
Total	***13.6***	
All emissions	**45.9**	

Sources: Bellarby et al. (2008) draw on data from the IPCC, US-EPA, and their own calculations: McKinsey (2009) derive their statistics from Houghton, IEA, UNFCCC, US-EPA and their own calculations.

Agriculture and forestry, however, are unusual amongst activities that emit GHG in that it is possible for net emissions to be reduced drastically — perhaps even to zero — thanks to the possibility of sequestering carbon in the soil and biomass of farming systems and forests.

Abatement of current agricultural emissions is both practical and comparatively low cost. McKinsey (2000) estimate potential reductions equal to 12 PgCO_2eq a year in agriculture and forestry—roughly the same order of savings as might be economically achieved in energy efficiency and low carbon energy generation.[1]

Set against these considerations is the need to feed the estimated 8.2 billion persons likely to be living in the world by 2030, and the eventual 9.3 billion persons by 2050.[2] Agricultural production will have to increase, perhaps doubling production. Most specialists believe this can be done — see, for example Bruinsma 2009, Fischer 2009. A little more land may be needed, but most of the increase can come from intensifying farming for higher yields of crops and animals per unit land or

[1] McKinsey consider options that cost less than €60 per tonne CO_2eq. Many of the agricultural and forestry abatement measures would cost less than €10 per tonne.

[2] US Census Bureau estimates

head. More irrigation, more fertilizer application, better crop protection plus (modest) technical progress to produce varieties that either yield more, or resist stresses or both, should achieve the goal.

But in the process emissions will rise. It seems that most of the modelling and scenario analyses that have been carried out to date have not included the need to cut these emissions in line with the amounts that the IPCC estimate will be necessary if increases in global temperatures are to be held to two degrees centigrade or less.

Indeed, there is a notable disparity between, on the one hand, arguments that stress the need for farmers in the developing world to raise production through higher yields per unit, relying heavily on increased fertiliser application; and, on the other hand, the need to move to agriculture that produces notably lower emissions. This is particularly the case in Africa where it is often taken as a given that agricultural development will imply much greater applications of fertiliser. For example, in the Abuja Declaration of 2006 African leaders committed to reaching an average fertiliser application of 50kg/ha on crop land, up from an average at the time of 8kg/ha (African Union 2006).

Agriculture may thus face a stiff challenge if it is to produce considerably more with lower emissions. Moreover, there are at least two other challenges that will increasingly apply to agriculture: adapting to a changed and more volatile climate; and the need in some areas to economise on use of water for irrigation. Can these different challenges be met?

1.2 Objectives and research questions

These issues are the focus of DFID's proposals for research on Emissions, Mitigation and Low Carbon Growth in April 2010, under the Climate Change, Agriculture and Food Security Policy Research Programme. The purpose was:

> To increase on our current understanding on agriculture's emissions and their mitigation, this study will answer the question: **What is our current understanding on agriculture's emissions and their mitigation, and what is needed for agriculture to help achieve low carbon growth?**

The ***original questions*** set out in the call from DFID were:

> **What is our current understanding on agriculture's emissions and their mitigation, and what is needed for agriculture to help achieve low carbon growth?**
>
> This study will answer the following specific questions:
>
> - How reliable are existing estimates and data sources of GHG emissions from agriculture and land use change[3] in developing countries, and what are implications from a policy perspective for GHG emissions of agricultural growth in developing countries?
> - What are the main trade offs, if any, in achieving agricultural growth and food security in developing countries versus GHG mitigation? To what extent is it possible to quantify (and monetise) the trade-offs in order to inform decisions on optimal strategies?
> - Are there potential for win-wins from using improved and more sustainable agricultural practices to get growth and mitigation (and, potentially, adaptation), and if so what needs to be in place to achieve these?

[3] This should consider direct emissions from agriculture (including CH_4 NO_2 and CO_2) as well as emissions for inputs, transport and processing.

- What are the most cost-effective mitigation measures, and which groups would benefit from these or would some, poor farmers, women and vulnerable groups, receive few or no benefits? If this is the case what policies and strategies could be put in place so that they do benefit?
- What is the economic potential of carbon sequestration of different agricultural practices and technologies, and what are the impacts of these on growth and poverty reduction in developing countries?

These were reformulated into three broad sets of questions, as follows:

A. What are the technical methods by which agriculture in the developing world can (a) reduce emissions of greenhouse gases (GHG), and (b) sequester carbon in soils and biomass so as to reduce net emissions from the sector? What is known about changes in methods, costs of production, and yields? What changes in input supply and technical support might be needed to allow farmers to reduce their emissions?

B. What would be the consequences of applying methods that would substantially reduce net emissions from agriculture in the developing world for farm incomes, farm employment, subsequent multiplier effects in the economy, and the impact on the welfare of poor, vulnerable and marginalised groups? To what extent would the use of techniques to reduce net emissions trade off against agricultural growth and poverty reduction? Are there double wins where improved practices might deliver more environmental and economic benefits?

C. What are the implications for policy-makers, especially with respect to the development of climate change mitigation initiatives after COP 15 in Copenhagen 2009? What measures would need to be taken to encourage changed practice towards an agriculture of low net emissions? What would need to be done to protect the poor and vulnerable from any adverse effects of this?

One change was made to the original set: that is, emissions within agriculture alone will be considered, omitting those in the food supply chain. This was to keep the research tractable, given the lack of existing data on emissions off the farm.

These questions were further reduced to allow research that would be possible with the resources and time available. Since there are potentially many variables that might change, and that potentially interact; two strategies were proposed: to restrict the detailed analysis to a country case; and to use a quantitative model that is capable of capturing the many potential interactions of major changes to an important economic sector. Mozambique was proposed partly since it is a low income country heavily dependent on agriculture for livelihoods, and partly since there was an existing model available that could be adapted to address the issues.

Hence the questions became:

- What might be done to move Mozambican farming to significantly lower net emissions? What are the technical challenges and options?
- If such a change were to be made, what would happen to the economy as whole in output, employment, and above all, incomes of the different groups of poor people in Mozambique? What would be the implications for food security?
- What are the implications for policy-makers trying to mitigate emissions in agriculture, while promoting agricultural development to relieve poverty and hunger in Mozambique?

1.3 Methods

The study proceeded in three blocks, as follows:

A. ***Selecting technical options for mitigation*** that appeared feasible, estimating how their implementation in selected farming systems would affect use of factors of production, costs, and yields. Options were developed for Mozambique that would be applicable to the main farm enterprises and systems of that country.

B. ***Modelling the implications of changed agricultural practice***. An existing Computable General Equilibrium model, Static Applied General Equilibrium (STAGE), was adapted to model changes in agricultural practice for the case of Mozambique and generate results to show the likely impacts on overall economic activity, agricultural output, returns to factors of production, incomes to defined groups of households including the poor and vulnerable, and effects on trade; and,

C. ***Qualitative assessment of the implications*** of the modelling results for poverty and food security, and for policy.

The rest of the report is set out as follows. Chapter 2 briefly sets out the recent record of economic growth and poverty reduction in Mozambique and the issues that face policy makers. Chapter 3 describes the agriculture of Mozambique, considers technical options for reducing emissions, and proposes a scenario that can be modelled. The model used, and the adaptations made to allow it to address the questions set, are presented in Chapter 4. Chapter 5 reports on the outcomes from the modelling. Chapter 6 then considers the implications of these results.

2. Growth and poverty in Mozambique

2.1 Economic growth

Mozambique is both one of the poorest countries in the world, yet one of the fastest growing. Recent history can conveniently be considered since 1992 when peace was declared after 15 years of civil war. The disruption of war and the mass displacements of people had left the country in extreme poverty. Subsequently, the economy has grown rapidly and poverty has fallen, see Table 2.1.

Table 2.1: Development indicators, 1990/92 to 2008

Country Indicators	1990/92	2005/06	2008
GDP per capita (US$)	150	310	370
Average inflation (%)	39	9.7	10.3
External debt (% of GDP)	286	81	36.8*
Poverty incidence (%) 69	69% (1997)	54% (2003)	
Net primary school Enrolment, %	43	71	89
Under-five child mortality (per1,000)	235	152	68
Population (millions)	16.5	20.1	21.3

Source: IDA 2009, using statistics from Instituto Nacional de Estatisticas (INE); Government of Mozambique; Banco de Moçambique and IMF; National Household Surveys; Ministry of Education; Demographic and Health Surveys.

Economic growth has between particularly rapid: averaging 8% a year from 1995 to 2006, subsequently varying between 6.3% and 7.8% — rates that are expected to apply for 2011 and 2012, see Table 2.2. The main drivers of the economy since the early 1990s have been minerals and energy, including a large aluminium refinery, Mozal, electricity from the Cahora Bassa dam, natural gas, and heavy sands from which ores such as ilmenite for titantanium dioxide are extracted. A large coal deposit at Moatize is under development. While these have produced exports, they have had limited linkages to the rest of the economy.

> For example, more than US$2 billion (about 25% of GDP) has been invested in the Mozal aluminium smelter producing aluminium ingots for export and accounting for close to 60% of total exports, while only creating a few thousand jobs. (IFAD 2010)

Table 2.2: Annual growth rates of GDP at market prices (2005 US$)

1995–2006	2007	2008	2009	2010 estimated	2011 forecast	2012 forecast
8.0	7.3	6.7	6.3	7.8	7.6	7.7

Source: World Bank 2011

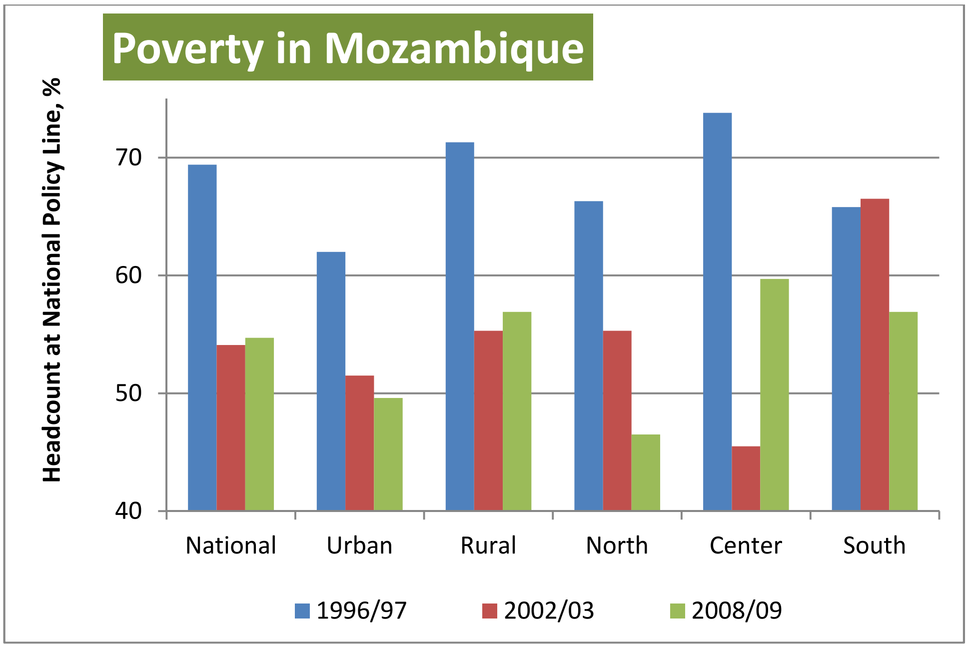
Most of the population, around 60%, live in rural areas. Agriculture is their main source of work: overall, 75–80% of Mozambicans work for at least part of the time in farming. While other sectors have grown faster, agriculture has also grown relatively quickly, at rates of '6% or more a year since the early 1990s' (IFAD 2010). Agriculture is largely carried out by small farmers, although there are some large-scale commercial farms: most of the agricultural growth has been gained by bringing new areas into production, taking advantage of the relative abundance of cultivable land. Productivity both per hectare and per worker remains low: despite occupying the large majority of the workforce, agriculture contributes just 25–30% to the gross domestic product.

Economic growth in Mozambique is thus not the problem: the issue is the pattern of growth, however, and its failure to create large numbers of reasonably well-paid jobs. That results in high levels of poverty and hunger, to which the discussion now turns.

2.2 Poverty, inequality and food insecurity

Three national household surveys of consumption have been carried out, in 1995/96, 2002/03, and 2008/09. The analysis of these shows that poverty headcounts fell rapidly from the mid-1990s to the early 2000s, see Figure 2.1, but subsequently may even have risen. One interpretation is that the earlier falls in poverty were those of a country recovering from war, where it was to be expected that very high rates of poverty would fall. Subsequently it seems the concentrated growth of the 2000s has not delivered benefits to the majority of Mozambicans.

Figure 2.1: Poverty in Mozambique

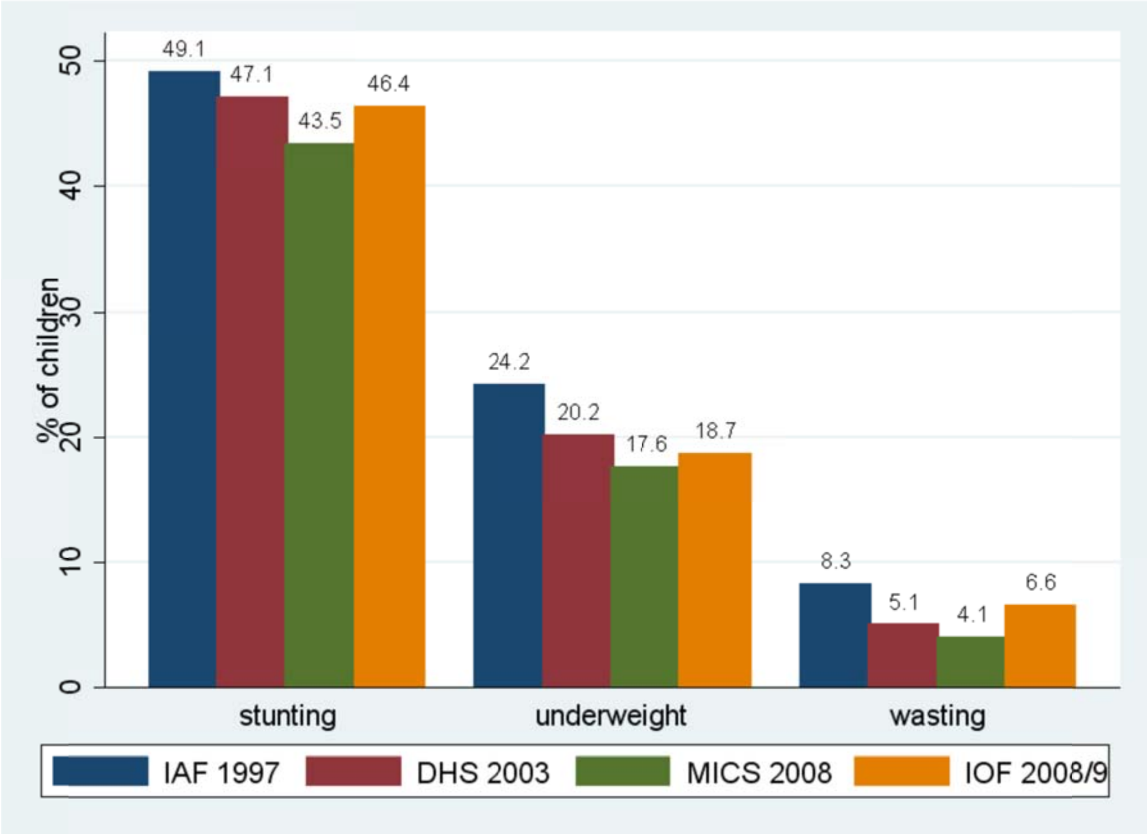


Source: Third National Poverty Assessment, October 2010 [DNEAP, MPD]

Income inequality is high, with an estimated Gini coefficient of 0.46 for 2008: almost unchanged since the estimate for 1996 [World Bank Development Indicators].

There are questions about how reliable the poverty statistics are, (IFAD 2010) since some nutrition surveys indicate opposing changes in stunting for some provinces. The record on child malnutrition, as measured by the percentage of under-fives who are stunted, can be seen in Figure 2.2. Progress has been made in bringing down the rates, but it has been modest and rather slow for stunting

Figure 2.2: Child malnutrition, Mozambique, 1997 to 2008/09



Source: Figure 3-11 in DNEAP, MPD 2011, compiled from four surveys.

In summary, then, this brief review shows a country with rapid economic growth, including reasonably rapid agricultural growth, but growth that increasingly does little to relieve the poverty of the majority of Mozambicans. Growth, it seems, has been too narrowly based with insufficient linkages to spread the benefits.

3. Mozambique: agriculture and reducing net emissions

3.1 Current farming systems in Mozambique

Main farming systems

Owing to different climatic and socio-economic conditions there are significant differences in cropping patterns and farming systems across Mozambique. The four main farming systems are mixed maize; root crops; mixed cereals and root crops; and, commercial and large scale producers (FAO, 2010). These can be broken down by province and region, as shown in Table 3.1. [See Figure 3.1 for provinces]

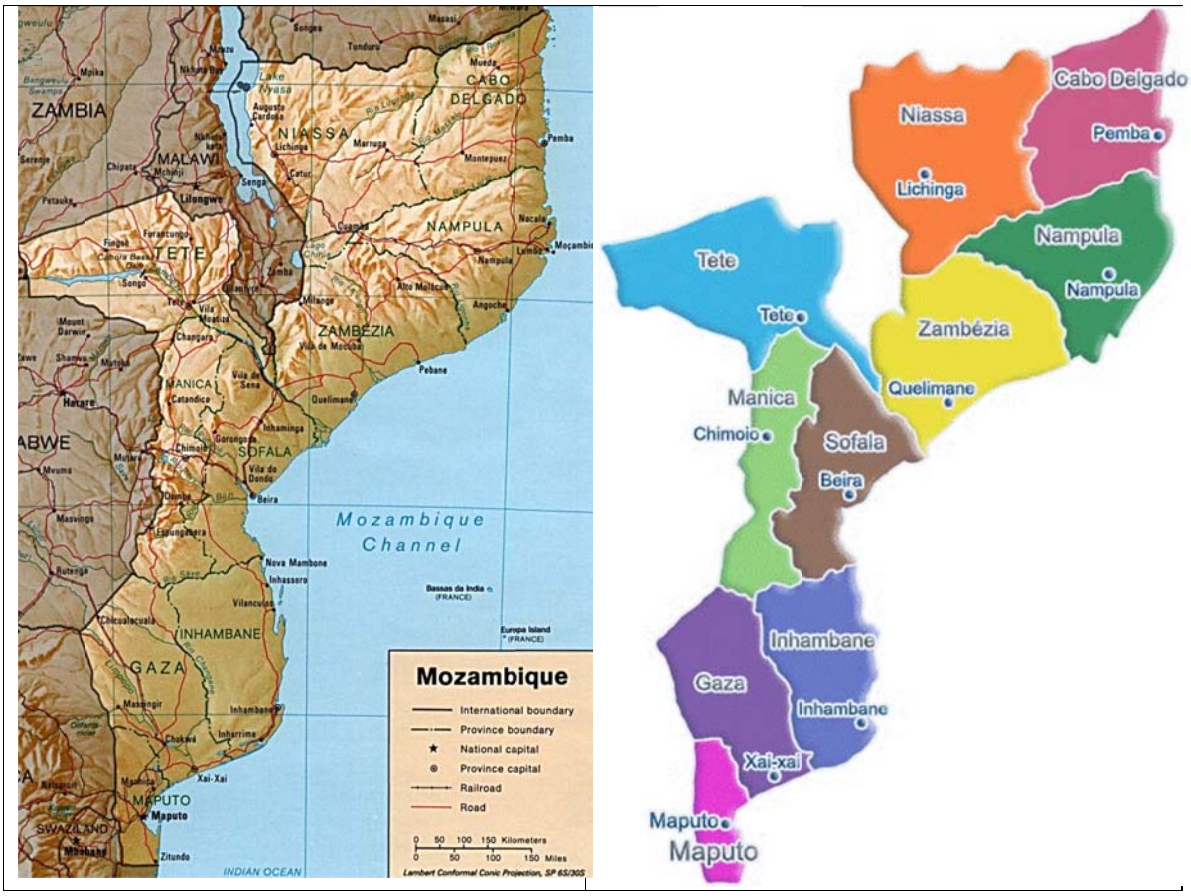
Table 3.1 Main farming systems by province and region

Characteristics	Main farming system types		
	North	Centre	South
Provinces	Cabo Delgado, Nampula, Niassa,	Manica, Sofala, Tete, Zambezia	Gaza, Inhambane, Maputo
Main food crops	Cassava, maize, rice,	Cassava, sweet potatoes,	Cassava, maize

	sorghum, sweet potatoes, beans	maize, rice, beans, sorghum, millet	
Main cash crops	Tobacco, cotton, cashew, groundnuts	Tobacco, cotton, groundnuts, horticulture	Limited
Main livestock	Limited pastures (in Tete)	Limited pastures (in Sofala)	Pastures for cattle and goats
Rainfall (mm)	1,000–1,800	1,000– 1,200	400– 1,000
Climate	Sub-humid	Sub-humid Humid highlands	Arid, semi-arid
Cultivated area, '000 ha	1,357	1,526	994

Source: World Bank, 2006

Figure 3.1 Mozambique, physical and administrative, by province



Mozambique has been classified into ten agro-ecological zones (Walker et al. 2006) that can be matched to each of the three regions as follows, see Figure 3.2:

South

Region 1: Inland Maputo and south Gaza. Year round cultivation. During rainy season (Nov–Mar, 20––25'C), grow maize, cowpea, peanuts, cassava. Short cycle varieties. Sweet potato on lowest land. Large areas of pasture – traditional herders. Potential for irrigation.

Region 2: Coastal region S. Maputo to N. Inhambane. Warm rainy season Nov–Mar. Dominant systems are maize/cowpea and cassava/peanut. Also sweet potato. Limited land available therefore intercropping and shortened fallow period. Cashew cash crop, rice in river valleys.

Region 3: Central and N. Gaza, and W. Inhambane. Rainfall only 400–600mm, Nov-Feb. Cattle and goat smallholdings. Short duration, limited cropping of sorghum, millet, maize. Soil moisture retention techniques important.

Centre

Region 4: Medium altitude region between 200–1000m asl in Sofala and Manica. Rainy season Nov-Mar (1000–1200m). Crop growing period 120–180 days, with average temp 17.5–22'C. Main crops: maize, sorghum, cassava, cowpea. Moister areas also sweet potato, rice.

Region 5: Low altitude of Sofala and Zambezia. High annual rainfall 1000–1400mm, rainy period Nov-May. Rice dominant on heavy soils, maize, sorghum, millet, cassava cowpea on well drained soils. Cashew and cotton cash crops.

Region 6: Semi-arid Zambezi and S. Tete province. Rainfall 500–800mm between Nov-Mar. Sorghum and millet. Potential for cotton and rice.

Region 7: Medium altitude interior Zambezia and Tete. Maize or sorghum cropping systems, also cassava, cowpeas and groundnuts.

Region 8: Coastal Zambezia. Average temp >25'C, annual rainfall 800–1200mm. Cassava and millet systems, with rainfed rice in low areas. Cashew important.

Region 10: High altitude Zambezia and Manica, above 1000m. Annual rainfall >1200mm, average temps 15–22.5'C. Main crops maize, common beans, and potatoes. Finger millet as food and cash crop.

North

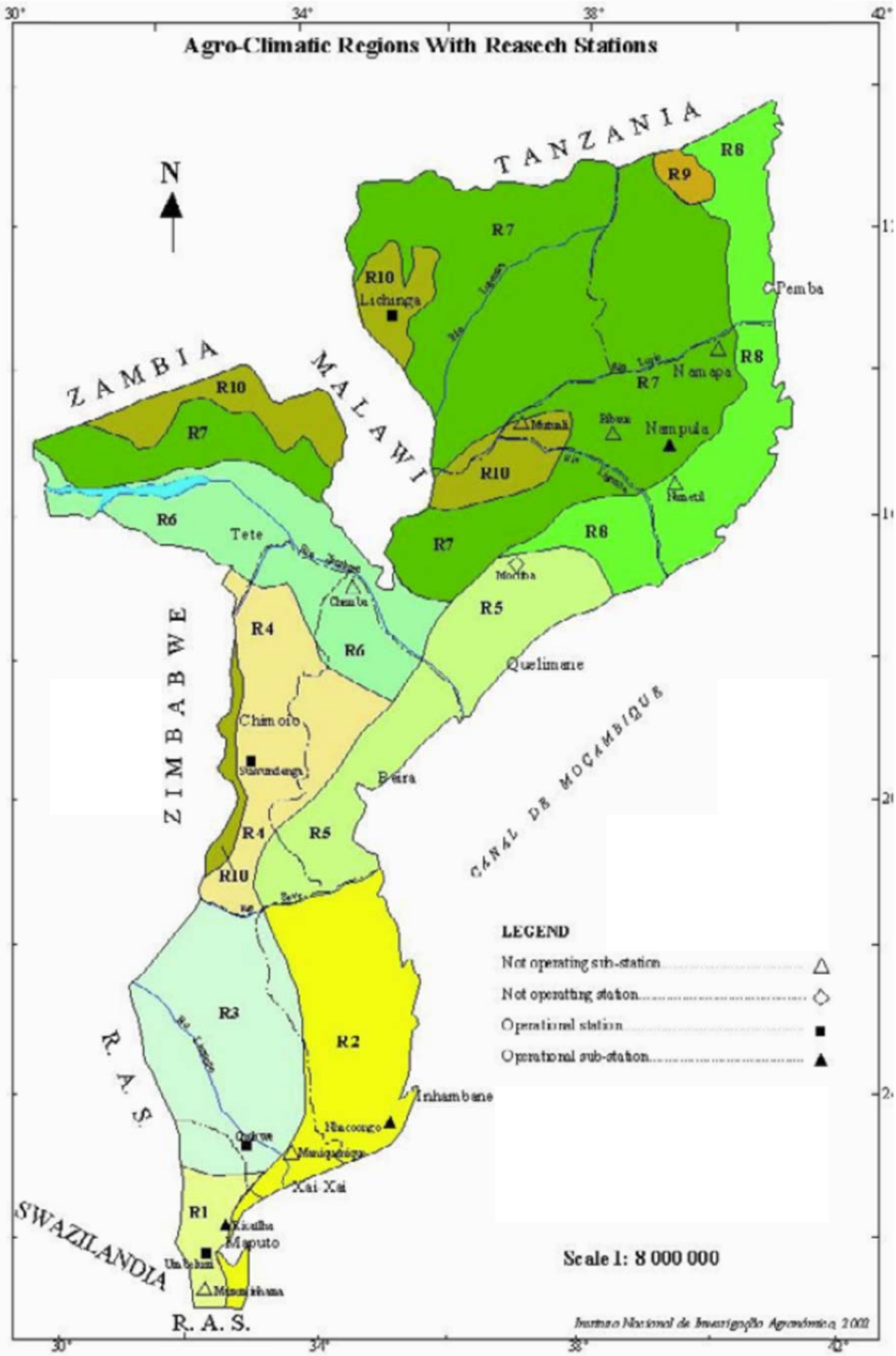
Region 7: Medium altitude Nampula, Niassa, Cabo Delgado. Temps 20–25'C. Maize or sorghum cropping systems, also cassava, cowpeas and groundnuts. Cashew important in the east, high potential for cotton.

Region 8: Coastal Nampula and Cabo Delgado. Average temp >25'C, annual rainfall 800–1200mm. Cassava and millet, with rainfed rice in low areas. Cashew important.

Region 9: North interior Cabo Delgado. Rainfall 1000–1200mm between Dec-Mar. Dominant crop maize; also sorghum, cowpea, cassava, sesame. Cashew important.

Region 10: High altitude Niassa above 1000m. Annual rainfall >1200mm, average temps 15–22.5'C. Main crops maize, common beans, and potatoes. Finger millet as food and cash crop.

Figure 3.2 Agricultural zones of Mozambique



Source: Ministry of Agriculture & Fisheries 1996, reproduced in Walker et al. 2006

These agro-ecological zones may also be grouped according to their dominant crops as shown in Table 3.2.

Table 3.2 Agro-ecological zones grouped according to main cropping system/crop types

Agro-ecological zone	Crops	Temp ^{o}C	Rainfall (growing season)
R1, R2, R4, R5, R7, R8, R9	Maize, cowpea, peanuts, cassava Other crops: R1: Sweet potato, large areas traditional pasture R2: cashew, rice R4: sweet potato R5: sorghum, millet, rice, cashew, cotton R7: sorghum R8: millet, rice, cashew, high rainfall R9: sesame, cashew	17.5–25+	Nov-Mar
R3	Sorghum, millet, maize Cattle & goat smallholdings		Nov-Feb 400–600mm
R6	Sorghum, millet		Nov-Mar 500–800mm
R10	Maize, beans, potatoes, finger millet	15–22.5	>1200mm

Farming scale, practices and yields

By scale, farms in Mozambique can be distinguished as follows (Bias & Donovan 2003):

Table 3.3 Classifying farms by scale in Mozambique

	No.	Average size	Characteristics	Criteria for irrigated holdings
Small-scale	3M	1.22	< 10 ha of cultivated land < 10 head cattle, < 50 goats/pigs/sheep, and/or < 5,000 poultry;	< 5 ha
Medium-scale	10k	6.6	10–15ha cultivated area 10–100 head cattle, 50–500 goats/sheep/pigs, and/or 5000–20,000 poultry	5–10 ha
Large-scale	429	282	One or more components higher than medium scale.	> 10 ha

Source: Bias & Donovan, 2003, taken from: Agricultural Census. 1999/2000, estimated by Department of Policy Analysis (DAP) for Mader (2001) Constrangimentos e prioridades para o desenvolvimento do sector agrario em Moçambique: A Perspectiva do Sector Público. Maputo

For family farms — the small-scale and most of the medium-scale farms, the main staple crops are maize, sorghum, rice, millet, potatoes, sweet potatoes, cassava and beans. Horticultural production comprises tomatoes, cabbage, pumpkins, garlic, piri piri (chilli), pepper, okra, cucumber and onions.

Cash crops within these systems are copra, cashew nut, sesame, sugar beans, sunflower and sugar cane; plus some contract production of cotton. Domestic livestock kept for household consumption include chickens, goats, ducks, pigs, sheep and some beef cattle in the south. Multipurpose trees are common, especially mango, paw paw, banana, papaya, citrus, crab apple and baobab.

Common lands provide important protein supplements to the household diet: gazelles, duikers and reedbuck are hunted. In drier zones, millet and livestock predominate.

The majority of farmers practice some form of shifting cultivation. Shifting rain-fed agriculture by some 3.2 million farm households occupies about 4.5 million hectares (World Bank, 2006). However, the limited data on farming approaches available reflects the comment by Bias & Donovan (2003) that

> "Intercropping and rotational cropping are commonly used, although there is no documentation on the number of households or land area under such cropping systems."

Commercial farms produce mainly cotton, tobacco, sugar cane, and rice.

Yields of most crops are relatively low, as shown in Table 3.4

Table 3.4 Production of main crops in Mozambique, 2006–08 average

Crop	Area, ha	Production, tonnes	Yield, t/ha
Maize	1,471,333	1,284,927	0.87
Cassava	852,333	5,578,651	6.55
Seed cotton	370,000	198,333	0.54
Sorghum	342,000	187,265	0.55
Pulses, nes	308,333	155,333	0.50
Groundnuts, with shell	295,000	94,454	0.32
Sugarcane	166,667	2,190,718	13.14
Castor oilseed	145,000	52,071	0.36
Sweet potatoes	124,333	898,371	7.23
Rice, paddy	111,667	101,914	0.91
Oilseeds, nes	90,000	30,000	0.33
Cashewnuts, with shell	75,000	74,072	0.99
Coconuts	70,000	281,667	4.02
Millet	58,333	23,967	0.41
Tobacco, unmanufactured	51,167	62,461	1.22
Sesame seed	30,000	20,167	0.67
Fruit Fresh nes	26,000	115,000	4.42
Vegetables fresh nes	19,000	105,000	5.53
Bananas	14,000	90,000	6.43
Sunflower seed	11,500	5,195	0.45
Tea	8,433	16,459	1.95
Potatoes	7,267	96,667	13.30
Other Bast fibres [e.g. sisal]	6,000	3,300	0.55
Oranges	4,400	18,633	4.23
Papayas	4,100	41,000	10.00
Mangoes, mangosteens, guavas	3,700	24,000	6.49
Sisal	3,000	602	0.20

Source: FAOSTAT, as at May 2011.

Note: 'nes' = not elsewhere specified, other

Other than poultry, few livestock are kept in Mozambique: for a country with around 3.5M farms, there were estimated to be around 1.2M cattle, 1.2M pigs, and 4.3M goats. For poultry, some 18M chickens are kept.

Land availability

Mozambique has a large land area of almost 79M ha of which less than 4M ha are under crops. Since grazing livestock are relatively few, additional areas used for pasture are not great. There are thus great tracts of forest, bush, natural pasture, some of which could be used to expand the agricultural area.

Before examining the statistics, a caution: data reported for area under forest and land used for agriculture vary considerably by source. Some of the these differences arise from differing measurements — or perhaps better said, estimating methods; some from differing definitions — how dense does tree cover have to before the area as described as forest? The statistics in Table 3.5 are those reported by FAO.

FAO reports a forest area of just under 40M ha, and agricultural area of almost 49M ha, of which arable and permanent crops occupy less than 5M ha. Taking the number of farming households as around 3.2M, this means that in theory there are up to 15 ha that could be farmed by each household — compared to the average of around 1.4 ha (Coughlin, 2006).

Table 3.5 Land usage in Mozambique, 2008

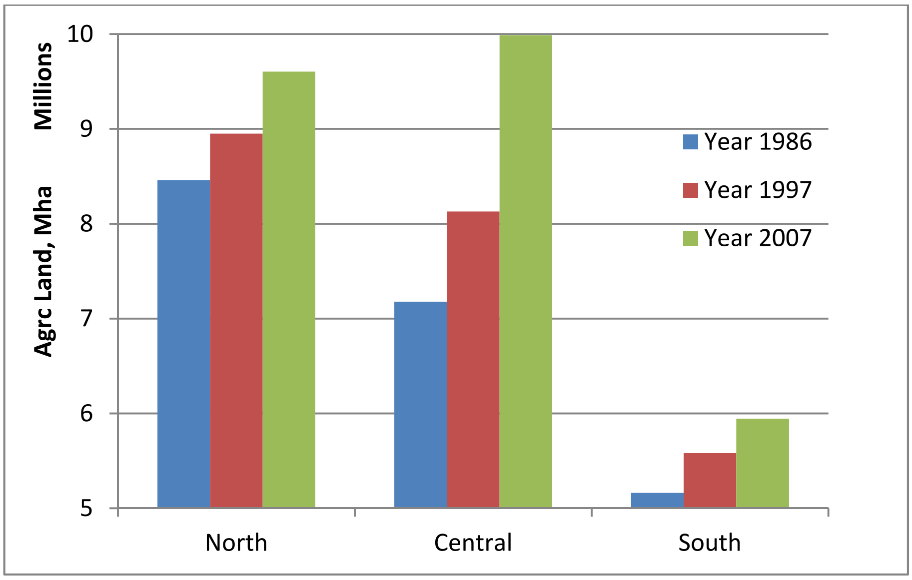
Land usage	Area (1000 ha)
Country area	79,938
Land area	78,638
• Agricultural area	48,750
• Arable land and permanent crops	4,750
• Arable land	4,500
• Fallow land (a)	NA
• Permanent crops	250
• Permanent meadows and pastures	44,000
Forest area	39,444
Total area equipped for irrigation	118

Source: FAOStat, 2008

Note (a): In the Censo Agropecuario 1999/2000, 310,573 ha of 'cultivated area' under fallows and without crops, or with permanent crops on large farms, were recorded.

It is thus not surprising that much of the agricultural growth seen since 1992 has come from expanding the cultivated area, see Figure 3.1. In total, the area used for agriculture is reported to have expanded from 20.8M ha in 1986 during the war, to 22.7M ha in 1997, and to 25.5M ha by 2007. As the Figure shows, expansion has been greatest in the Centre Region.

Figure 3.3: Agricultural land use changes in Mozambique, 1986 to 2007



Source: Table 4, INGC 2009, drawing on IIAM data 2008

With two to three million hectares being added to the agricultural area every decade, there is concern over depletion of forests. Currently it is estimated that every year 219,000 hectares of forest are lost, equivalent to 0.6% of estimated forests; although this rate varies from province to province (Ambiental, 2010).

The potential for further agricultural expansion, without infringing on valued habitats, has been calculated by IIAM at 6.8M ha (INGC 2009). This varies by region: most of the suitable areas for expansion lie in the Centre and North Regions of the country. The main limitation for most smallholders to expanding their farms is labour: without machinery, clearing and cultivating more than five hectares is beyond the capacity of most households.

Most of the agricultural land is worked under customary tenure, although these rights are recognised by the 1997 land law. The state may allocate land to large farms but investors are expected to negotiate with local authorities and leaders. (Prommer 2001, World Bank 2006)

Labour availability and costs

Family farms engage 90% of the agricultural labour force; state and commercial farms make up the rest. Within this, women and children undertake the majority of agricultural activities, and off-farm income comprises 25% of total farm income. Labour input varies according to availability, with family farmers adapting their systems to suit. In the Zambezi Valley Cotton and Tobacco Concession Area, for example, maize production required an average of 141 family labour days and 82 hired labour days per ha (Benfica et al. 2005). The activity requiring the highest labour inputs was land clearing and preparation, and then weeding and harvesting.

Some basic labour costs for specific production practices are shown in Table 3.6.

Table 3.6 Wage rates by activity, for tobacco, cotton and maize production in Mozambique, 2005

Estimated wage rate by activity ($US/person/day)

	Tobacco	Cotton	Maize
Land clearing	1.55	1.08	0.75
Seed bed prep.	0.65		
Land prep.	0.97	1.44	1.52
Trans-plant	2.50		
Plant		1.93	3.66
Fertiliser/Pesticide application	1.85	3.28	0.90
Barn constn maintenance	0.89		
Weeding	0.61	1.43	1.09
Harvest	0.66	0.67	0.47
Drying	0.41		
Grading	0.54	0.83	
Baling, Bagging	0.43		0.64
Cut and burn residues	0.78	0.40	0.75

Source: Benfica et al., 2005

At the same time, one-fifth of the population is unemployed, and 50% of recent urban graduates currently migrate to find work (Quatorze 2006). Therefore there is labour potential if the appropriate enabling environment is provided such as decent working conditions, wages, transport, training and prestige.

Input use

Family farming is characterised by a very low — often negligible — level of mechanisation and farm inputs. Some 95% of the households did not use fertilizer in Mozambique in the 2004/05 season, and less than 2 kg/ha fertiliser was used on arable land. The provinces with the highest potential for agricultural production had very modest uses of fertilizer: Nampula had 3% of households who used, and Zambezia province had less than 2%. Agro-ecological zone R10, the upland of the North, holds most potential for increasing fertiliser use. Regarding the use of pesticides, the picture is similar: 95% of the households in Mozambique do not use them. Within this however, approximately 10% of medium scale farmers use fertiliser and pesticide, and 30–35% of large scale farmers.

Animal traction is largely restricted to provinces in central and southern Mozambique, comprising 10% of small farmers, 70% of medium scale farmers and 64% of large farmers.

Agriculture is mainly rainfed where water sources are prioritised for potable supplies. Thus the country depends on the consistency of the annual rainy season and this particularly affects monocultural production. Flooding is a risk to both crop and livestock production.

Irrigation is found mainly on larger farms in lowland areas under rice production or smaller vegetable production units, covering only 3% of the potential of Mozambique's 138 districts and used by 11% of households. Inhambane and Maputo provinces, in the south, have the highest percentage of smallholders applying any type of irrigation, 26% and 24% respectively, whereas in Nampula and Zambezia provinces, for instance, only 7% and 3% of the households irrigate their fields. Medium scale farmers use more: 17%, and 35% of large scale farmers use irrigation. Of the three million hectares that are estimated to be irrigable, about 97,000 ha are equipped for irrigation but only 37,000 ha (or 40%) actually are irrigated. Zone R1 in the South particular holds high potential for increasing irrigation.

Main farming systems used in this study

Based on the above, the various farming systems in Mozambique for the purpose of this exercise are divided into three main types: small to medium scale maize-root mixed farming, large-scale commercial, and semi-arid millet and pasture. Table 3.7 summarises their main characteristics.

Table 3.7: Characteristics of main farming systems used in this study

Characteristic	Farming system type		
	S-M Maize-root mixed	Large scale commercial	Semi-arid millet pasture
Total cultivated area (ha)	3,804,346	120,977	40,000
Average cultivated area (ha)	1.24	282	1.2 (millet)
Basic crops	Maize, cassava, sorghum, sweet potato, beans, groundnuts rice	Maize, cassava, sorghum, sweet potato, beans, groundnuts rice	Millet
Cash crops	Cotton, sesame, tobacco, sunflower, horticultural crops	Cotton, sesame, tobacco, sunflower, cashew, sugarcane, horticultural crops	-
Livestock	Cattle, pigs, chickens	-	Cattle, goats, sheep

3.2 Assessments of emissions from agriculture and rural land use

Mozambique's national communication to UNFCCC

In 2003, Mozambique submitted an initial national communication to the UN Framework Convention on Climate Change (UNFCCC) that assessed its emissions from the agricultural sector (MICOA, 2003). However the information on which this assessment was based goes back as far as 1993. According to this national inventory of greenhouse gases (GHG), total emissions in Mozambique were approximately 9,262Gg of CO_2, 272Gg of CH_4, and 3Gg of N_2O. When expressed in terms of global warming potential, these emissions are the equivalent of 15,907Gg of CO_2.

The communication covered five sectors, including agriculture, land use change and forestry. The energy sector included a subsector on agriculture/fisheries/forestry where only emissions from mobile sources were considered, mainly arising from fishing and energy generation. Land use change and agriculture account for more than 80% of Mozambique's GHG emissions.

In agriculture, the products considered were maize, wheat, soya, tobacco, cashew nuts and coconuts. Other products were not considered owing to the lack of emission factors. Livestock products included dairy cattle, non-dairy cattle, buffalos, sheep, goats, pigs and poultry. The five sources of GHG emissions in the agricultural sector comprised: enteric fermentation and manure management, rice cultivation (flooded rice fields), agricultural soils, burning of savannah, and field burning of agricultural residues.

Enteric fermentation and manure management:

Methane [CH_4] emissions from domestic livestock enteric fermentation and manure management produced in country in 1994 were calculated as 11,372 tonnes and 606 tonnes, respectively: see Tables 3.8 and 3.9.

Table 3.8 Livestock population (1994) and corresponding Default Emission Factors

Animal type	Number ('000)	Emission factor for enteric fermentation (kg/head/year)	Emission factor for manure management (kg/head/year)
Dairy cattle	4	35	1
Non dairy cattle	235	32	1
Buffalo	1	55	
Sheep	30	5	0.21
Goats	240	5	0.22
Pigs	144	10	2
Poultry	855	1	0.23

Source: Table 2-2 from MICOA 1003. Animal population from the National Directorate of Livestock (1994) and Emission factors from the IPCC (1996). Note these numbers are markedly lower than those reported by FAOSTAT

Table 3.9 Methane emissions from enteric fermentation and manure management

Animal type	Number ('000)	Emissions from enteric fermentation (Tons CH_4)	Emissions from manure management (Tons CH_4)	Total annual emissions (Gg)
Dairy cattle	4	139.19	3.784	0.14
Non dairy cattle	235	7,525.95	235.19	7.76
Buffalo	1	66.44	0.0	0.07
Sheep	30	149.49	6.28	0.16
Goats	240	1,196.80	52.66	1.25
Pigs	144	1,442.06	288.44	1.73
Poultry	855	854.98	19.66	0.87
Total		11,371.91	605.98	11.98

Source: Table 2-8, MICOA 2003

Rice cultivation

According to the available data, the harvested rice area in 1994 was equivalent to 174,000 ha, with one cropping season and 121 cropping days, that is the period of irrigation water management. To estimate GHG emissions the annual average temperature of 24°C and the emission factor of 5.56 kg/ha/day (IPCC) were considered. In 1994, the total amount of methane emitted from rice fields was of 54.36Gg. This value was attributed to two rice cultivation categories grown in Mozambique:

rice cultivation in intermittently flooded areas (single aeration) contributed with 2.2Gg of CH_4 emissions, while the flood prone areas emitted 52.16Gg of CH_4 emissions.

Emissions from other agricultural fields were confined to nitrous oxide which accounted for 110 tonnes.

Burning of savannah

This occurs between August and September annually, mainly hunters flushing out wild animals but also for clearing land for agriculture. Areas burned are poorly documented: available statistics from the Ministry of Agriculture and Fisheries showed areas burned to be 22M ha a year, made up of different vegetation as shown in Table 3.10. More recent estimates of burning come from INGC 2009:

> Approximately 6-10 million hectares of forest (11-18% of total forest area) and 9-15 million hectares of other lands are burned yearly in Mozambique (DNFFB, 2002).

Table 3.10 Areas and categories of vegetation burned (savannah burning)

Type of vegetation	Area burned (ha)
Low forest HD	696,266
Low forest MD	1,362,266
Low forest LD	3,415,330
Thicket	6,140,663
Medium and low thicket	4,562,176
Wooded grassland	4,562,176
Grassland	1,036,572
Total	**21,775,449**

Source: Table 2-12, MICOA 2003

In 1994, the estimated GHG emissions derived from uncontrolled fires were about 1,590 tonnes of N_2O, 57,550 tonnes of NOx, 128,670 tonnes of CH_4,and 3,377,520 tonnes of CO_2.

Field burning of agricultural residues

Again, data were poor, and it was assumed that the balance of $C0_2$ emissions was zero because of reabsorption of carbon during the subsequent growing season. Other gases were not considered.

Land use change and forestry

The annual growth rate of natural forests in Mozambique ranges from 0.19 to 1.04 m3/ha/year (Saket, 1995, based on data from 1990). The average rate of deforestation from 1972 to 1990 was 4.27%. This corresponds to 2.74 million hectares. In terms of vegetation loss, it corresponds to about 150 000 ha/year. During the decade of 1980–1990, the annual average rate was found to be around 135 000 ha/year. In this sector, the most relevant GHG released was $C0_2$ which resulted from forest and grassland conversion activities (8,983,240 tonnes) and partially removed through changes in forest and other woody biomass activities (1,303,700 tonnes). This sector emitted 7,679,540 tonnes of $C0_2$.

Changes in forest and other woody biomass

Changes in forest and woody biomass emissions resulted from the harvesting, for commercial purposes, of 47,480 m^3 of round wood from tropical thickets, corresponding to 13,618,700 tonnes of dry matter. This dry matter (biomass) stock exchange was responsible for a carbon uptake of 1,303,700 tonnes of CO_2, acting as an important carbon sink. The changes were a direct consequence of plantation of *Eucalyptus spp* (18,300 ha), *Pinnus spp* (21,450 ha), or stock exchange of *moist forest* (6,526,000 ha), *dry forest* (10,065,440 ha), *thickets* (14,765,680 ha), *shrubs* (7,877,640 ha) and *montane forest* (189,360 ha) as well as commercial harvest of *tropical thickets* equivalent to 118,700 tonnes of dry matter.

Forest and grassland conversion

The forest and grassland conversion emitted about 8,983,240 tonnes of CO_2 as a result of:

- An annually converted area of 133,900 ha, corresponding to a loss of 6,423,500 tonnes of dry matter through clearing activities;
- 177,710 tonnes of carbon released from the biomass that was burned on site;
- 666,390 tonnes of carbon burned off site; and,
- 1,605,880 tonnes of carbon released from decay of biomass above ground.

As well as the emission of 8,983,240 tonnes of CO_2, 2,840 tonnes of CH_4, 710 tonnes of NOx, 24,880 tonnes of CO and 20 tonnes of N2O, were also emitted from this subsector.

Energy subsector of agriculture, fisheries and forestry

Table 3.11 Energy consumption and emissions from agriculture, fisheries and forestry

Type of fuel	Consumption (t)	Emissions (Cg)					
		CO_2	CH_4	CO	N_2O	NOX	NMVOCs
Gasoline	151,200	0.470	-	-	-	-	-
Kerosene	2,690	0.010	-	-	-	-	-
Diesel	30,115,720	94.960	0.1	1.29	0	0	-
Residential fuel oil	2,840	0.010	-	-	-	-	-
Lubricants	23,160	0.070	-	-	-	-	-
Total		95.52	0.1	1.29	0	0	-

Table 3.12 Summary of emissions of GHG: percentage contribution per sector

Sector	Percentage of emissions per sector (%)					
	CO_2	CH_4	N_2O	NOX	CO	NMVOC
Energy	16.56	0	33.33	37.81	28.56	-
Industrial process	0.55	-	-	-	-	100
Agriculture	0	71.69	66.67	61.22	70.94	
Land use change & forestry	82.89	1.10	-	0.97	0.50	-
Waste	0	27.21	-	-	-	-
Total	100	100	100	100	100	100

Source: MICOA, 2003

The submission also discusses vulnerability, scenarios under climate change, adaptation and mitigation.

Based on Mozambique's emissions assessment, the total annual emissions for each main agricultural activity can be calculated, along with its global warming potential, as shown in Table 3.13.

Agricultural emissions thus come overwhelmingly from two sources: burning savannah and conversion of forest and grassland to farm fields.

Table 3.13 Agricultural emissions in Mozambique and their global warming potential

Emissions source	Total annual emissions (tonnes)				Global warming potential [a] (tonnes)	
	CH_4	N_20	NOX	CO_2	CO_2	% contribution
Livestock- enteric fermentation	11,372	-	-	-	238,810	0.7%
Livestock – manure management	606	-	-	-	12,726	0.0%
Rice cultivation – intermittently flooded	2,200	-	-	-	46,200	0.1%
Rice cultivation – flood prone	52,160	-	-	-	1,095,360	3.1%
Burning savannah	128,670	1,590	57,550	3,377,520	24,412,990	69.3%
Agricultural fields	-	-	110	-	34,100	0.1%
Forest & grassland conversion	2,840	20	710	8,983,240	9,269,180	26.3%
Energy use in agriculture, fisheries & forestry	100	-	-	95,520	97,620	0.3%
Total emissions	**197,948**	**1,610**	**58,370**	**12,456,280**	**35,206,986**	

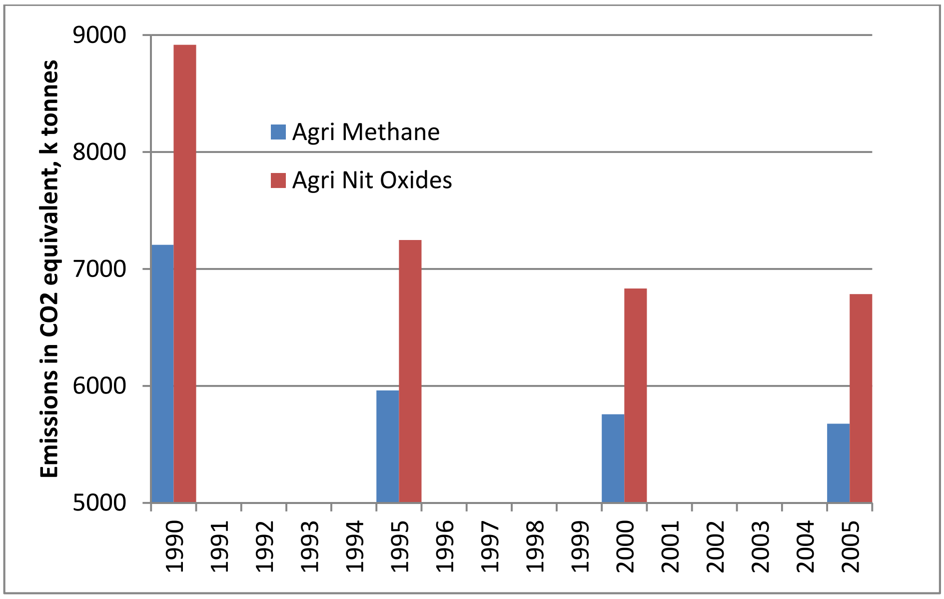
[a] Global warming potential using factors to equate to CO_2 as follows: CH_4 factor 21, N_2O & NOX factor 310.

Other sources of data on emissions

Since the date of the submission to the UNFCCC, the expansion of agricultural areas, illegal forest exploration, logging, coal and charcoal production for energy, and uncontrolled burning have contributed greatly to the transformation of closed forests and wooded grasslands into agricultural areas, open spaces and shrub land. Between 1991 and 1999, agricultural areas increased by 38.8%, open areas by 35.2% and shrub land by 24.6% (Ambiental, 2010).

The World Bank publishes estimates of agricultural emissions of methane and nitrous oxides at five-yearly intervals, see Figure 3.4. Interestingly, these show declining emissions during the 1990.

Figure 3.4: Agricultural emissions, methane, nitrous oxides, 1990 to 2005



Source: World Bank: World Development Indicators

From the PAS 2050 specifications for assessing life cycle GHG emissions (BSI, 2008), the default land use change values for Mozambique are provided for annual and perennial cropping land, as shown in Table 3.14.

Table 3.14 Default land use change values for Mozambique

Current land use	Previous land use	GHG emissions (t CO_2eq/ha/year)
Annual crop land	Forest land	24
	Grassland	3.6
Perennial cropland	Forest land	22
	Grassland	3.2

Source: BSI 2008

Likely impacts of climate change

Assessments have also been made that express future climate change in Mozambique in terms of changed average temperature and rainfall, and the effects of carbon fertilisation (see, for example: Cline 2007, Fischer, 2009, Nelson et al. 2009). These show that yields may be down by as much as 20%.

Some of these assessments are, however, fairly rough and ready estimates. Two sources may give more reliable guides for Mozambique. Knox et al. 2011 conducted a systematic review of estimates of changed yield in the main crops for different regions: for Southern Africa, the only crop for which yields are expected to fall significantly is maize, by a median of 11.4%. For other crops, such as sorghum, studies so far have no shown significant impact on mean yields.

The INGC (2009) compiled the best estimates it had of predicted climate change in Mozambique and their impacts, including on crop production. Global warming is likely to lead to higher temperatures and for much of Mozambique, more rainfall. Climate will be more variable:

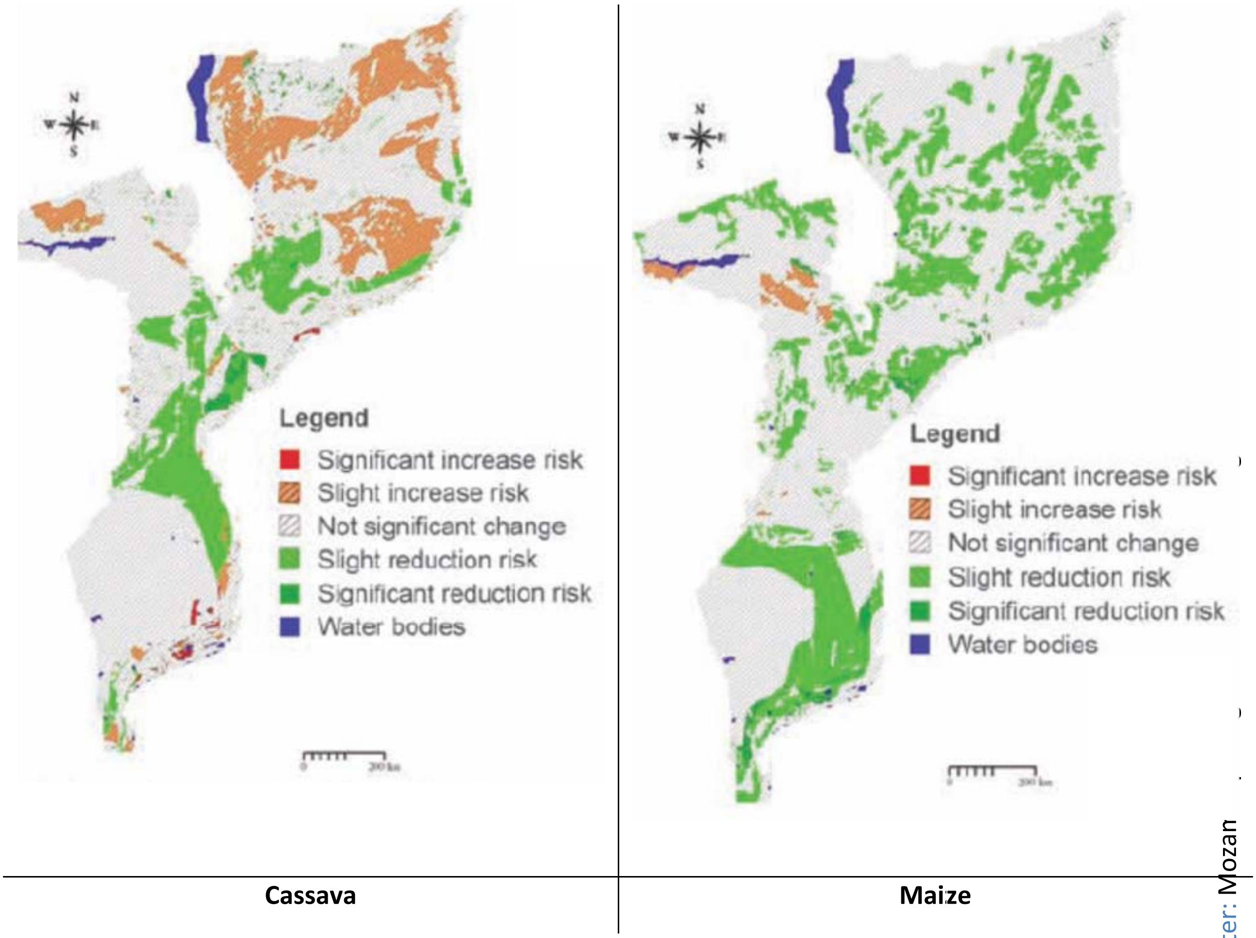
> Generally, the climate may be more extreme, with drought spells being hotter and more extreme floods. The Central zone is likely to be the hardest hit in terms of climate change, particularly those regions at lower altitude, which are already hot. For example, the Zambezi valley. [INGC 2009]

Estimates of changes in land suitable for cassava, maize and soybean do not show for the most part much change, although there are reductions for the semi-arid margins.

> Overall, suitable areas may increase in the Centre and the North, whilst the zones most affected by loss of suitable area will generally be those that already struggle from the impacts of irregular and extreme climate events. These include the mixed arid-semiarid systems in the Gaza and semiarid systems in parts of northern Inhambane and south of Tete, the coastal zones of the South and southern Central zones, and many of the drier zones of major river systems like Limpopo, Save and Zambeze.
>
> The North is not likely to experience major reduction in river flows so irrigation potential is higher assuming water availability for irrigated crop production. [INGC 2009]

Changes in suitability for crops have been mapped by IIAM, see Figure 3.5. For cassava, climate change makes parts of the North less suitable, but these are offset by greater suitability in Centre and South regions. In the case of maize, small areas of the Zambezi valley are expected to become less suitable, while there are large areas of increased suitability across the country and especially in the semi-arid South.

Figure 3.5: Expected changes in suitability of cassava and maize as a result of climate change



Source: INGC 2009, from work by IIAM

Note: Mention of risk here refers to probability of crop failures owing to poor weather in the growing season.

The average yield reductions that may apply with a warmer climate are likely to be offset by increases in productivity.

> The above analysis indicates that the increases in yields attainable with the intensification of agriculture and technological development are higher than the expected decreases in yields caused by climate change. [INGC 2009]

The 11% reduction in maize yields that are predicted for the region are well within the magnitude of yield variations that farmers cope with every year as a matter of course. The potential for raising yields, moreover, is great: average yields per hectare on small farms in Mozambique could be more doubled. The main threat however comes not from falling averages but from increased variances. More extreme weather will be the main hazard that farming faces in the future. In this sense, farming practices that reduce the likely variance in the face of extreme weather patterns are to be favoured.

3.3 Options for reducing net emissions from agriculture

Mozambique's National Adaptation Plan

In 2008, Mozambique prepared and submitted a National Adaptation Programme of Action to UNFCCC (MICOA, 2008). With regard to agriculture, the programme will strengthen the capacity of producers to deal with climate change, through three sets of activities.

One, with the long term aim to reduce losses of crop production and livestock in regions prone to drought, floods, cyclones, tropical storms and other climatic events, key activities proposed comprise: promoting producer associations; rainwater harvesting; drilling wells and boreholes; installing small scale irrigation systems and use of renewable energy; rehabilitating tanks; administering vaccinations; research into drought and disease resistant crops and plants with short growing cycles; promoting sacred forests for eco-tourism; promoting certified seeds at agricultural fairs; encouraging local seed production; agricultural fairs in vulnerable areas; and use of hay for cattle feed.

Two, the programme also aims to reduce the degradation of soils owing to inappropriate agricultural practices, through classifying degraded areas, promoting the use of renewable energy in proximity to cattle breeding communities, conservation agriculture, erosion monitoring, community reforestation for energy biomass and to replant native species, and community management of fire and erosion.

Three, alternative ways to increase family income are proposed as: simple food and seed processing and conservation technologies, cash crop cultivation, small enterprise financing, use of sustainable resources, planting of biofuels in arid and semi-arid areas, and encouraging livelihood diversification into fish farming, bee-keeping, handicrafts, etc.

All the above activities aim to increase agricultural production and improve rural livelihoods while mitigating climate change. Risks and barriers to success of this programme foreseen include weak involvement of local communities or stakeholder coordination, delays in fund allocation, weak network of extension services, lack of access to infrastructure and rural markets, and poor capacity of agricultural research.

Key vulnerable areas are identified for the first phase of implementation: the districts of Magude, Moamba (Maputo), Mabalane, Massangene (Gaza), Funhalouro, Mabote (Inhambane), Chemba, Muanza (Sofala), Machaze, Tambara (Manica), Angónia, Changara (Tete), Mueda, Macomia (Cabo Delgado), Chinde, Morrumbala (Zambezia), Moma, Memba (Nampula), Sanga and Cuamba (Niassa). These districts were chosen for their vulnerability to drought and floods, their poverty levels and the availability of agricultural extension.

Balancing emissions reduction with yield increases and resilience building

Given the low yields on most farms, the above programme recognises that investment in basic, conventional improvements such as access to inputs, improved varieties and irrigation and animal traction would greatly increase productivity. In 2007 for example, fewer than 10% of farmers were using improved varieties of maize, rice or peanut (CountrySTAT, 2007).

In terms of emissions, some of these basic improvements are relatively benign, whilst others vary in their degree of potential GHG emissions or savings. Increases in use of transport, nitrogen fertilisers, fossil-fuel driven irrigation, and paddy rice production could all significantly raise emissions. Not only do they emit GHG, but also they sustain mono-cultural annual cropping that tends to have high emissions. Low-emissions practices need to be able to reduce, displace or avoid current emissions, increase productivity and, preferably, also capture carbon. They also need to be appropriate for the majority of small to medium scale producers in Mozambique. Practises that reduce emissions but do not increase production or even reduce it may also be included, although promoting their uptake will require incentives.

The classification that follows is based on the IPCC assessment of mitigation technologies (Smith et al. 2007). Table 3.15 summarises options and their yield implications. Based on the Government of Mozambique's submission to the IPCC (2003), land clearance for cultivation, especially when it involves burning, is a major emitter. Therefore strategies are required that avoid land clearance: that is, strategies that intensify production on existing land. Options include intercropping, reduced ploughing by zero tillage, improved perennial pastures through holistic management, and analogue forestry approaches that enable forests to be more productive without resorting to complete forest clearance. Other approaches are also considered.

Table 3.15 Measures to mitigate greenhouse gas emissions and increase yields from agriculture in Mozambique

Measure	Description	Mitigation effect (mean estimate), tonnes CO_2eq/ha/year			
		CO_2	CH_4	N_2O	All GHG
WARM-DRY ZONES					
Cropland management	Agronomy	0.29	0	0.10	0.39
	Nutrient management	0.26	0	0.07	0.33
	Tillage and residue management	0.33	0	0.02	0.35
	Water management	1.14	0	0.00	1.14
	Set aside and LUC	1.61	0.02	2.30	3.93
	Agroforestry	0.33	0	0.02	0.35
Grasslands	Grazing, fertilisation, fire	0.11	0	0.00	0.11
Organic soils	Restoration	73.33	-3.32	0.16	70.18
Degraded lands	Restoration	3.45	0	0.00	3.45
Manure/ bio-solid management	Application	1.54	0	0.00	1.54
Bio-energy	Soils only	0.33	0	0.02	0.35
WARM-MOIST ZONES					
Cropland management	Agronomy	0.88	0	0.10	0.98

	Nutrient management	0.55	0	0.07	0.62
	Tillage and residue management	0.70	0	0.02	0.72
	Water management	1.14	0	0.00	1.14
	Set aside and LUC	3.04	0.02	2.30	5.36
	Agroforestry	0.70	0	0.02	0.72
Grasslands	Grazing, fertilisation, fire	0.81	0	0.00	0.81
Organic soils	Restoration	73.33	-3.32	0.16	70.18
Degraded lands	Restoration	3.45	0	0.00	3.45
Manure/ bio-solid management	Application	2.79	0	0.00	2.79
Bio-energy	Soils only	0.70	0	0.02	0.72

Note: Warm dry equates to Agro-ecological zones R1, R2, R3, R6; Warm moist equates to R4, R5, R7, R8. R9, R10

LUC: land use change whereby previously tilled areas are set aside then covered with grass and trees.

Source: Smith et al, 2007

At the same time, these strategies need to ensure the resilience of the farming system against extremes of weather such as drought, floods and high winds. Although there has been little research into this, anecdotal evidence indicates that certain sustainable agriculture farming methods are able to do so. Specifically, in the aftermath of Hurricane Mitch in Central America in 1998, when two metres of rain coupled with mudslides and landslides led to 10,000 deaths, farms that suffered less were those practicing low-external-input agriculture. The specific agronomic techniques being applied were: soil and water conservation, cover cropping (especially with vetiver grass), agroforestry, minimum tillage, and integrated pest management. In particular, the longer rooting systems of grasses and perennial tree crops, and the terracing of hill slopes, prevented the landslides that affected surrounding conventionally managed farms. Crop diversity further minimised economic losses (Holt-Gimenez 2001). Several of these techniques are synonymous with those that lower agricultural emissions, as described below.

Three sets of measures are now set out in more detail: intensifying production; agro-forestry; and restoration of grazing and pasture improvement.

i) Intensifying production

By far the most important activity to maintain a productive low emissions annual cropping system is to increase the diversity of crops in field. Permanent ground cover reduces GHG emissions by reducing carbon loss from soils. Poly-cropping reduces or eliminates the need for pesticide and herbicide usage, and increases the water holding capacity above and below ground, therefore reducing irrigation needs. With reduced threat of pests and diseases, rotations are not required and ploughing can be avoided. Increased above-ground biomass sequesters more carbon.

Zero tillage/no till/ conservation agriculture can lock up 0.1 to 1 t carbon per ha per year, in addition to cutting carbon dioxide emissions by over 50% through the reduced use of fossil fuels in ploughing. Global analysis of long term conservation agricultural experiments showed a change from conventional to no tillage sequestered 2.09 +/- 0.51 CO_2/ha/yr (West & Post, 2002). Table 3.16 compares CO_2 emissions of conventional and no till methods.

Table 3.16 CO_2 emissions over 19 days following different tillage methods

Tillage method	Cumulative CO_2 lost (t/ha)
Moldboard plough	9.13
Disk harrow	3.88
Chisel plough	3.65
No till	1.84

Source: Reicosky, 1998; Reicosky & Lindstrom, 1993

A large-scale trial at the IITA in Nigeria found zero tillage required 52 MJ energy and 2.3 hours labour per hectare compared to 235 MJ and 5.4 hours on conventional tillage (Wijewardene, 1979). Use of pre- and post-plant herbicides in no till in Ghana required only 15% of the time required for seedbed preparation and weed control with a hand hoe, while the reduction in labour days required in rice in Senegal was 53–60% (Findlay & Hutchinson, 1999). Comparisons in Brazil showed the increase in yields and decrease in labour and equipment usage when zero tillage was introduced, in Table 3.17.

Table 3.17 Comparison of no-till with conventional tillage in Brazil

Farm type and crop	Yield (kg/ha)		Yield increase (%)	Decrease in hours /ha/year (%)		
	Conventional	No till		Labour	Equipment use	Fuel consumption
Mechanised soya	2,440	3,100	27	-10	-27	-27
Mechanised maize	4,500	5,840	29.8	-51	-19	-19
Animal traction – maize	4,000	4,800	20	-55	-66	-
Animal traction – bean	1,460	2,000	37	-59	-46	-

Source: World Bank 1998a, 1998b

Denardin (1998) documented similar results in a comprehensive analysis of the socio-economic impact of the adoption of no till systems in wheat and soya crops in Rio Grande do Sul, Brazil. Reductions were substantial: 31% for labour, 41% for equipment use and 44% for fuel consumption.

Using a raft of cropland management approaches as listed in Table 3.15, yields can be increased several-fold, as shown in Table 3.18.

Table 3.18 Estimated actual and potential crop yields in Mozambique

Crop	Average actual yield (t/ha)	Average potential yield (t/ha)
Maize	0.9	5.0–6.5
Sorghum	0.4	0.8–2.0
Rice	1.0	2.5–6.0
Beans	0.5	0.5–2.5
Cassava	6.0	5.0–10.0
Cotton	0.5	1.0–2.0

Source: Loening & Perumalpillai-Essex, 2005

ii) Agro-forestry

Agro-forestry covers a broad spectrum of practices ranging from the introduction of single trees into annual cropping to managing semi-wild forests. The most simple approach is the introduction of trees and in particular multi-purpose nitrogen-fixing species that improve soil fertility as well as providing a new source of shade, fodder and/or other outputs. Intercropping with the indigenous African acacia, Faidherbia albida, has been shown to increase maize yields by 280% in Malawi (ICRAF, 2010). Unfertilised maize near the trees yielded an average of 4.1 t/ha, compared to 1.3 t/ha yields of maize beyond the tree canopy. Each tree sequesters a minimum of 22.6 kg carbon a year.

Analogue forestry is a more complex approach, and entails the establishment of a tree-dominant ecosystem analogous in structure and function to the original indigenous forest system, as a form of bio-mimicry, yet designed to provide food and economic benefits. These systems produce a range of commodities including leafy vegetables, insect protein, fruits, nuts, herbs, cut flowers, honey, pharmaceuticals and fuel wood. In Africa, approximately 600 species of insect are gathered from forests (DeFoliart, 1992). Not only rural communities use these resources; but also affluent urban households are willing to pay 43–157% more for bushmeat in Mozambique (Barnett, 2000).[4]

Conversion of natural forest to this perennial production system requires sustainable felling and coppicing which also supplies wood products for possible use as biochar. It avoids clearing and ploughing, and therefore avoids GHG emissions from these activities as well as maintaining the carbon capture potential of forest lands. Careful selection of species is required, to fell those that are not required and that with their absence provide glades for annual cultivation, whilst higher value trees are maintained.

Alternatively, existing mono-cultural perennial systems, such as some types of tree crop production, can be made more complex by this method to increase carbon capture rates to levels similar to those of forests.

The protein sources of the forest (bushmeat, insects, green leaves, etc.) can support the reduction of domesticated livestock production and its emissions. Within tropical latitudes, it is estimated that one ha of sustainable agroforestry can provide goods and services which potentially offset 5–20 ha of deforestation (Dixon, 1995).

One acre (0.4ha) of Analogue Forest typically sequesters 200 tons of carbon (CCC, 2008). Other examples of agroforestry systems sequestering carbon are the fodder bank system in West Africa, sequestering 1.06 tCO_2/ha/yr (Nair et al. 2009), coffee- based systems in Kenya at 1.8 tCO_2/ha/yr (Forest Trends, 2010), homegardens in Sumatra Indonesia at 29.3 tCO_2/ha/yr and mixed species stands in Puerto Rico at 55.77 tCO_2/ha/yr (Nair et al. 2009). For all these, the potential depends on a variety of factors including type of system, species composition, age of component species, location, and management practices.

Production costs of agroforestry include nursery establishment, use of fertilisers, machinery, land access, management changes over time, and yield increases over time. For example, the departments of agriculture in both Malawi and Zambia are encouraging farmers to establish *Faidherbia* trees in their maize fields, and national programmes recommend that farmers establish 100 *Faidherbia* trees on each hectare of maize field, with seedlings grown on-farm, planted out during the rainy season and thinned as the canopy spreads (ICRAF, undated). Precise costs depend on the type of system being developed, for example whether dense analogue or a simple tree-crop intercrop.

There are few data on establishment costs. A case study performed on the Sahel region of Africa calculated the cost for establishing an agroforestry system (Sahelian Eco-Farm or SEF) with millet crops. The researchers estimated the cost per hectare to be approximately US$60 for plant materials

[4] Bushmeat, together with fish, provide 20% of protein in the majority of developing countries (Bennet & Robinson, 2000).

and a one-time application of US$10 of fertilisers (MIT, undated). In Uganda, plantation establishment costs are up to Ushs1.6M per hectare (Watasa, 2010). Labour time to plant up fields have been estimated at 100–600 plants per day including seedlings planted, fertilised and treated with insecticide (Evans, 1992).

iii) Restoration of grazing lands and pasture improvement

The improvement of existing grazing lands to create perennial systems would halt the burning of rangelands and the clearance of forests to create new temporary pastures. This improvement would also increase carbon sequestration, and can be done through increasing the grazing intensity, fertility management, fire management and species introduction, as shown in Table 3.19.

Table 3.19: Carbon sequestration potential of rangeland management practices

Management practice	Mean change in tCo_2eq/ha/yr
Vegetation cultivation	9.39
Avoiding land cover change	0.40
Grazing management	2.16
Fertilisation	1.76
Fire control	2.68

Source: Tennigkeit & Wilkes 2008

The improvement of livestock feeding practices and longer term changes in management also make a difference, although the potential here is limited as can be seen in Table 3.20.

Table 3.20: Technical reduction potential of emissions from ruminant livestock, southern Africa

Proportion of animal's enteric methane emissions from improved feeding, management and animal breeding, southern Africa

Animal	Improved feeding practices	Structural/ management change and animal breeding
Dairy cow	0.01	0.004
Beef cattle	0.01	0.006
Sheep	0.01	0.004

Source: Smith et al. 2007

Of these practices, fire control can be avoided through vegetation management in terms of introducing a broader range of grassland species, and grazing management in terms of changing the grazing intensity to one of high density over short periods (also known as 'mob grazing'). Vegetation management results in higher yields, and mob grazing in higher yields compared to traditional grazing. Both together have lower input costs over the long term in reduced veterinary inputs, zero inputs of feed and fertiliser. Labour costs are unknown but likely to be the same or lower than previous, owing to the reduced need for input application or manure collection, versus the increased need to move the herd rather than free roam. Establishment costs are mainly for labour, grass seeds, fencing and stockwater.

The following provides some examples of this holistic grazing system (where no burning is required). In one example in South Africa, livestock units increased from one to every 28 ha to one for every 8 ha (Adams, 2007).[5] Stocking density increased sixfold in an example from Colorado, from grazing 400 pairs on 1,200 ha to the same size herd on 200 ha (Howell, 2007). Using this approach, soil organic carbon can built by 1% over 12 months; that is 12 tonnes carbon/ha (Earl, 2009). In Vermont, a stock density of between 1,000–2,000 animals/ha can be achieved. Overgrazing occurs when the animals stay too long, come back too soon, or graze too soon after dormancy. Three years of twice yearly sub-soiling, in concert with planned grazing, builds 18 inches (450 mm) of new topsoil that can be maintained indefinitely through continued planned grazing (Collins, 2006). In Canada, cattle on one farm are stocked at 650 head per ha, and moved every 6 hours, with no area being grazed more than twice a year. In 2006 this farm required only 0.55 ha per head. This type of grazing system requires 3.5 hours a day more work than conventional (Adams, 2006).

In the livestock sector, mitigation activities have the greatest chance of success if they build on traditional pastoral institutions and knowledge with a strong understanding of ecosystems goods and services, and provide pastoral people with food security benefits at the same time (Reid et al, 2004).

3.4 Scenarios proposed

Summary of main GHG reduction activities

As noted in the MICOA report, the main source of GHG emissions by land use type in Mozambique is burning of savannah; mainly to hunt wild animals, secondarily to clear land for agriculture and collecting woodfuel. The area of savannah burned for each of these reasons is not known. Nor is it known, within agriculture, how much is cleared for field crops and how much for grazing. Therefore it is difficult to apportion any one GHG reduction activity to halting the burning of a known area of savannah.

For this study, assume that 40% of savannah burning is apportioned to livestock production, and 40% to clearing land for field crops, that is 51,468 tonnes CH_4 each (based on MICOA data). Deforestation rates are 135,000 ha/year (MICOA) and are mainly for agricultural purposes, wild fires, fuelwood and charcoal. Assume that 100,000 ha/year is deforested for agriculture.

The introduction of complex agroforestry systems could directly halt forest conversion, and would enable traditional activities to continue. Agricultural production would be on a more extensive basis, and it is estimated that 20% of the agroforestry area would be given over to annual crops that would themselves be managed by zero tillage and sustainable grazing management. MICOA data does not provide for the CO_2 emissions released by tillage. Whilst arable areas may not be emitting significant GHGs, compared to savannah burning for example, zero tillage and introduction of nitrogen-fixing trees into these areas increases yields and so enables sustainable intensification and halts slash and burn activities. We can presume that ploughs are used for cash crops and by large scale farmers.

For each of these activities, there is debate over their efficacy, but this debate is largely to do with the levels of knowledge and understanding around their practice. For example, the positive sequestration impacts of zero tillage are negated if ploughing is then performed a couple of years later. For this study it is assumed that there is a high level of eco-literacy in this regard, and conservative estimates of positive change are made based on the empirical evidence from examples of success in these practices. Obviously if several activities are applied over the same area, the changes in labour, inputs and so on will vary. Table 3.21 summarises the main GHG reduction activities proposed for Mozambique.

[5] The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs.

Table 3.21: Summary of main GHG reduction activities for Mozambique

Changes in:	Farming practice			
	Zero tillage field crops	Introduce nitrogen fixing trees into arable fields	Complex agroforestry (instead of forest & grassland conversion)	Grazing improvement (instead of savannah burning)
GHG emissions	Reduced 50%	n/a	Avoided deforestation emissions	Avoided burning emissions
Carbon capture	0.5 t C/ha/yr	2.3 t C/ha/yr	500t C/ha/yr	12 tC/ha/yr
Yield	20% increase	50% increase	Low density production of all crops/livestock, 10% per ha of each.	Change from 1 LSU/28 ha to 1 LSU/8 ha
Labour	50% reduction	0.5 day/ha increase (for maintenance)	90% reduction	30% increase.
Inputs	20% reduction (30% for fuel)	Zero fertiliser	Zero	50% less
Land area	No change	No change.	New	No change

Note: where percentages are given, there are no more accurate figures available, and figures can be calculated relative to the control (current) situation. Resourcing for establishment not included.

Of the four GHG reduction activities above, three can be directly applied to the selected farming systems; that is zero tillage and the introduction of nitrogen-fixing trees are introduced into all three systems, and grazing improvements into the small-medium scale maize-mixed system and the semi-arid system. The complex agroforestry activity is by its nature applied to uncultivated forest and grassland and therefore is applied to the area that would otherwise be burned or cleared for agricultural production.

Economics of transition

For the typical small farm, growing maize and root crops, with some small areas for additional food and cash crops, the aim will be to introduce:

- Conservation tillage, with less ploughing; moving either to ripping the soil or using planting pits — the former when there is draft power, the latter when methods are manual. This should allow more penetration of water to the root zone. Careful placement of fertiliser — with methods such as micro-dosing — offer better returns to any fertiliser used, whether manufactured or organic manures; and,
- Nitrogen fixing trees, such as Faidherbia albida, planted at around 100 trees per hectare to provide additional fertilisation.

These two measures would mean less movement of the soil, less chance of manufactured fertiliser emitting nitrous oxides, and hence reduced emissions. They should also help conserve moisture, with less loss of crops to drought and allowing water economy where irrigation is used.

They should also raise yields, allowing farmers to produce more without converting forest, bush and grass to cultivated fields: and thereby avoiding emissions in land conversion. The trees would in addition provide forage.

The economics of these proposals can be examined through use of analysis of gross margins, looking at costs and returns to cultivation of a typical hectare of the main smallholder crops, see Table 3.22. Additional costs: the new system may save labour in land preparation, especially in cases where previously the soil was ploughed. This may not, however, apply in manual cultivation. Here there can be heavy costs in preparing the land when making planting pits, and in additional weeding, especially in the early years: by 15% more, Rockström et al. 2009. There may also be extra labour in managing the Faidherbia trees, such as recommended practices in pruning low branches.

The extra costs have been included in labour per hectare, taken at 110 days a hectare, see Table 6 from Mazvimavi & Twomlow (2009) when preparing planting basins by hand. For systems with the trees, an additional 2 days a year have been added to reflect pruning and lopping of trees.

Although the additional labour is costly, the gross margin per day worked increases, showing that the extra effort will repay farmers: see Table 3.22, and Figures 3.6 and 3.7. Gross margins per hectare increase for all crops: the implicit return to household labour increases for all crops other than sesame and sunflower, although by small amounts.

Figure 3.6: Gross margins, US$ per hectare, three systems

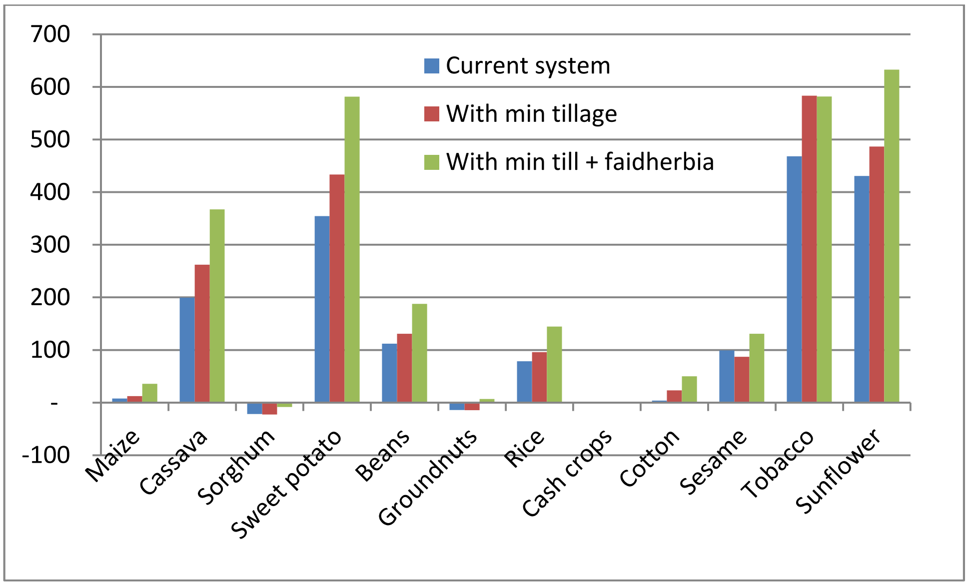
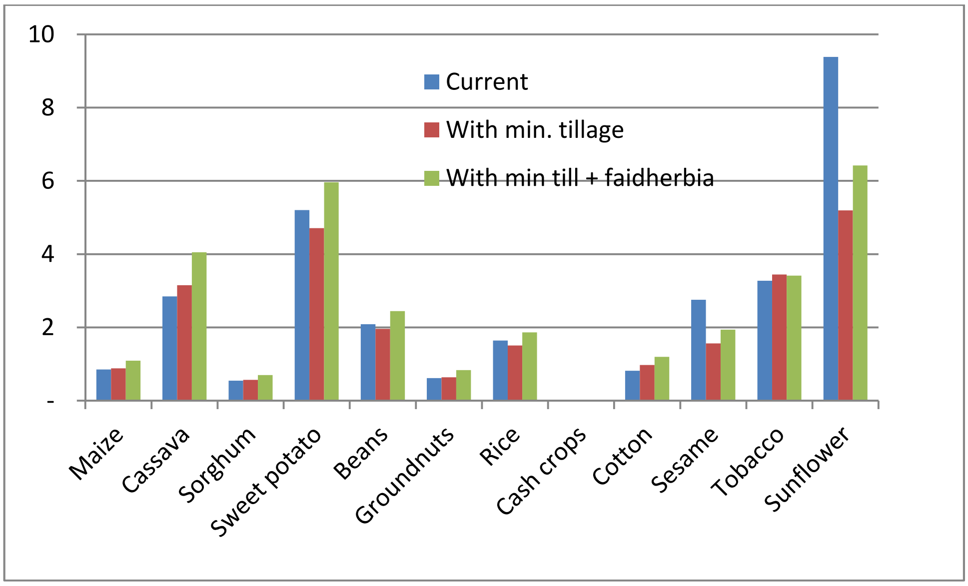


Figure 3.7: Implicit returns to family labour, US$ a day



Hence it should be possible to encourage farmers to make the conversion on purely financial benefits, without having to appeal to environmental gains.

Table 3.22: Gross margins for smallholder crops

(a) Existing system

	Yield	Unit Output Value	Labour days/ha		Labour Costs	Seed costs	Total costs	Total value outputs	Gross margin	Gross margin
	(kg/ha)	US$/kg	Family	Hired	US$/ha	US$/ha	US$/ha	US$/ha	US$/ha	Implicit return to family lab, US$/day
			Day	Day						
			0.77	0.77						
Maize	918	0.09	95	0	73	2	75	83	8	0.85
Cassava	5,928	0.06	96	3	76	80	156	356	199	2.85
Sorghum	585	0.09	95	0	73	1	74	53	- 22	0.54
Sweet potato	7,120	0.07	80	3	64	80	144	498	354	5.20
Beans	495	0.39	85	0	65	16	81	193	112	2.09
Groundnuts	320	0.24	90	0	69	22	91	77	- 14	0.61
Rice	926	0.18	90	20	85	4	88	167	78	1.64
Cash crops										
Cotton	631	0.15	85	30	89	2	91	95	4	0.82
Sesame	688	0.22	50	5	42	10	52	151	99	2.76
Tobacco	1,980	0.44	187	31	283	120	403	871	468	3.27
Sunflower	2,240	0.22	50	5	42	20	62	493	431	9.39

(b) System with minimum tillage

	Yield	Labour	Labour	Seed	Land area	GHG reduction	Carbon capture	Total value outputs	Gross margin	Gross margin
	(kg/ha)	Day/ha	US$/ha	US$/ha	ha	CH4(kg)	tC/Ha/yr	US$/ha	US$/ha	Implicit return to family lab, US$/day
			day							
			0.77							
Maize	1,102	110	85	2	0.40		0.5	99	12	0.88
Cassava	7,114	110	85	80	0.20		0.5	427	262	3.15
Sorghum	702	110	85	1	0.07		0.5	63	- 23	0.57
Sweet potato	8,544	110	85	80	0.01		0.5	598	433	4.71
Beans	594	110	85	16	0.10		0.5	232	131	1.96
Groundnuts	384	110	85	22	0.10		0.5	92	- 15	0.64
Rice	1,111	130	100	4	0.06	96	0.5	200	96	1.51
Cash crops										
Cotton	757	115	89	2	3.5		0.5	114	23	0.97
Sesame	826	110	85	10	0.4		0.5	182	87	1.56
Tobacco	1,980	218	168	120	0.8		0.5	871	583	3.45
Sunflower	2,688	110	85	20	0.2		0.5	591	487	5.19

(c) System with minimum tillage and use of faidherbia to fix nitrogen

	Yield	Labour	Labour	Seed	Total value outputs	Gross margin	Gross margin
	(kg/ha)	Day/ha	US$/ha	US$/ha	US$/ha	US$/ha	Implicit return to family lab, US$/day
			0.77				
Maize	1,377	112	86	2	124	36	1.09
Cassava	8,892	112	86	80	534	367	4.05
Sorghum	878	112	86	1	79	- 8	0.70
Sweet potato	10,680	112	86	80	748	581	5.96
Beans	743	112	86	16	290	188	2.44
Groundnuts	480	112	86	22	115	7	0.83
Rice	1,389	132	102	4	250	144	1.86
Cash crops						-	
Cotton	946	117	90	2	142	50	1.20
Sesame	1,032	112	86	10	227	131	1.94
Tobacco	1,980	220	169	120	871	582	3.41
Sunflower	3,360	112	86	20	739	633	6.42

Table 3.23: Public investment costs

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
No farmers reached			613,604	613,604	613,604	613,604	613,604					
Area converted												
• Year 3 farmers			153,401	153,401	153,401	153,401	153,401					
• Year 4 farmers				153,401	153,401	153,401	153,401	153,401				
• Year 5 farmers					153,401	153,401	153,401	153,401	153,401			
• Year 6 farmers						153,401	153,401	153,401	153,401	153,401		
• Year 7 farmers							153,401	153,401	153,401	153,401	153,401	
Total area converted, k ha	-	-	153	307	460	614	767	614	460	307	153	
Cumulative area converted, k ha	0	-	153	460	920	1,534	2,301	2,915	3,375	3,682	3,835	
Cost Faidherbia + fertiliser, USM			10.74	21.48	32.21	42.95	53.69	42.95	32.21	21.48	10.74	
Cost farmer package, US$M			3	7	10	13	17	13	10	7	3	
Total costs to farmers, US$M	**-**	**-**	**14**	**28**	**42**	**56**	**70**	**56**	**42**	**28**	**14**	
Extension costs, US$M	1	2	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53
Total public cost, US$M	**1**	**2**	**17**	**31**	**45**	**59**	**73**	**59**	**45**	**31**	**17**	**3**

Costing transition

Assume that farmers switch 0.25 ha every year of their typical 1.25 ha farm, making the cultivation changes and planting Faidherbia albida, so that it takes five years to convert the farm to the proposed system.

Full benefits of the Faidherbia trees in fixing nitrogen will only be realised when the trees have 10 year's growth (maturity reached at 10–20 years). Until then, assume yields will increase from current levels towards the mature expectation linearly.

How difficult would it be for farmers to convert from current practice to system with less tillage and use of faidherbia trees to fix nitrogen? The changes do not involve much capital: indeed, perhaps the only capital cost is the tree seedlings. Planting the trees at 100 per hectare will incur costs of:

- nursery establishment,
- use of fertilisers,
- labour in planting

Experience from Malawi, Zambia and Uganda suggest the investment costs in trees, per hectare, at US$60 for planting material , US$10 for fertiliser, plus US$0.77 for a day of planting.

Public investment to support this

The changes contemplated may not be that drastic, but they are substantial: farmers are unlikely to adopt the package without being made aware of the possibility, being convinced that this will improve their returns, perhaps receiving some small incentive to switch practice. So what might this come to in practice?

Awareness and training: Extension workers need to be hired to carry out this work. Assume that one extensionist can cover 500 farmers. They will also need some materials to establish demonstration plots. At a minimum, this would be 5 year's effort, more realistic would to budget for 10 years.

This would require around 6,136 additional extension agents, plus supervisors for them, and managers of the supervisors. Total cost has been estimated at US$2.5M a year.

Incentives: Farmers could receive planting material in Faidherbia seedlings for free. For switching to conservation farming, they could be rewarded with the value of their additional investment. While a cash payment would be ideal, in practice this would be administratively difficult and risky in the opportunities for corruption. A grant of seed and tools, on the other hand, could be made more transparently.

Cost per farmer would be US$70 for the seedlings and fertiliser, plus US$22 for the grant of seed and tools.

Public investment costs

Table 2.23 sets out the costs, assuming that it takes three years to set up the extension effort, that thereafter one fifth of all small farmers are contacted, and they each convert one fifth of their area every year. The annual cost builds to reach US$73M in Year 7, then tapers to Year 12.

Deterring land clearance and savannah burning

The greatest challenge in making a transition, however, would not be in carrying out a programme of extension backed by incentives; but rather in deterring farmers from further clearance of grass, scrub or forest, and in burning the savannah. To appreciate the policy options, it is necessary to understand why land clearance and annual burning are so commonly practiced.

Land clearance responds to three factors. One is increasing population and the need for young farmers to create their own holdings from bush and forest. So long as rural populations are increasing and there are few other ways to earn a livelihood, this will persist. While fertility rates may be falling in Mozambique — currently estimated at 5 children per females on average, in the early 1990s the rate was 6 — and rural-migration takes place, it is unlikely that there will not be some net increase in rural populations for the next 20 years or more. Recent rural population growth has been a little more 1% a year: not much but still increasing.

A second driver is that of economic incentive: when farming offers good returns and there is access to markets, farmers will want to raise production. When land is plentiful, expanding the area is usually less costly than intensifying production from the existing land.

The third driver is that of fallowing to maintain soil fertility. Where and when it is possible owing to presence of bush and forest, farmers throughout history have found that fallowing systems are a good way to maintain soil fertility and hence field productivity. (Boserup 1965) This is because nearly cleared bush and forest has loose soil with nutrients, to which burning of cleared vegetation can add further nutrients and organic matter, relatively few weed seeds, pests and diseases. Consequently, fir the first few seasons, the farmer enjoys relatively fertile soil, easily worked with hand tools, few weeds, and relatively few pests and diseases. Crops can thus be produced with little effort and very few external inputs. With every year, however, these advantages diminish, as nutrients are taken out of the system by the crops, weeds, pests and diseases all begin to accumulate. Yields thus fall. At this point the farmer has two options: to intensify production with nutrient replacement through manuring or application of manufactured fertiliser, more intense weeding, and protection of crops against pests and diseases; or to leave the field to revert to bush and open a new plot. Usually the costs of clearing new plots is less than intensification; so the farmer sets up a systems of fallowing, returning to the original plot later when it has recovered from cultivation — given enough land farmers will leave land for up to twenty-five years before returning. (Ruthenburg 1980)

Burning of the savannah in Mozambique arises from several motives: to clear areas to farm, either to accommodate new farmers or new fields; to burn off old grass before the rains and thus encourage growth of fresh grass when the rains arrive, so that herders will have better pasture for their stock; and to drive game from their cover and make them easier to hunt. These are longstanding practices, but it seems that burning may have become more frequent and extensive than it used to be:

> Mozambique, like other southern African countries, is highly affected by wildland fires. It is currently estimated that nearly all of the forests in central and northern Mozambique burn at least once a year (FAO, 2005)—a considerable increase from the previous return cycle of about 12 years for all of southern Africa (Abekerli, 2001). The current perceived rise in fire frequency in Mozambique appears to be driven by two main factors: population growth and an associated increase in demand for land and income; and a breakdown in traditional land-use management systems over time due to changes in the political context in which these local institutions have existed. This situation has negative implications for people and the miombo forest ecosystem that dominates central Mozambique. Uncontrolled fires can damage and destroy critical infrastructure, cause the loss of human life, and adversely affect livelihoods and economic activities. Burning on nearly an annual basis also leaves little or no chance for tree species—even those that are fire tolerant—to regenerate and can lead to forests and woodland areas transitioning into grassy savannah. [Hoffmann 2009]

In sum, clearance of forest and burning of savannah respond in part to the management of natural resources when capital and labour is scarce while land is abundant; to increasing pressure on resources from increased populations; and to incentives to expand production. Hence these practices are unlikely to change, and indeed could intensify as appears to be happening with burning, unless policy regulates behaviour or changes the incentives facing farmers.

Possible policy options are set out in the conclusions. Their impacts are not modelled, since it is difficult to specify the impact that they would have without making some wild assumptions.

4. Modelling agriculture and changed practice

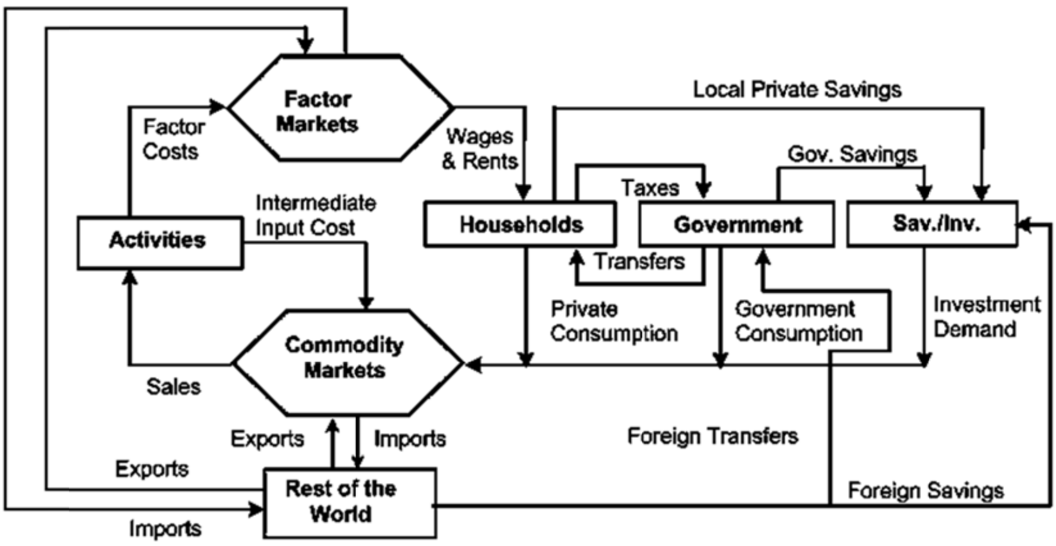
4.1 Modelling with a computable general equilibrium model (CGE)

To examine what might be the results of measures to mitigate agricultural emissions, a computable general equilibrium (CGE) model was used, run for twenty years — the model is dynamic, not static — for a baseline, business-as-usual scenario, and for the simulated changes to reduce emissions.

CGE models are designed to represent the economy of a country, region or the world: in this case, Mozambique. The models are general equilibrium since they attempt capture all the economic and financial flows that have occurred within the economy during a given year: thus they describe the linkages between economic agents and markets for production factors, goods and services, with equations to reflect the behaviour of these economic agents and the functioning of these different markets — see Figure 4.1. The models are used to show the impacts of some economic change: for example, a particular policy such as a cash transfer to the poor, or a change in exchange rate, or the consequences of an exogenous event such as rise in the price of commodities exported or of oil imported.

A key feature of most CGE models is that they can show what happens to the incomes, consumption and welfare of groups of households. These may be differentiated by their income class, ownership of factors of production — for example, those with and without land, and location — often rural and urban households are distinguished. This makes the models powerful in predicting impacts of economic changes on poverty.

Figure 4.1 Links between the major building blocks of a CGE model



Source: Löfgren 2004

CGE models can be static, modelling the eventual equilibrium that would be reached by the economy in response to some economic change; or they can be dynamic, simulating changes through time. The latter is more challenging technically, but adds the power of tracking changes year-by-year — rather than showing the eventual outcomes at some unspecified future date when all adjustments have fed through the economy.

The model used

For this study the STAGE (Static Applied General Equilibrium) CGE was used (see McDonald 2007). This model is characterised by several distinctive features, as follows:

> First, the model allows for a generalised treatment of trade relationships by incorporating provisions for commodities that are neither imported nor exported, commodities that are imported and domestically produced, commodities that are imported but not domestically produced, commodities that are exported and consumed domestically and commodities that are exported but not consumed domestically.
>
> Second, the model allows the relaxation of the small country assumption for exported commodities that do not face perfectly elastic demand on the world market.
>
> Third, the model allows for (simple) modelling of multiple product activities through an assumption of fixed proportions of commodity outputs by activities with commodities differentiated by the activities that produce them. Hence the numbers of commodity and activity accounts are not necessarily the same.
>
> Fourth, (value added) production technologies can be specified as nested Constant Elasticity of Substitution (CES). And
>
> Fifth, household consumption expenditure is represented by Stone-Geary utility functions which allow for subsistence consumption to be explicitly modelled.

The model is designed for calibration using a reduced form of a Social Accounting Matrix (SAM) that broadly conforms to the UN System of National Accounts (SNA).

The model is a member of the class of single country computable general equilibrium (CGE) models that are descendants of the approach to CGE modelling described by Dervis et al. (1982). More specifically, the implementation of this model, using the GAMS (General Algebraic Modelling System) software, is a direct descendant and development of models devised in the late 1980s and early 1990s, particularly those models reported by Robinson et al. (1990), Kilkenny (1991) and Devarajan et al. (1994).

The model is a SAM based CGE model, wherein the SAM serves to identify the agents in the economy and provides the database with which the model is calibrated. Since the model is SAM based it contains the important assumption of the law of one price; that is prices are common across the rows of the SAM. The SAM also serves an important organisational role since the groups of agents identified by the SAM structure are also used to define sub-matrices of the SAM for which behavioural relationships need to be defined. As such the modelling approach has been influenced by Pyatt's (1997) 'SAM Approach to Modelling'.

The STAGE model has been used recursively in this case: it remains a static model, but has been run through successive periods to generate results through time, as though it were a dynamic model.

Data and accounts

This simulation exercise was conducted using a recursive dynamic variant of the STAGE computable general equilibrium (CGE) model (McDonald, 2007) that was customised to the situation existing in Mozambique, see the appendix for details of model adjustments and the implementation of the recursive dynamics. The model was calibrated using a Social Accounting Matrix (SAM) for Mozambique (McCool, *et al.*, 2009); the SAM being modified slightly to conform more closely to the analysis of agricultural technical changes and model characteristics, see the appendix for details of database adjustments.

The Social Accounting Matrix (SAM) used for this study is for the year 2002; it is the latest available SAM and is one of a sequence produced by Channing Arndt and Finn Tarp and various collaborators over the last 15 years. The SAM was originally structured to operate with variants of the International Food Policy Research Institute (IFPRI) CGE model; it was necessary to make a small number of adjustments to the published SAM to render its structure consistent with the STAGE model (see appendix for details).

The SAM has 130 accounts: 51 commodity accounts of which 19 are agricultural and 5 are food commodities, 48 activity accounts with 18 agricultural and 5 food activities, 9 factors accounts of which 6 are labour types, 10 household types and 7 tax accounts. The SAM is constructed around input-output data hence each activity produces only one type of commodity: the disparity between the number of activity and commodity accounts is explained by the fact that 3 commodities — wheat, petroleum and diesel — are not produced domestically.

The factor types and household types in the SAM are reported in Table 4.1 and 4.2. Rural and urban labour types are sub-divided between skilled, semi-skilled and unskilled labour, capital distinguishes between agricultural (fcapag) and non-agricultural (fcapin) capital and there is only a single type of land. No urban labour is used in agricultural activities, but some amounts of rural labour are used in non-agricultural activities, capital is fully segmented while land capital is only used by agricultural activities. Labour accounts for 64% of factor incomes, with 25% rural and 39% urban. Of the rural labour income 92% is classified as unskilled while for the urban labour only 41% is unskilled. Non-agricultural capital accounts for 87% of capital income.

Table 4.1 Factor Types

Factors	
flab-sk-r	Rural Skilled labour
flab-ss-r	Rural Semi-skilled labour
flab-un-r	Rural Unskilled labour
flab-sk-u	Urban Skilled labour
flab-ss-u	Urban Semi-skilled labour
flab-un-u	Urban Unskilled labour
fcapin	Capital Industry
fcapag	Capital Agriculture
flnd	Land

Source: McCool *et al*. 2009

For the 10 types of households, the rural-urban split is maintained and within the rural and urban populations the households are divided into quintiles based on incomes and the number of households. The five rural households account for 37% of household incomes with no household group accounting for more than10% of total household income. Of the 63% of income accounted for by urban households, 48% is accounted for by the richest household group – Urban Quintile 5. As Table 2.2 demonstrates there is a relatively even spread of incomes across quintiles 1 to 4 of the rural and urban households; but then a leap upwards to the fifth quintile, so that average incomes of rural quintile 5 being double those of rural quintile 4, and incomes for urban quintile 5 being three times those of urban quintile 4. There are therefore large income disparities between the richest and other households.

Table 4.2 Household Types

Label	Description	Income per capita (metical)	Population
hhd-r-q1	Rural Quintile 1	1,147	2,301,900
hhd-r-q2	Rural Quintile 2	1,401	2,655,400
hhd-r-q3	Rural Quintile 3	1,856	2,671,800
hhd-r-q4	Rural Quintile 4	2,410	2,297,500
hhd-r-q5	Rural Quintile 5	4,860	1,237,120
hhd-u-q1	Urban Quintile 1	1,297	626,180
hhd-u-q2	Urban Quintile 2	1,731	788,860
hhd-u-q3	Urban Quintile 3	2,180	1,120,120
hhd-u-q4	Urban Quintile 4	3,384	1,454,200
hhd-u-q5	Urban Quintile 5	11,172	2,552,000

Source: McCool *et al*. 2009

Table 4.2 also indicates that there are large difference in the size of households since the numbers of households within each rural quintile and urban quintile are (apparently) the same.

Other characteristics of the economy justify mention. The trade deficit accounts for 16% of the value of imports (*cif*) and provides some 26% of investment funds. There is also a substantial inflow of foreign funds direct to the government; 61% of government income comes from abroad. Furthermore the government provides nearly 60% of the total savings with private households providing very little. Of the domestic tax revenue 62% is accounted for by commodity taxes, 20% by import duties and 19% by direct and income taxes.

3.2 The analysis

The implementation of recursive dynamic CGE models requires the initial development of a 'business as usual' (BAU) baseline that simulates how the economy would evolve over time under the presumption that that were no changes in the planned policy environment. Thus for instance if the government was not currently planning to intervene by facilitating adaptation of agricultural activities to impending climate changes then it would be assumed that this plan would be adhered to through the baseline periods. An important feature of baselines for dynamic CGE models is that they, typically, presume that the economy evolves along a steady state trajectory; this reflects the fact that CGE models are Walrasian and hence do not include behavioural relationships that explain the evolution of macroeconomic variables, the source of many fluctuations in the evolution of economies. Furthermore, many fluctuations in the evolution of economies are consequences of unpredictable events that by definition cannot be incorporated in the BAU baseline; this is especially the case for agricultural activities that depend upon fluctuations in weather.

For the BAU baseline in this case it has been assumed that while the non-agricultural activities develop ‘normally’ the agricultural activities are subjected to forces of climate change that cause agricultural activities in Mozambique to lag behind the rest of the economy.

Once a baseline has been calibrated the model can be used to simulate policy interventions. In this case the policy intervention simulated is an injection of aid funds into the Mozambique economy that facilitate adaptation of agricultural production systems that can offset the adverse effects of climate change on the performance of agricultural activities. It is then possible to compare the differences between the economy under the baseline and simulation.

The discussion of the results begins with a section that specifies the BAU baseline and assesses how the economy might develop without the intervention. The next section details the interventions adopted, which in this case are deliberately parsimonious, for which the results are discussed in the fourth section.

Baseline

Closure Conditions

The macroeconomic closure and market clearing conditions were selected so as to represent both the macroeconomic and labour market conditions within which Mozambique is, and is expected to continue, operating. They also, by necessity, need to be conditioned so that the intended simulations are viable.

Foreign Exchange Market

The external balance was fixed in foreign currency units and is assumed to represent a sustainable level of capital inflows; thus the exchange rate was flexible to allow the external account to clear. Consequently any deterioration in Mozambique’s international competitiveness will be reflected in a depreciation of the exchange rate.[6]

The small country assumption means that world prices are fixed in the closure. However, growth and technical progress in the world economy means that real prices of commodities will typically fall, i.e., increasing real incomes mean that for constant nominal incomes prices must fall, and hence the prices of imports and exports were allowed to decline over time — see section on world prices below.

Investment-Savings Closure

It was assumed that the share of investment in domestic final absorption was constant, an assumption that makes changes in real absorption a good measure of economic welfare. Thus as the value of final demand increases, so does investment. To clear the investment-savings account it was assumed that the savings rates of households and incorporated enterprises were flexible; the variations in the savings rates need to encompass changes in the domestic value of the external balance, which is fixed in foreign currency units, changes in the domestic value of international remittances to households (remittances) and the government (aid) and payments to and from foreign owned factors. Investment is fixed in terms of the value share of domestic absorption so the real volume of investment can vary as the relative costs of capital investment commodities vary. This is particularly important since a substantial proportion of investment commodities have to be imported.

[6] In this model the exchange rate is expressed in terms of the domestic currency units per ‘world’ currency unit. Hence a depreciation of the exchange rate causes the variable to increase.

Government Account Closure

The internal balance (government borrowing/savings) was fixed in real terms[7] as were any transfers for the government to domestic institutions, while government expenditure was assumed to be a fixed share of domestic final absorption – this assumption makes changes in real absorption a good measure of economic welfare. Government income consisted of returns from state-owned enterprises, transfers from abroad (primarily aid) and tax revenues; all tax rates except income tax rates on households and enterprises were fixed with incomes tax rates flexible to clear the government account.

Factor Market Clearing

The supplies of rural and urban skilled and semi-skilled labour, capital and land were assumed to be fixed, within each solution period, and it was assume that these factors were fully mobile between the activities that employ the factors. Thus for these factors increases/decreases in demand produces increases/decreases in real wage rates.

Rural and urban unskilled labour, however, was assumed to available in perfectly elastic supply at the current real wage rate; thus for these factors increases/decreases in demand produce increases/decreases in the quantities of these factors employed.[8] While there is considerable rural-urban migration in Mozambique, the rural population continues to grow, albeit by only 1% a year. It is unlikely that falling fertility and migration from rural areas will bring this to a halt in the near future.

Between solution periods the quantities of factors may change, either through endogenous or exogenous factor accumulation (see below).

Technologies

It was assumed that all technologies were fixed within each solution period, except when calibrating the baseline when one set of technology parameters were free to vary so as to ensure the tracking economic growth (see below for details on the calibration).

Between solution periods the technology parameters may change, due to exogenous forces, except for the technology parameters that were free to vary when calibrating the baseline; these are fixed during the simulation phase.

Numéraire

The numéraire was the consumer price index (CPI) so all the levels results for variables are in real terms and all percentage changes are percentage changes in real values.

Calibration

Calibration involves several stages.

Factor Accumulation

Capital accumulation depends upon the existing stocks of capital, the capital stock specific depreciation rates, the volume of investment and the distribution of new capital across the different

---

[7] This means the government cannot increase its borrowings to fund current expenditures at the unaccounted for cost of future generations.

[8] The results are monitored to ensure that this did not generate unrealistically large increases in the supplies of unskilled labour.

types of capital. In this system there are two types of capital; agricultural and non-agricultural capital. Once new capital is created for each type of capital it cannot be converted into the other type of capital but it can be moved between those activities that employ that type of capital.

At the end of each solution period the existing capital stock experiences depreciation and is then incremented by new capital funded by investment expenditures. The allocation of new capital between the different capital types depends upon the relative rates of return to the types of capital in the previous period: that is, the decision rule is *only* backward looking, according to a partial adjustment rule. The partial adjustment rule is expressed as a change in the share of new capital relative to the share of existing capital, which means that in each period there is new capital accruing to each type of capital but in different proportions. The calibration is sensitive to the depreciation rates; the results below assume that both types of capital depreciate at 8% per period, which is arguably low for simple agricultural capital and serves to bias the results against the benefits from the policy intervention.

Note how both the absolute and relative rates of capital accumulation will change as economic performance changes.

There are no endogenous behavioural relations to determine the accumulation of different types of labour or population, so the rate of accumulation of rural and urban skilled and semi-skilled labour is fixed exogenously: in the results below skilled and semi-skilled labour grows at 2% per period, which is intended to reflect the existing age structure of the Mozambique population. The calibration procedure is configured to allow sensitivity analyses by varying these exogenously imposed rates; however since these rates are fixed in both the baseline and the simulation the results are far less sensitive to these rates than to the capital accumulation process.

Land is assumed to be available in fixed supply, however the flow of services from a given area of land does change (see below).

World Prices

Growth and development typically produce reductions in the real prices of commodities. For this baseline it is assumed that the prices of traded commodities decline at constant rates that are commodity specific; for this baseline it is assumed that agricultural commodity prices decline by 1% per period and that manufactured commodity prices decline by 1.5% per period. This means that for Mozambique to remain internationally competitive it must achieve efficiency gains that reduce its costs of production by that amount each year.

The calibration procedure is configured to allow sensitivity analyses by varying these exogenously imposed rates; however since these rates are fixed in both the baseline and the simulation the sensitivity of the results to these rates is damped down.

Technologies

There are two types of technology changes embedded into the baseline calibration. The first imposes a presumption that the productivity of land declines at a rate of 1% per period as a consequence of climate change; thus over the 20 periods for which this model is solved the productivity of land reduces to 82% of its initial productivity.

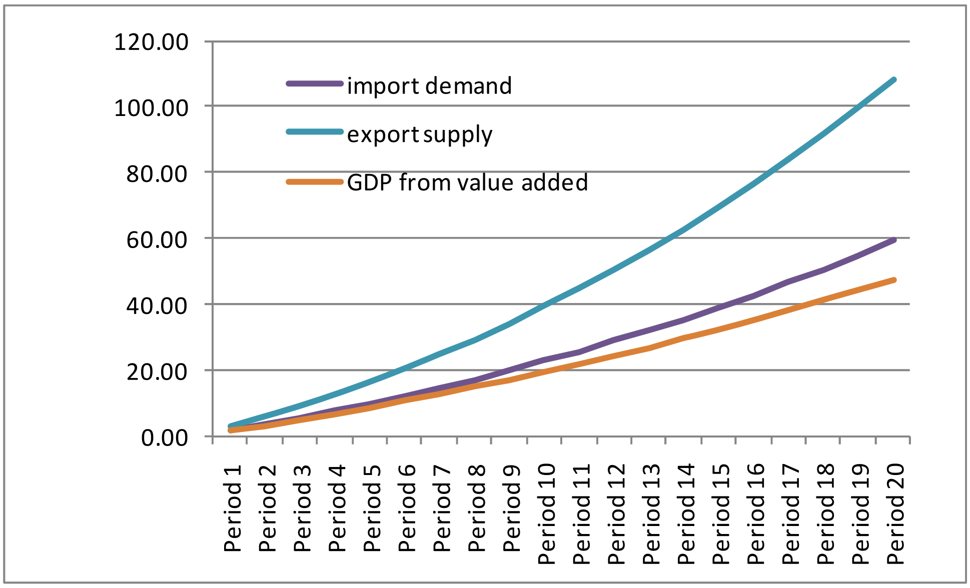
The second productivity effect is the increase in factor productivity needed to achieve a target economic growth rate. In the baseline calibration this is solved for endogenously, with GDP (or some other) target variable fixed exogenously, and then the resultant productivity rates are used as parameters with the target variable now solved for endogenously. In this case the balancing variables for the factor productivities were multiplicative changes in the productivities of all factors (labour and capital) used by non-agricultural activities. The values of these productivity changes, given labour and capital accumulation, lay between 0.5 and 1.5% per period; these estimates reflect the range of estimates for GDP growth and hence, to avoid an apparent claim of spurious accuracy, the final baseline used a simple 1% per period growth rate for the factor productivities. These are relatively low.

Note how the factor productivities for labour and capital used in agriculture were assumed to be constant. This reflects the presumption that declining land productivity would place a break on the productivities of other factors in agriculture and avoids creating a situation where other factors excessively substitute for land as a consequence of the declining productivity of land.[9]

Economic Outturn

The most important insights presented by the baseline are the implications of doing nothing in response to the declining productivity of land in Mozambique. The overall (macroeconomic) impact does not appear to be serious. GDP grows by some 44% over the 20 periods (Figure 3.2), roughly 2% per period, and the increases in real private consumption, investment and absorption are all somewhat greater suggesting that welfare may be even more buoyant. However some concerns might be raised by the very much more rapid growth in real export supply relative to real import demand, which, given the closure conditions, suggests the need to export more to achieve the desired volume of imports (Figure 3.3).

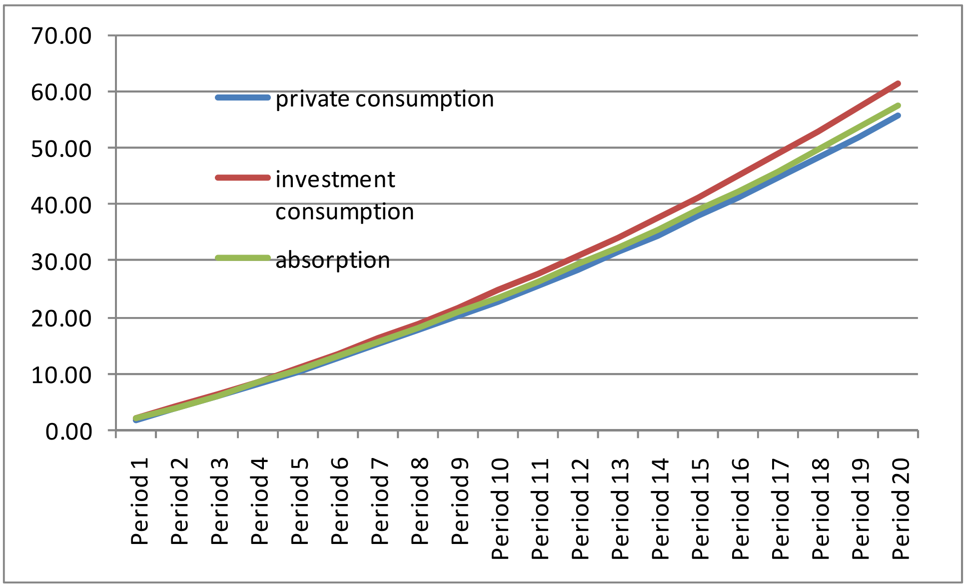
Figure 4.2 GDP and Trade (cumulative % changes from base)



Source: Model baseline results.

[9] The extent to which such substitutions are realised depends upon the elasticity of substitution. The alternative means of damping down the substitution of labour and capital for land would be to reduce these elasticities, but then these elasticities would either require changing for the simulations or would impose tight restrictions on the efficacy of the simulated policy intervention.

Figure 3.3 Consumption, Investment and Absorption (cumulative % changes from base)

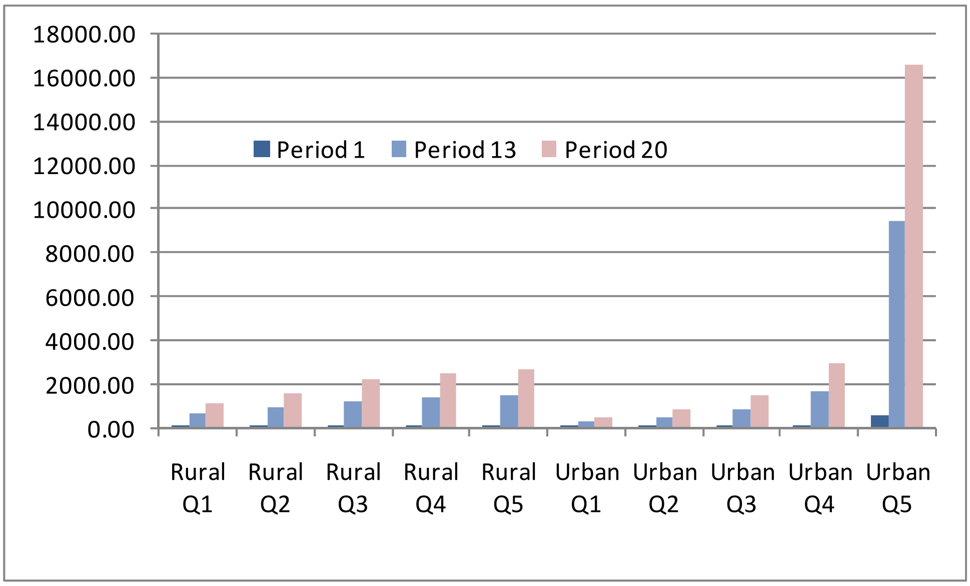


Source: Model baseline results.

Similarly the welfare results (Figure 3.4) are supportive of the macroeconomic results; welfare for each household group increases with the gains seemingly greater for rural households than urban except for the richest urban group. This does serve to flatter since the rural household groups contain larger number of households, which is also reflected in the fact that welfare increases by between 44% and 46% for rural households and between 61% and 63% for urban households.[10] But given that the factors owned by urban households are experiencing productivity gains, and therefore would be expected to demonstrate enhanced income growth, while the factors owned by rural households are not experiencing efficiency gains it is difficult to see immediately why the rural household seem to be doing as well as the welfare results suggest.

Figure 3.4 Household Welfare (Equivalent variation in million meticais)

[10] Urban Q4 is the largest (62.75%) while urban Q5 is second smallest at 61.2%.

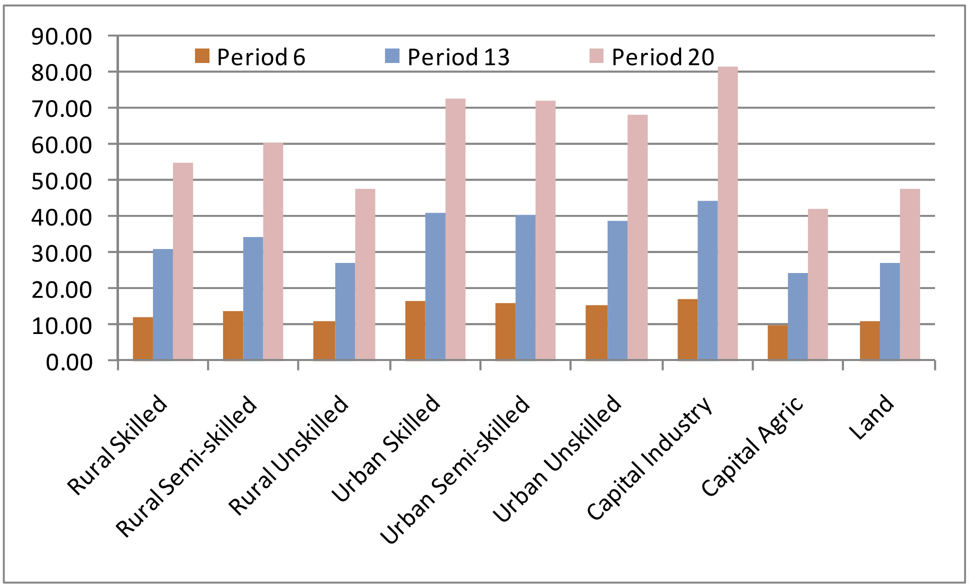


Source: Model baseline results.

Note: Local currency is expressed in million meticais, at values of 2002. The exchange rate at that time was US$1 = MZM23,679

Since the principle sources of household income are factor sales it is instructive to consider factor incomes (see Figure 3.5). At first sight these indicate that factor incomes increase by approximately similar orders of magnitude, but this is deceptive since land is in fixed supply and the other factors are accumulating and while capital accumulates it is evident that agricultural capital accumulation lags behind non-agricultural capital accumulation, see below. Also the income increases to urban labour are more rapid those to rural labour, which indicates that there are likely to be incentives to expand the provision of those labour types and shrink the provision of rural labour.

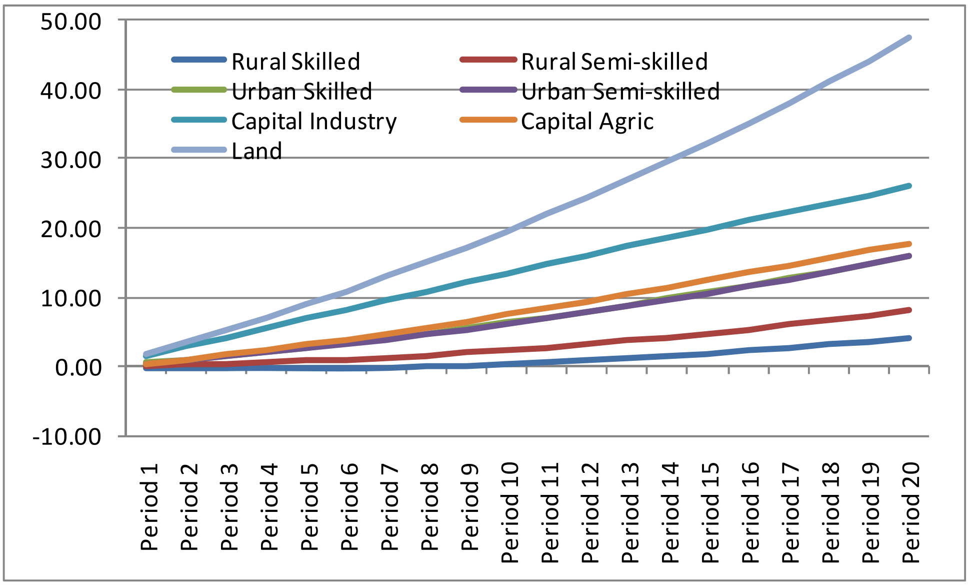
Figure 3.5 Factor Incomes (cumulative % changes from base)



Source: Model baseline results.

The forces driving factor incomes are a combination of factor quantities and prices. In this case the factor prices are the most interesting dimension. While the increases in the prices of rural labour and agricultural capital are lower than for urban labour and non-agricultural capital, respectively, the increases in the price of land are approximately twice those of other factors. Clearly land is becoming relatively scarcer and hence its price is being bid up despite the fact that imports of agricultural products are becoming relatively cheaper and exports relatively less profitable. Consequently returns to agricultural labour and capital are increasing less rapidly than returns to non-agricultural labour and capital; in the case of capital this is despite new capital being disproportionately allocated to non-agricultural activities owing to greater returns on non-agricultural capital.

Figure 3.6 Factor Prices (cumulative % changes from base)

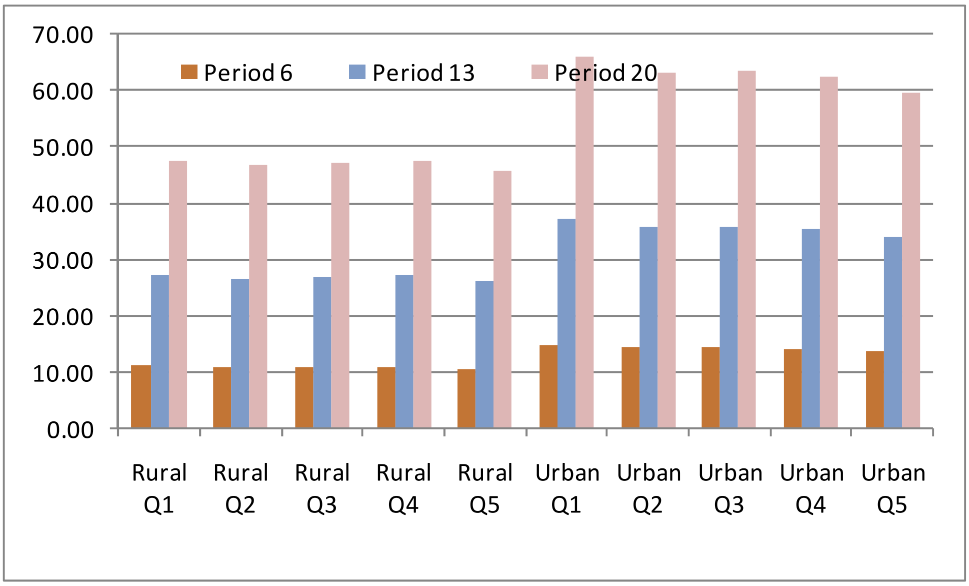


Source: Model baseline results.

These changes in factor prices and incomes are realised as changes in household incomes with the variable of interest in this case being disposable household incomes.[11] Disposable incomes, Figure 3.7, also seem to project a different image to that derived from the welfare measures (see above) since they suggest that urban household disposable incomes are increasing more rapidly that rural disposable incomes. Of itself such a result is not an issue since development would typically mean returns to expanding activities are greater than contracting activities such as agriculture, but in this instance it masks a major change.

Figure 3.7 Disposable Household Incomes (cumulative % changes from base)

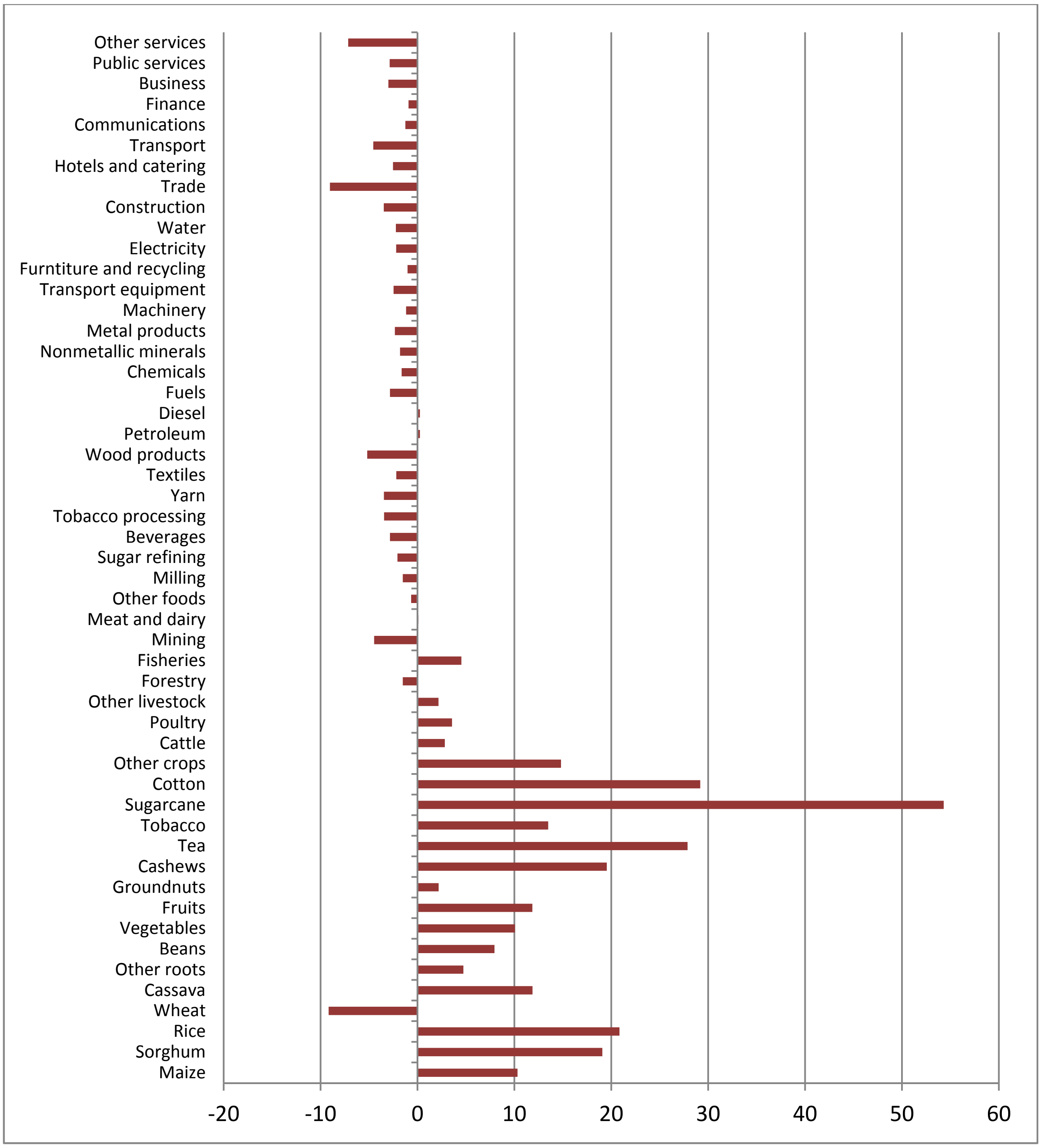
[11] These are defined as household incomes after direct taxes and savings; the latter two components are free to vary so as to achieve the desired market clearing and closure conditions.



Source: Model baseline results.

Disentangling the matter of how changing factor incomes and supplies, and wages rates are translating into household incomes and welfare requires exploring the impacts of the baseline scenario on consumer prices. Since the CPI is fixed the changes in consumer prices will involve both positive and negative effects, so what matters is the relative changes. The percentage changes in consumer prices over the 20 periods are reported in Figure 3.8. These demonstrate a very clear pattern; agricultural prices rise substantially — typically 10% or more, while non-agricultural prices all decline by relative smaller amounts. Among other things this indicates that the cost of living for relatively poorer households, for whom agricultural commodities command a bigger share of their expenditures, will be increasing and that the rates of returns to factors should, *ceteris paribus*, be increasing. Since the latter is not happening this indicates that but for price escalation wage rates and factor incomes for rural factors would increase by less than reported above and that consequently the increases in rural incomes would be much less.

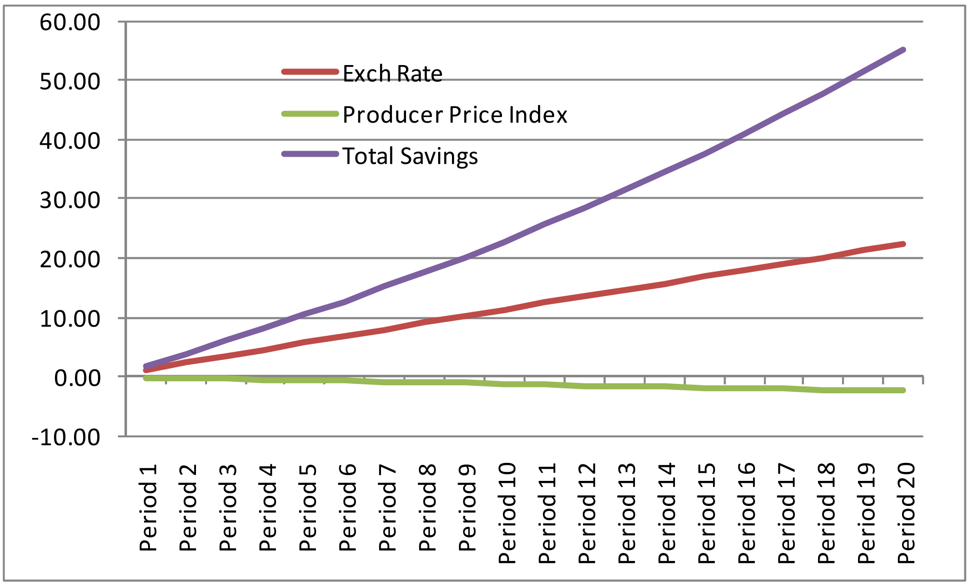
Figure 3.8 Consumer Prices (% changes from base)



Source: Model baseline results.

One important factor driving these results is the pronounced depreciation in the exchange rate. This depreciation is needed since the economy is losing competitiveness and the depreciation in the exchange rate is required so as to able to earn sufficient foreign exchange to purchase desired imports. As the exchange rate depreciates so the prices of imports are driven up and so also are the costs of intermediate inputs, which reduces the overall returns to factors. Moreover since investment commodities are relatively intensive in their use of imports so the cost per unit of new capital rises, which means that any given value of investment funds realises a smaller volume of new capital and this retards the accumulation of capital.

Figure 3.9 Exchange Rate, Savings and Producer Price Indices (cumulative % changes from base)



Source: Model baseline results.

In summary, the baseline results indicate that while the economy of Mozambique would be expected to prosper under business-as-usual, it will do so in a manner that further widens the rural-urban divide while benefiting disproportionately the owners of land at the expense of labour and capital employed in agriculture. Only the fact that land incomes are relatively widespread across rural households — no group receives less than 7% and no group (Q4) more than 30% — mitigates the impact on household incomes. But not only will the incomes of the poor be adversely affected, but they will also be affected by the changes in prices: typically food prices will rise appreciably and consequently poor households are likely to bear a disproportionate share of the burden.

Simulation

The simulation is implemented as a departure from the BAU baseline. The presumption is that unrequited foreign resources are used to effect changes in the technologies employed by Mozambique farmers. The range of options available for changes to agricultural technologies in Mozambique has been explored in the previous chapter. The available evidence indicates that the unrealised productive potential in Mozambique is theoretically substantial and is such as to indicate that some impediments must exist that go beyond knowledge, for example, imperfections in credit markets that militate against the necessary investments. In this instance it is assumed that these impediments can be relaxed through technology transfers and the use of aid funds to support the transition.

The analyses of the technological options available to adapt Mozambique agriculture provide a wealth of detailed information about technologies. It is not practical, however, to use such detailed information in a CGE model, which by definition is less disaggregated. Moreover in the context of a recursive dynamic model there are also limitations imposed by the necessity of allowing for relatively 'smooth' transitions for computational reasons. Thus while the simulations reported here derive from the review of technology options they have had to be simplified. Changes in productivity and efficiency used in the simulations are very much smaller than those suggested by the review and the assumed costs are appreciably greater: the intention being to bias the results against the adoption of the technology changes. Hence actual outcomes may well be better than the simulations suggest.

It is assumed that during the process of transitioning production technologies that there would be possible reductions in agricultural and land productivity that could be compensated by using agro-chemicals, especially fertilizers, as a land saving technology. These additional fertilisers are funded in the model by aid transfers.

It is assumed that agro-chemical and fertiliser use increases by 100% per unit volume of output over 5 periods — periods 2 to 6 — in 20% steps per period, this level of use is maintained for the next 7 periods and then declines in 20% steps per period over the next 5 periods. In the initial 5 periods the increased agro-chemical usage is assumed to arrest and reverse the decline in land productivity; raising land productivity growth to 1.5% per period by period 6. In the middle 7 periods — 7 to 13 — it is assumed that the combination of new technologies and agrochemical use initially raises land productivity to 2% per period and by the end of this phase to 2.5% per period and then, in phase three, that this rate of land productivity growth is maintained as the enhanced use of agro-chemicals is phased out. These rates of land productivity growth are well below those often achieved by agriculture and a long way below the potential gains suggested by the review of agricultural technology options. Labour and capital productivity is allowed to increase by 1% per period.

The additional purchases of agro-chemicals are funded by foreign transfers under the presumption that the agro-chemicals are valued in foreign currency units; the values of these transfers are updated in each period to allow for exchange rate effects. It is assumed that these transfers are financed through the government, i.e., by transfers of aid to the government.

On the expenditure side the transmission of the funds to the intended activities is achieved via the model structure but control over the precise use made of these funds by the government is not controlled *beyond* the government closure condition that constrains government other consumption expenditure to a fixed share of domestic final demand and fixes the internal balance.

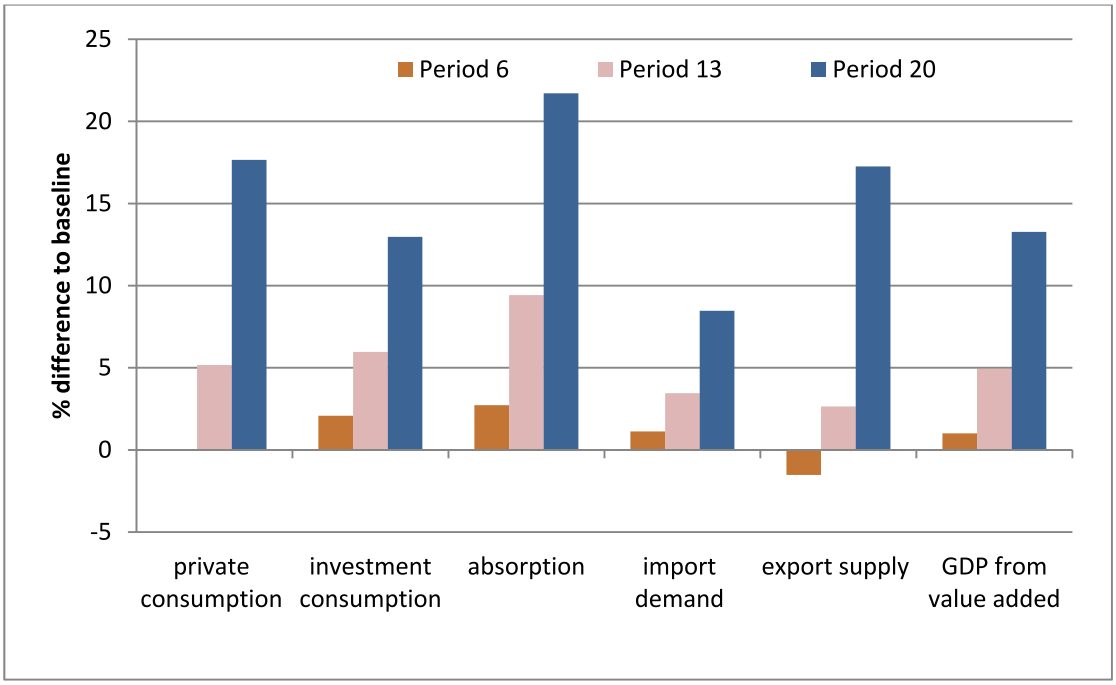
It is also assumed that the agricultural activities provide matched resources equivalent to the increase in agro-chemicals expenditure that are used to implement the investments necessary for the establishment of the new technologies. Thus questions about the operation of credit markets that may or may not allow farmers to make these investments are ignored.

The simulations are kept deliberately simple, to avoid obfuscation, and the impacts upon land productivity are also kept very substantially below the potential increases. By so doing the simulations are deliberately biased so as to understate the potential benefits.

Simulation Results

The results indicate that the introduction of such new technologies has the potential to produce appreciable socio-economic gains. The emphasis in a recursive dynamic model is on the deviations from the baseline, i.e., the impact of the shock separated from the BAU baseline; thus positive differences indicate benefits from the intervention and negative differences indicate costs. Over most of the results the trends are broadly even and consistent and hence the graphics below identify the differences after 6, 13 and 20 periods.

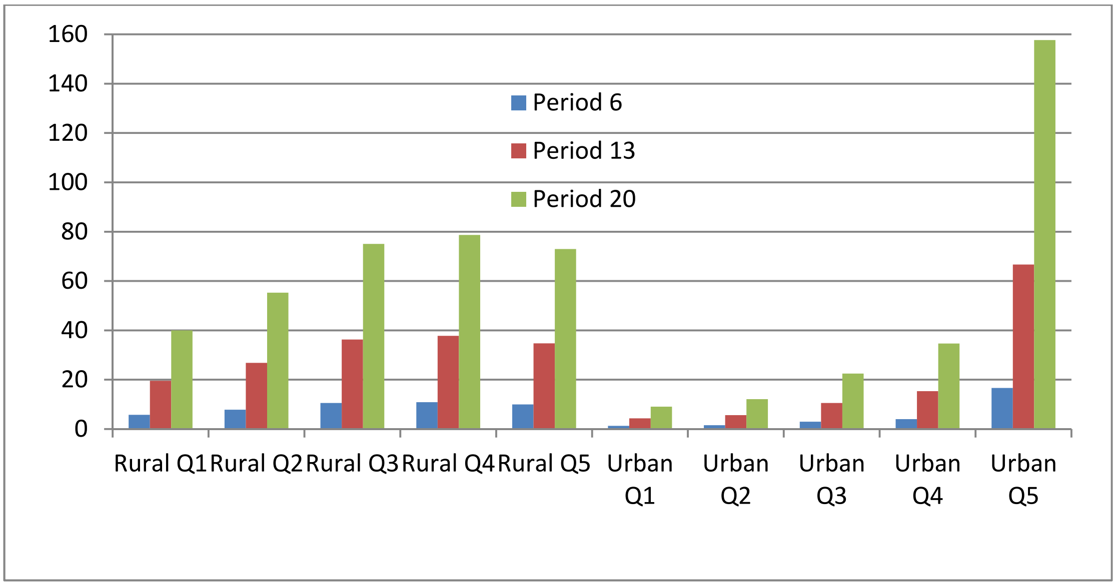
Figure 3.10 Real GDP and Trade (differences in cumulative % changes from baseline)



Source: Model simulation results.

The macroeconomic results indicate that there are small but non-trivial increases in all the key macroeconomic indicators, see Figure 3.10, this is especially so for the welfare indicator, absorption, and private consumption. A particularly notable impact is how the ordering of final demand components reverses with investment expenditure falling back relative to private consumption and absorption.

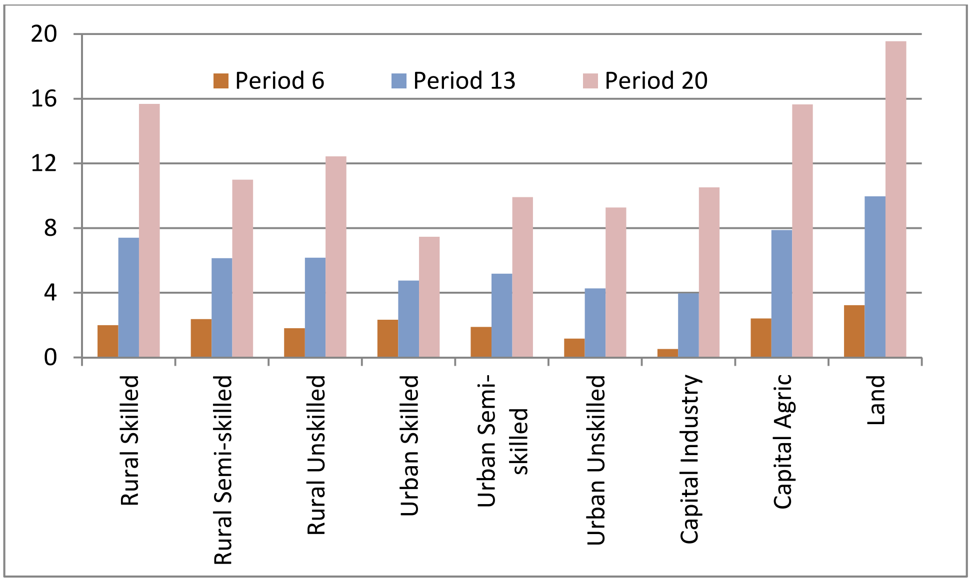
Figure 3.11 Household Welfare (differences in equivalent variation in millions Meticais from baseline)



Source: Model simulation results.

The impacts of these changes on household welfare, See Figure 3.11, are all positive and biased somewhat towards the rural households, which might suggest that the intervention is poverty alleviating. But the increases in the rural household welfare are not sufficient to reverse the results that the absolute and percentage changes in welfare are greater for urban households. The extent of the bias to urban households is reduced with proportionate welfare gains for rural households, in period 20, between 59% and 60%, while those for urban households are between 67% and 72%, with the richest household groups relative welfare gain falling back appreciably. Overall the welfare indicators demonstrate that while the intervention does not reduce the gap between urban and rural households it does reduce the extent to which the welfare gap increases.

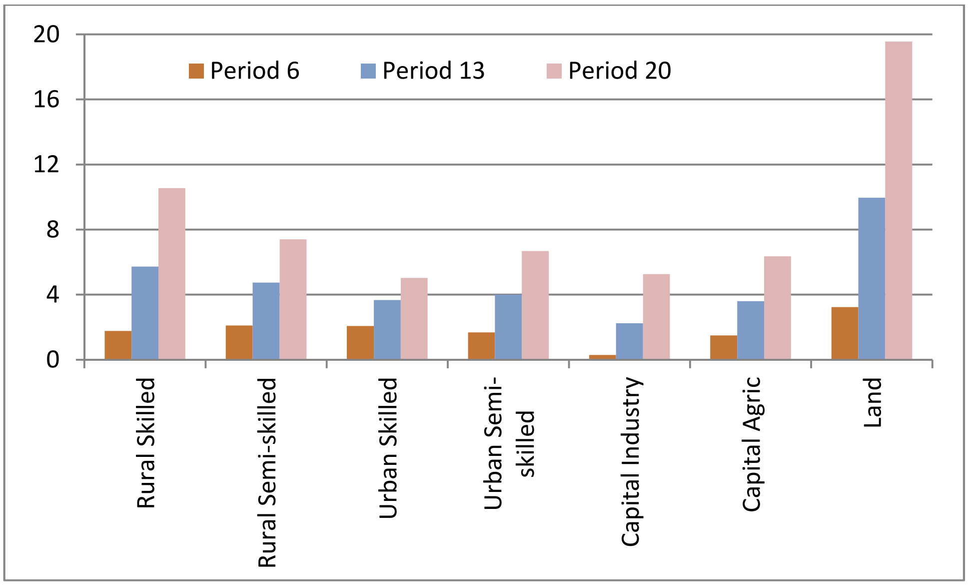
Figure 3.12 Factor Incomes (differences in cumulative % changes from base)



Source: Model simulation results.

This is reinforced by the extent to which relative returns to rural factors — rural labour, agricultural capital and land — all experience greater increases in factor incomes than the urban factors. In part this is driven by the increasing productivity of factors in agriculture raising the returns on agricultural capital and thereby inducing greater proportions of new capital to be invested in agricultural capital; this conclusion is intuitively comforting since it conforms to expectations that a land abundant country such as Mozambique would experience growth that emphasises the use of abundant factors. In this sense the intervention in technologies is nudging the economy towards a growth path more consistent with its endowments by relaxing the restrictions that induce the economy to move to a different growth path.

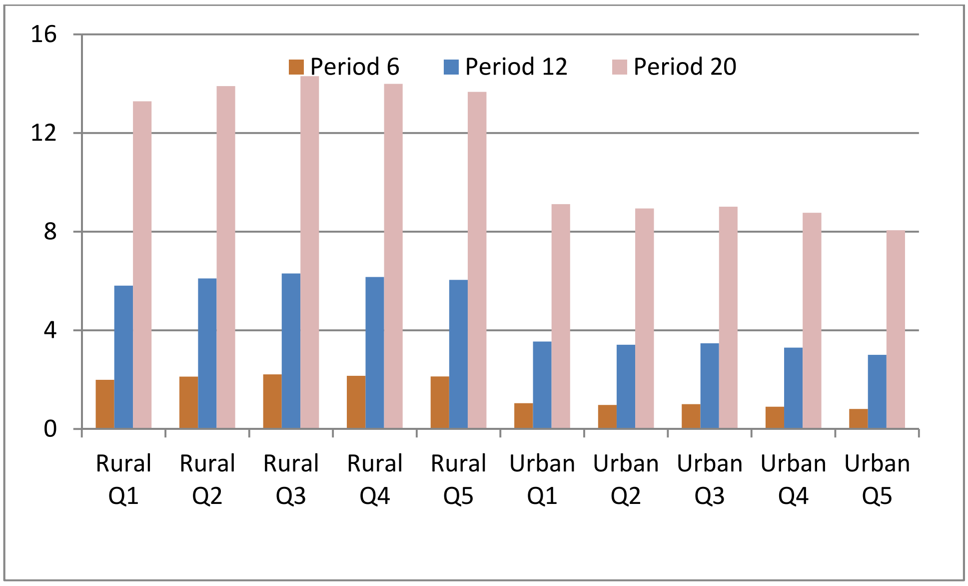
Figure 3.13 Factor Prices (differences in cumulative % changes from base)



Source: Model simulation results.

This conclusion is reinforced by the results for factor prices, Figure 3.13. The interventions see all factor prices increase by small amounts: between 0.25% and 0.5% per period for labour and capital and by about 0.75% per period for land. But the driving forces are now different. The increases in the price of land, and other factors used by agricultural activities, is driven as much by the increased productivity of land generating increased returns to land, as by increases in demand, coming from income growth, driving up factor prices due to factor scarcity.

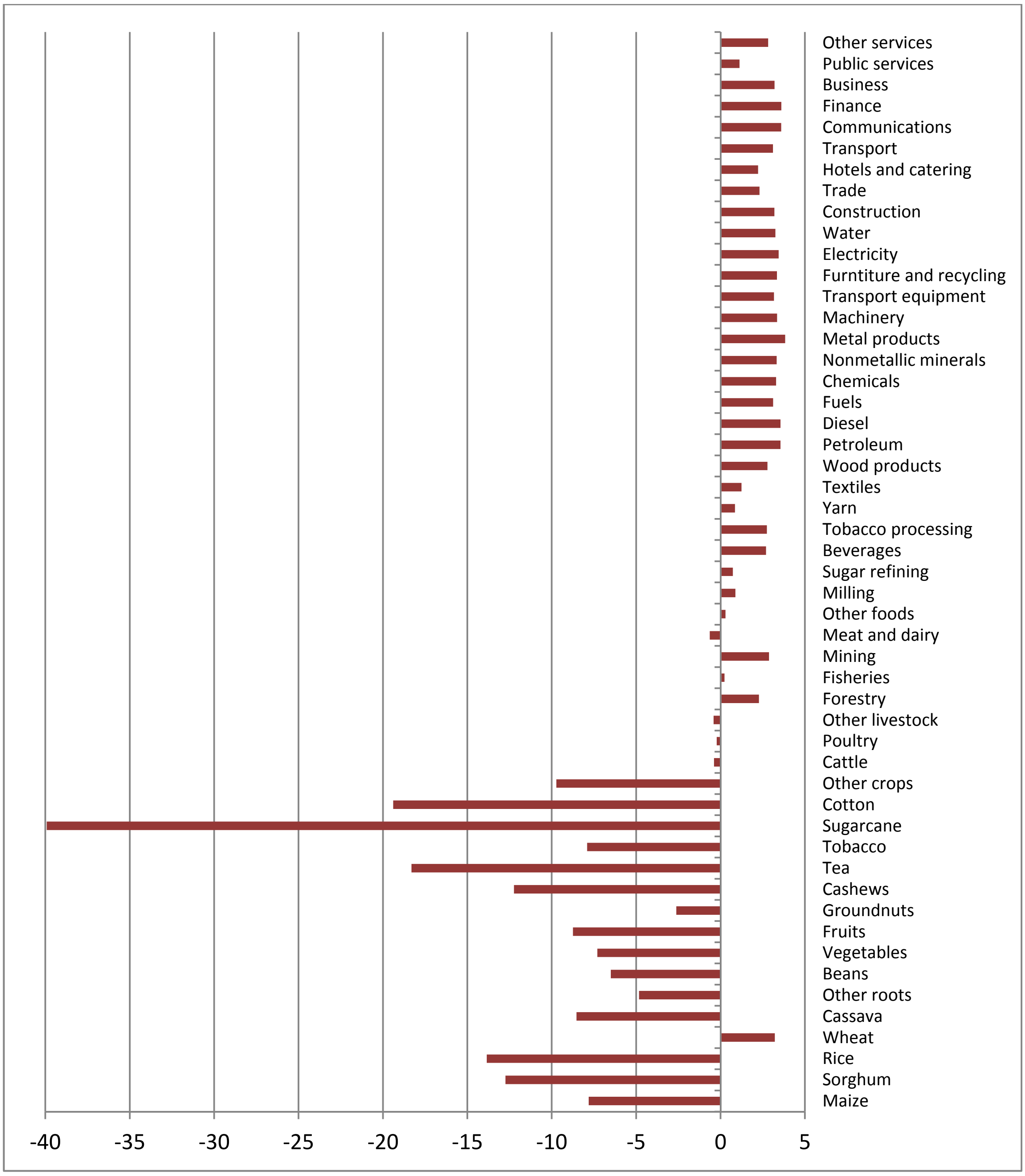
Figure 3.14 Disposable Household Incomes (differences in cumulative % changes from base)



Source: Model simulation results.

The increases in factor incomes and prices together with the reduced bias against agriculture translate into greater proportionate increases in disposable incomes for rural households, see Figure 3.14. In absolute terms these shifts are not very large, but rather it seems that reducing the bias against agriculture based activities serves to reduce the extent to which rural populations are likely to be induced to migrate to the urban areas.

Figure 3.15 Consumer Prices (differences in % changes from base)

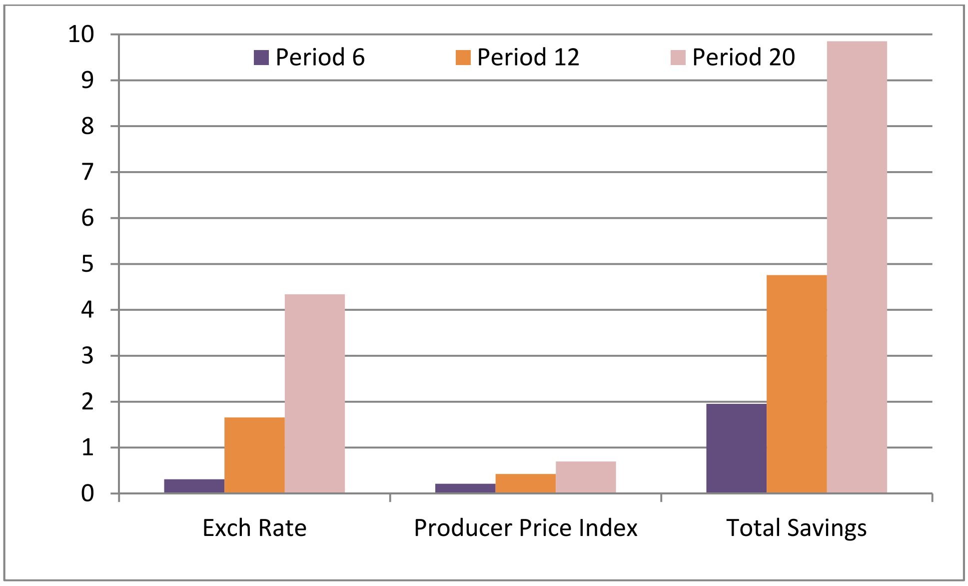


Source: Model simulation results.

Figure 3.15 reports a particularly interest consequence of the simulations. The relaxation of the constraints on the agricultural activities reverses the pattern of price changes; the changes in relative agricultural prices are now typically negative while those for non-agricultural commodities are positive.

This suggests that relaxing this constraint on agriculture has the potential to help reduce poverty through both higher incomes and a relative decline in the prices of food products.

Figure 3.16 Exchange Rate, Savings and Producer Price Indices (cumulative % changes from base)



Source: Model simulation results.

The intervention significantly increases savings that feed through into increases in investment that in turn generates a virtuous circle of increased investment, increased growth and then further increases in investment. In the circumstances it may be expected that the depreciation of the exchange rate might have been reversed but there are several forces at work. First, the redirection of investment towards the agricultural activities means that the expansion of non-agricultural activities is reduced, and since non-agricultural sectors — for example, aluminium, electricity, gas — are the main sources of exports (93% in the base period), this impacts on exports. Second, the boost to investment increases import demand for capital goods. Third, imports of agro-chemicals increase sharply thereby further expanding import demand. And fourth, the extra growth induces increases in import demand. The combined effect is a minor deterioration of the exchange rate, although this seems a minor price to pay for the improved economic performance.

4. Conclusions and discussion

4.1 Summarising: the story so far

The bulk of GHG emissions in rural Mozambique come from clearing forest and from burning savanna, rather than from fields. Nevertheless much of forest clearance, and some of the burning, takes place to create cropland. Hence intensification of farming could help to mitigate pressure on the forests and savanna.

As a first step towards a more intensive cropping with low emissions and some carbon capture, moving to minimum tillage with use of trees to fix nitrogen is a relatively simple change to current practices by the three million small farmers who dominate the farming of Mozambique. Later more complex agro-forestry systems with higher yields, low emissions and carbon capture would be an option.

Making the first change might involve little more than an extended extension effort, since the changes recommended would increase gross margins and returns to labour for most of the corps grown by small farmers; accompanied by small public subsidies to pay for tree seedlings and equally small grants to farmers prepared to switch to the proposed system.

A general equilibrium model of the Mozambican economy has been used to explore the consequences of farmers making these changes and of the public investment involved, through time for up to twenty years. It model shows that technical improvements in agriculture will increase GDP — as well as raise investment, exports, and private consumption. All households are better off under this scenario, especially rural households.

In more detail, what are the effects on poverty and food security?

4.2 Effects on poverty and food security

All five income groups in rural areas see their incomes rise above what would otherwise have happened over 20 years, by more than 30% over the business-as-usual baseline. Urban households also gain but by less over the baseline, by around 20%. Given that in the baseline run urban households gain so much more than rural, the difference with the changes is not sufficient to overcome the urban advantage. The key point, nevertheless, is that with the proposed changes there are gains to the poor in both rural and urban areas; and that the interventions modelled favour rural groups more than urban.

These gains arise from two outcomes: the demand for rural factors of production rises — especially for rural and urban unskilled labour, typically the main way the poor earn their livelihoods; and increased relative prices for factors of production, of which the most notable are an 21% increase in that for rural semi-skilled labour, and a 55% rise in the value of land, more than what might have been expected in the baseline.

In income terms, then, the interventions must reduce poverty over and above what would have happened given business as usual.

Income is principal determinant of individual and household food security; another is the price of food. Here the interventions also make a difference in favour of poor consumers. Whereas in the baseline by year 20 the prices of staple foods rise by 5% to 22%, the intervention mitigates this: the rises are now in the range 2% to 13%. The increases in staples food prices are small compared to the income rises projected of 140% or more.

Hence the interventions proposed should reduce both poverty and hunger, for both urban and rural poor, with slightly greater effect in rural areas.

4.3 Policy implications

The model confirms the intuition that in a country where almost two-thirds of the population live in rural areas, most with farming as a major activity, that measures to improve the productivity of agriculture have broad benefits — and benefits that feed across from rural to urban areas. If these are the results for the quite modest productivity increases that went into the model, much greater gains arise if there were an even stronger push for agricultural development — assuming, of course, that this did not require a disproportionate increase in public investment. Changes designed to reduce emissions, and to capture carbon on farm, are also likely to have broad benefits: the modelling reveals few trade-offs at this level of public intervention.

This invites consideration of just how much should be publically invested in agriculture. Recent government spending on agriculture runs at 4.6% to 5.6% (World Bank 2011), about half the level of 10% that was agreed as desirable by the African Union in 2003 meeting in Maputo (African Union 2003). The modelling here suggests scope to increase those investments. In particular, the public expenditure review (World Bank 2011) for agriculture indicates a particularly low level of spending on agricultural research: around 0.24% of agricultural domestic product — a level than can be compared to 2% or more for most OECD countries. This is a critical limitation: for lower emissions agriculture, much needs to be done to develop and test farming systems — potentially a more complex endeavour than, for example, producing higher yielding seeds and animals.

Another policy challenge, however, will be to find ways not only to encourage lower emissions agriculture, but also to discourage conversion of forest and bush. How might this be done? The simplest instrument would be a ban on such clearance. This would be difficult to implement and probably overly repressive. An outright prohibition would be unlikely to be respected, as well as being seen as unfair to those who currently have little land but would like to expand their farms, and inefficient when there is good quality land that could be converted to cropping. Any information that such a ban was imminent, moreover could lead to people clearing all the land they believe they are entitled to as a pre-emptive measure, thereby making things worse.

The other extreme would be to offer incentives sufficient for farmers to change their behaviour; such as an annual payment conditional on not clearing forest or burning savannah. The main problem with this is cost: payments would need to be greater than the value of current practice, and would need to be paid to more than three million farm households. Even US$100 a household a year might not be sufficient, yet a cost of US$300M to the government would be more than could be afforded. In addition, compliance would need to be monitored across the vast areas of rural Mozambique.

Better would be to entrust this to communities. For example, for each locality, a land use plan could be devised that aims to limit additional clearance for cropping. It would be unrealistic to prevent all additional clearance, but nationally a limit might be set — say, 20% more crop land, the broken down by province and district according to land use suitability. District conventions would then further break down the allocations by communities.

Each community would thus have a land bank to allocate to those wanting additional land. This might be allocated on the basis of need. Communities might agree, for example, that those having less two hectares having the right to clear land up to that limit; and beyond that, and within the overall quotas, additional land would be assigned on payment of an annual rent to the community — perhaps charging $100 a hectare a year; but with local freedom to raise this amount to match the returns to land. Some communities might then enter into negotiations with larger-scale farmers seeking land and gain revenues.

Similarly, bush burning might be allowed on a limited scale and early, when burning can apparently be controlled and is less likely to cause wildfires. This would be accompanied by community education, and local management of any burning (see Hoffmann 2009 for a detailed proposal for Buzi District, Sofala).

There may be other options: the point being that debate on these should begin.

4.4 Modelling and research: what next?

There are major difficulties with the derivation of economic estimates of the gains from technology change. The traditional model for agricultural technology change was public sector research and development (R&D) expenditures buttressed with extension services that disseminated information about new technologies; typically this approach depended on the presumption that farmers were rational and relatively rapid adopters of these technologies where other constraints, such as imperfect credit markets, did not impede adoption. There is extensive evidence that the rates of return realised by this approach have been substantial, the classic examples of this vision being the 'green revolution' and the Consultative Group on International Agricultural Research (CGIAR). By and large this approach has been driven by a high-input high-output technology that has been transferred or adapted from the agricultural systems found in developed market economies. But it is arguable that agricultural systems heavily dependent on non-renewable energy inputs are potentially problematic in a world where climate change is an important consideration. Despite the move away from the emphasis on public sector R&D it is arguable that the underlying model has seen little change although it has been suggested that the distribution of the benefits has changed markedly towards private research companies.

For economic modelling, the traditional approach is relatively straightforward. Input and cost structures change in well-known ways: there are reasonably deterministic relationships between choices of inputs and volumes of outputs that can be transferred from trial plots to field scale. Combining these technical relationships with some simple assumptions about adoption rates, often following a sigmoid function, generates a series of economic estimates. Such relations can be relatively easily specified in detailed partial equilibrium or multi-market models and broader brush CGE models. One major reason why this can be achieved so easily is the presumption that there are smooth transitions.

Step changes to agricultural technologies present a far more challenging problem for economic evaluations. Input and cost structures change in ways that are not that well understood, the relationships between inputs and outputs are less clear, the transitions from trial plots to field scale are heavily dependent upon the human capital of farmers who are often being urged to depart radically from their own experiences. Hence many of the assumptions classically made in economic evaluations are less easily justified.

This suggests that analyses of agricultural system changes cannot rely on the use of single dimension economic tools. At the very least it appears that there are strong arguments for analyses on four levels simultaneously. First, at the village level models can emphasise the micro-level details that determine the adoption, implementation, risk profile and efficiency of the 'new' technologies. Second, at the regional or local market level analyses can capture the interactions and effects generated by the adoption of 'new' technologies that almost inevitably will experience a range of different adoption patterns. Third, at national level the effects of the 'new' technologies will impact upon the whole economy through aspects such as trade balances, rural-urban migration, the cost of living and competitiveness; and where developments within the economy will impact on the aggregate demand and supply of food. And fourth, internationally where the impacts across different regions and economies will interact to influence the global patterns of production, demand and trade.

At this point it seems that if funds are to be directed towards shifting agricultural technologies towards practices with low emissions then village studies on the economics of such technologies would be the first priority. Not only would such studies focus on the immediate impacts of the technologies on farmers, arguably the most vulnerable people in this process, they would be more able to adopt a more nuanced approach, since the need to accommodate the analyses within a set of constraints imposed by other considerations would be less pressing, and they would provide the information bases upon which other more macro analyses could be conducted.

4.5 Are results from Mozambique likely to apply to other developing countries?

Mozambique is typical of countries that have relatively abundant land of at least medium potential, with low input agriculture with low yields per hectare. This would apply to several other countries in Sub-Saharan Africa, such as Angola, Congo and DR Congo, Sudan, Tanzania and Zambia. In some parts of Latin America and Southeast Asia this would also be true. It would not reflect conditions in many the more densely-settled parts of Asia.

The most important results from this work are that there would appear to be few trade-offs between reducing agricultural emissions and raising production and productivity. This may surprise some readers, so why is this? The answer lies in the very low yields per unit area in much of Mozambican farming, while there is the potential to raise these by large fractions.

Of course, there may be implicit trade-offs: the model was not used to address the question of what would the maximum increase of agricultural outputs that might be achieved for a given level of public and private investment, regardless of emissions. While an interesting academic question, it is less relevant for policy-making as and when the mitigation of GHG emissions becomes a critical objective for all countries in the world — without which holding global warming to two degrees Centigrade or less will be very difficult.

The point here is that where farming is carried out at such low intensity, when the time comes to give reducing emissions high priority, there will not necessarily be a threat either to the livelihoods of farming households, many of them currently poor, or to goals of raising agricultural output. Which is not to say that it will easy to achieve a double win: on the contrary, more detailed agricultural research will be required, backed up by appropriate policies to encourage changes, and implemented with determination based on a long-term vision shared by governments, citizens and farmers.

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Appendix A: Adjustments to STAGE model

Core Model Adjustments

Only one adjustment to the standard STAGE model was required for this study. The efficiency parameter governing the relationship between stocks and flows of activity specific uses of factors ($ADFD_{f,a}$) is treated as a set of parameters in the standard model. In this variant of the model these are treated as variables so that the modelled can be calibrated in a recursive dynamic mode. To maintain the equation/variable balance the following equation was added to the model:

$$ADFD_{f,a} = \left[\left(adfdb_{f,a} + dabadfd_{f,a}\right) * ADFDADJf_f * ADFDADJa_a * ADFDADJ\right]$$

where

$ADFD_{f,a}$ = the efficiency factor for factor f in activity a;

$adfdb_{f,a}$ = the efficiency factor for factor f in activity a in the base period;

$dabadfd_{f,a}$ = the absolute change efficiency factor for factor f in activity a;

$ADFDADJf_f$ = a multiplication adjustment efficiency factor for factor f in all activities;

$ADFDADJa_a$ = a multiplication adjustment efficiency factor for all factors f in activity a;

$ADFDADJ$ = a multiplication adjustment efficiency factor for all factors f in all activities.

This did require the additional of a number of additional lines of code simply to ensure this equation block operated as intended.

This modification involves no changes to the underlying behavioural relationships.

Recursive Dynamics

In this class of models, as implemented using the General Algebraic Modelling System (GAMS), can be implemented as a series of comparative static models solved sequentially, in a loop, by updating the dynamic components between each solve statement. This was the method used here.

The core endogenous updating relationship was for capital. The amount of new capital of type *k* in a period is

$$delkap_k = \left(\frac{GFCF}{PK_k}\right) * invkapsh_k$$

where

$delkap_k$ = change in supply of capital type k;

$GFCF$ = gross fixed capital formation;

PK_k = price of capital type k;

$invkapsh_k$ = share of capital type k in GFCF.

Total new capital is determined by the value of investment funds and the price of new capital, which can, and do, change period by period and the share of new capital allocated to each type of capital stock. These shares change according to the relative profitability of capital in the previous period, i.e.,

$$invkapsh_k = kapsh_k * \left(1 + capmob * \left(\frac{(wfkapav_k - wfkap)}{wfkap}\right)\right)$$

where

$kapsh_k$ = shares of existing capital type k in all capital;

$capmob$ = capital mobility parameter;

$wfkapav_k$ = average price paid for the use of capital type k;

$wfkap$ = average price paid for the use of all capital.

The ratio of the returns to different capital types to average returns to capital drive the allocation of new capital between different types and the extent of the response is determined by the capital mobility parameter; the large the parameter the more responsive is the reallocation to change sin returns to different types of capital.

Database Adjustments

The Social Accounting Matrix (SAM) used in this study was structured to conform to the properties of a slightly different CGE model so two minor changes were required for its use in this study.

- The trade and transport margins were reallocated as intermediate input costs rather than as components of the 'wedges' between basic and purchaser prices. This change has no implications for the results of this study since a maintained assumption was that these trade and transport margins retained a constant rate.
- The SAM contains transactions that record home production for home consumption (HPHC) commodities; these were aggregated with the matching commodities. The implicit presumption behind this is that HPHC remains a constant proportion of household demand for agricultural commodities. This may have a minor effect on the results but since the incentives to switch between HPHC and marketed commodities were not altered as a direct effect the effects will have been minor. The simplification however had benefits of improving model performance in a recursive dynamic context.
- Some intra institutional transactions were reallocated as incomes/expenditure to expenditures/incomes. This has no impact upon model performance but simply captures minor differences in model formulation.

It was deemed appropriate to make two substantive changes to the database due to the limitations the existing data structure placed on the intended analyses.

- All factor incomes from capital were passed through the incorporated business enterprise account, but farmers, especially small family farmers and peasant farmers are not incorporated business enterprises. Hence additional data were used to reallocate factor incomes from capital direct to the rural households; thereby ensuring that the functional distribution of income was consistent with the way such incomes are distributed. Without this adjustment the distribution of income within the simulations would have been biased.
- In the original database there was only a single account for the factor capital. Hence agricultural and non-agricultural capital was separately identified. This (a) segmented the capital accounts, (b) allowed for the injections of capital direct to agricultural activities without it leaking out very quickly to the no agricultural activities and (c) allowed the separate accumulation of agricultural and non-agricultural capital.