Land Use Planning for Enhanced Resilience of Landscapes (LAUREL)

Land Use Simulation Platform: Approach Paper

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Executive Summary

Mozambique faces numerous challenges including high rates of poverty, low agricultural production and depletion of natural resources and their related services. The Governments of Mozambique and their development partners have a number of options to respond to challenges, including through investments in landscape restoration, agriculture intensification, road network improvements, etc. A key question is: what mix of interventions (e.g. policy reforms, investment programs) should be adopted, and where should they be implemented to ensure that landscapes deliver development benefits in a lasting manner?

The Land Use Planning for Enhanced Resilience of Landscapes (LAUREL) program led by the World Bank aims to support integrated decision making for landscape management in Mozambique, through improved spatial data on land degradation, and through the development of prototype platform (LANDSIM) for simulating, evaluating, and re-orienting as appropriate, land use and land use change processes.

In this project, we will follow several key steps: i) estimate population and population density; ii) describe household architecture, production practices and natural resource use, iii) link the households to the economy and markets, iv) incorporate climate change effects, v) design future scenarios, run model and link to policy. Several strategic output variables have been identified, but are subject to change in discussion with local stakeholders, including: land use change, agricultural production.

The general framework proposed in this project is to develop a spatially explicit land-use modeling prototype that focuses on the rural household as entry point of the modeling framework. The methodology relies on compiling and verifying national datasets, developing dedicated household model based on population statistics and surveys, projection of location, and share between rural and urban population. Another key aspect of this work is to design realistic decision rules at household level that impact land use and change and formalize their links with local and global economy. This key component will be performed by doing Mozambique literature and database review, carrying out field survey and gathering local knowledge. Others steps include the integration of other model such as land degradation outputs and crop yield models into one user friendly platform. Simulation will include climate change and selected national policy scenarios. Finally, we will validate or improve the LANDSIM outputs during national workshops and publish the results on WebGIS portal. To meet policy expectations we will follow two driving principles: start simply and add complexity progressively in the model development; and include local institutions and expertise in all aspects of the model design and building, scenarios development, and results analysis.

We will use DINAMICA EGO,[1] a simulation modeling software developed at the Federal University of Minas Gerais, Brazil, we will also test another and recent modeling platform called Ocelet,[2] which provides complementary features and will be used for spatializing crop yields. The development of the prototype will be based on several years of project implementation in Zambezia by ETC Terra and its partners.

The outcome of this prototype is to estimate the impacts of government policy on household welfare as well as agricultural production and environmental impacts. The models are designed specifically to be accessible and understandable to policy makers. And all modeling design and implementation will be done in coordination with MITADER and other local partners.

[1] http://csr.ufmg.br/dinamica
[2] http://ocelet.fr/ocws/index.php?lang=en

Sumário executivo

Moçambique enfrenta inúmeros desafios, incluindo altas taxas de pobreza, baixa produção agrícola e depleção de recursos naturais e serviços ambientais relacionados. O Governo de Moçambique e seus parceiros de desenvolvimento têm levado a cabo uma série de ações para responder a esses desafios, especificamente através de investimentos em restauração de paisagens, intensificação da agricultura, melhorias da rede rodoviária, etc. Uma questão-chave é: que combinação de intervenções (por exemplo, reformas políticas, programas de investimento) devem ser adotadas e onde elas devem ser implementadas para garantir que as paisagens do país continuem a oferecer benefícios ambientais às populações que vivem no meio rural?

O programa de Planejamento do Uso do Solo para a Resiliência de Paisagens (LAUREL) liderado pelo Banco Mundial visa apoiar a tomada de decisão integrada para o gerenciamento das paisagens rurais de Moçambique, através do levantamento de dados e modelagem da degradação da terra e do desenvolvimento de uma plataforma protótipo (LANDSIM) de simulação de mudanças no uso da terra, para com isso avaliar e reorientar os processos de mudança de uso do solo e seus potenciais impactos ambientais e sociais.

Neste projeto, seguiremos as seguintes etapas principais: i) estimar a população e a densidade populacional rural; ii) descrever o modelo de agricultura familiar, as práticas de produção e o uso de recursos naturais, iii) vincular os agregados familiares à economia e aos mercados, iv) incorporar os efeitos das alterações climáticas; v) desenhar e avaliar cenários futuros visando informar às principais políticas públicas em debate.

A abordagem proposta neste projeto centra-se no desenvolvimento de um protótipo de modelagem espacialmente explícito do uso da terra focada no agregado familiar rural. A metodologia baseia-se na compilação e verificação de conjuntos de dados nacionais, incluindo estatísticas populacionais e pesquisas rurais para a projeção da população rural e sua localização espacialmente explícita. Outro aspecto fundamental deste trabalho consiste em modelar as regras de decisão dos agregados familiares que determina o uso e mudança no uso da terra, bem como seus vínculos com a economia local e global. Esta componente chave será realizada a partir de uma revisão de literatura e compilação de banco de dados, aliada às pesquisas de campo com o objetivo de reunir conhecimento local.

Outras etapas incluem a integração de outros modelos, como os que geram estimativas de degradação da terra e produtividade de culturas, em uma plataforma amigável para usuários leigos. A simulação de mudanças no uso da terra analisará os impactos de cenários climáticos e de políticas nacionais. Finalmente, vamos validar e aprimorar os resultados da plataforma LANDSIM através de oficinas nacionais e por fim publicar os resultados do nosso trabalho em um portal WebGIS. Para atender às expectativas políticas, seguiremos dois princípios no desenvolvimento da plataforma: Adição progressiva de complexidade no desenvolvimento do modelo; e a inclusão de instituições e conhecimentos locais em todos os aspectos do modelo, desde sua concepção ao desenvolvimento de cenários, operação e análise dos resultados.

Usaremos o DINAMICA EGO, um software de modelagem de simulação desenvolvido pela Universidade Federal de Minas Gerais, no Brasil. A esse software, acoplaremos a plataforma Ocelet, a ser usada para espacializar os rendimentos de culturas agrícolas. O design do nosso modelo será construído com base na experiência de vários anos de implementação de projetos de desenvolvimento na Zambésia pela ETC Terra e seus parceiros.

O desenvolvimento desse protótipo permitirá avaliar os impactos positivos e negativos de políticas públicas propostas sobre o bem-estar doméstico, bem como a produção agrícola e impactos ambientais. Os modelos são projetados especificamente para serem acessíveis e compreensíveis para os formuladores de políticas públicas. Todo o projeto de implementação da modelagem será feito em coordenação com o MITADER e outros parceiros locais.

1.Introduction

1.1 Land use change in Mozambique

Although it has slowed in the past couple years, Mozambique has registered an impressive record of economic growth in the past few of decades. During that time Mozambique has been a darling of development, even listed in a recent publication as one of Africa's [economic] Lions[3]. The picture of land use, however, while changing as well, has remained stubbornly linked to subsistence production, poverty[4] and a lack of economic progress. The recent economic slow-down, which has resulted in a spike in food prices has been felt most keenly by the poor.

With the current population of 27 million expected to increase to 41 million by 2035,[5] the impact of these households on the environment may be significant. At the same time, if access to markets, technology or health services do not improve it is likely that poverty and food security risks will remain. Furthermore, if soils erode, land productivity declines and climate-induced crop yield reductions become more frequent, rural households that are dependent on the informal economy will see a higher risk profile, and the likelihood of food insecurity will increase.

Mozambique, however, is often described as having tremendous agricultural potential, with an estimated 36 million ha of arable land (45% of the country), of which only 5 million are said to be currently under production (World Bank, 2016).[6] Furthermore, some estimates put agricultural potential at a USD 570 Billion dollars[7] (for reference the agriculture sector produces 3.5 billion annually).[8] But, while agriculture delivers a significant 25 % of the country's GDP, it employs an overwhelming 80 % of the population.

The challenge of transforming an agricultural sector where 80 % of the farmers produces only a quarter of the marketed volume is significant, and the task ahead of the Mozambican government daunting. There has been effort on the part of the government

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[3] Jones, S. and F. Tarp. 2016. Mozambique: Growth Experience through an Employment Lens. In *Africa's Lions*, H. Bhorat and F. Tarp eds. Brookings Institution Press, Washington, D.C. 282 pgs.

[4] Baez, J., J. Nijhoff, G. Elabed, A. Thiebaud & C. da Matta. 2016. *Why is Agriculture not more effective in reducing Poverty in Mozambique? Understanding the Constraints to Productivity and market-based Agriculture*. World Bank. 54 pgs. At only 0.26, Mozambique's growth elasticity of poverty reduction is half that of the rest of sub-Saharan Africa (Para 34, pg 29.)

[5] INE - http://www.ine.gov.mz/estatisticas/estatisticas-demograficas-e-indicadores-sociais/populacao

[6] World Bank. 2016. *Republic of Mozambique: Systematic Country Diagnostic*. Report No. 103507-MZ 138 pgs.

[7] World Bank. 2016. *Accelerating Poverty Reduction in Mozambique: Challenges and Opportunities*. Paragraph 54, page 38.

[8] Larson D.F. G. Elabed, M. Norton, & S. Murray S. 2017. *Agricultural productivity, Agriculture productivity, market access and vulnerability in Mozambique: Insights from spatial analysis*. World Bank.

to encourage large-scale agricultural production, but the efficacy of these investments remains in doubt as well the spillover effect, or technology trickle down effect,[9] albeit with some evidence of local access to fertilizer and pesticide technology.

Details about the context of land use and opportunities for rural development are sometimes oversimplified and abundance does not necessarily equal to opportunity in the face of cultural, bureaucratic and economic hurdles.[10] It is therefore imperative that development planning be supported by ex-ante analysis that focuses on the relationship of the rural population with the landscape and with the interaction, or lack thereof, of connection with the formal economy.

1.2 The LAUREL program

The World Bank has initiated a program of technical assistance in Mozambique called Land Use Planning for Enhanced Resilience of Landscapes ((LAUREL), which is intended to support integrated decision making for landscape management across sectors and levels of government. The premise of the program is the observation that improved tools for land use planning can make a critical contribution towards answering the questions listed above. The LAUREL program is intended to improve land use planning in Mozambique, which will then be consolidated and scaled up through complementary efforts and financing channels.

There are two components to this technical assistance: A land degradation baseline estimation and a land use simulation platform hereby called LANDSIM prototype.

This document describes the Technical Approach to be undertaken in the development of this Land Simulation Platform which **will be a simulation model of land use and land use change focused on household production and consumption activities on the national landscape** with exogenous links to the overarching economic changes in the national economy.

The LANDSIM prototype will provide a tool for national stakeholders to design consistent and relevant policy and support on-going land use planning efforts, such as the *Plano National do Desenvolvimento Territorial* (PNDT) led by MITADER, the *Plano Especial do Ordenamento Territorial*, and Growth Corridor development.

In the first section, this Approach Paper presents the Strategic Output Variables (SOV) the model will produce, a preliminary description of the scenarios, and the expected integration into country specific policy processes. We then present the initial technical description of the simulation platform, with linkage between model components,

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9 Deininger, K., F Xia, A. Mate & E. Payongayong. 2015. *Quantifying Spillover Effects from Large Farm Establishments: The Case of Mozambique*. World Bank Policy Research Working Paper 7466. 30 pgs.

10 Chamberlin, J., T.S. Jayne, & D. Headey. 2014. Scarcity amidst abundance? Reassessing the potential for cropland expansion in Africa. *Food Policy* 48:51–65

software, and the methods to analyze climate change effects on land use change. The last section describes the dataset requirements and work plan for a successful implementation of the prototype.

2.The Simulation Platform

This section describes the tool to be developed and highlights our plans for building local partnerships and ownership of the process and results, which are a key elements of success in this program.

2.1 General framework

The platform will comprise both ecological and economic models, integrating household economy as the main entry point. It will incorporate layers of spatial data and address a suite of policy questions.

Below we show a conceptual diagram depicting the main model components that make up the framework for the platform. It includes data layers, a population forecast and spatial allocation model, a household model composed of attributes and decisions rules, that will interact with both the crop yield model and land model. Spatialization will be enabled using proximate spatially explicit biophysical variable (e.g. land cover, proximity to rivers, suitability of crops, etc.) and socio-economic variables (ex. proximity to roads, town, village, infrastructure or market).

Integration of other drivers of change, connection of local economy within the global economy and description of exogenous/endogenous are not presented in this graph but will be describe more in-depth in the initial technical description section of this paper.

Recall that a land use simulation model is a tool that imitates actual land use change processes and enables us to describe the system's possible future state. In other words, it provides an estimation of the future of land use under a set of assumptions (scenarios) in Mozambique and calculates the implications for selected key indicator variables (see initial description of output variables and scenarios below). The results are intended to support the policymaking and economic development processes by providing timely and spatially-explicit representation of possible future impacts of current choices.

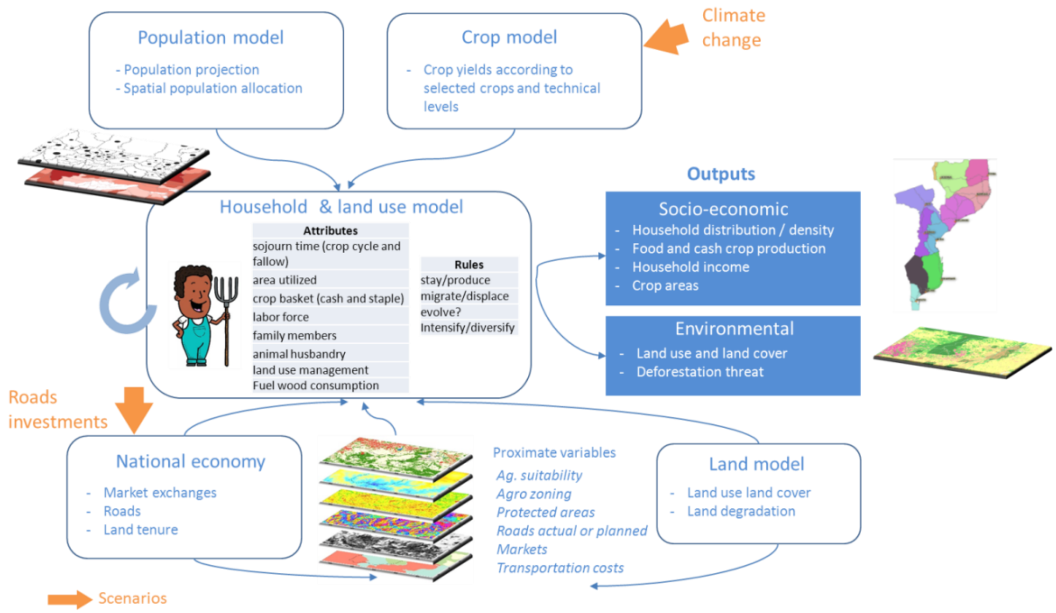

Figure 1. The LANDSIM prototype conceptual model including the household attributes, main models, and interactions

Simulation models, such as the proposed LANDSIM prototype, are built from the ground up and so begin life simply and gradually become more complex over time as more information becomes available and as researchers delve more deeply into individual components. Moving from simple to complex will be a theme throughout his document as we discuss each of the individual components in the technical section.

Interaction of model components

As shown above in Figure 1, the platform is a series of interacting models focused around the rural household. Models can interact "offline" (whereby exogenous results from other models are used as inputs) or "online" (where results from one model are taken up and incorporated endogenously by the main model at preset time-steps during the model run).

- ✓ The **population models** (top left), run online, project how many people are there and where. Population projection can be done with a crude growth rate, and then complexity can be added by controlling for in- and out-migration between regions as well as changes in birth and death rates. A spatial population allocation model allocates the population over space. This model is a function of physical and social characteristics (GIS layers e.g., infrastructure, soils, topography, rainfall, current land use, proximity to populated cells, etc.). Feedbacks will be provided by the land-use simulation model to the population model triggering, for example, population displacement and out-migration.

- ✓ The **crop model** (top right) will provide spatially-explicit estimate of crop yields. Yield models are developed offline but interact with the main model by giving a range of potential yields for the household to select and respond to. The choice of the potential yield output will depend on the household characteristics (level of income, share of croplands, risk taking household, level of degradation of the land). Crop yields model are based on plant characteristic and exogenous factors such as climate, solar radiation, and soil properties. To provide realistic and spatially-explicit estimates for various crops it requires a large amount of historical climate dataset (climate station or satellite images) and knowledge on cropping practices (eg. cropping season). Once calibrated and validated for several crops, it can easily be adjusted to account for climate change scenarios.

- ✓ The **household and land use model** (center) will then be the core and active model in the framework, whereby the household allocates its factor of production to produce goods that meet, exceed or do not meet a consumption demand (consumption includes the use of natural resources). All the attributes of the household will be considered as endogenous variables. The household can grow and migrate over time. Depending on region, population density and current economic, social, technical and ecological conditions, the household will allocate its resources to minimize risk while maximizing benefits. Additional details are in the technical section.

- ✓ **Linking local economy to national economy** (bottom left). The tool is expected to simulate government decision at national scale that includes development of new roads network or investing in commercial agriculture. The linkages define quantitative relationship of such infrastructure project or policy to the household distribution, attributes or share. This task will requires in depth literature review and knowledge of previous experience to account for national circumstances.

- ✓ The **land model** (bottom right) will be run offline to provide the required initialization spatial layers on land use land cover and land degradation. It includes of wide range of modeling exercises fully described in the Land Degradation Baseline Approach Paper (first component of LAUREL program). The spatially explicit land degradation status will be used in the household and land use model to account for decrease levels of yields in degraded lands. In addition, the Land modelling activities may provide important insight in the factors of change (land productivity trend analysis) and trend in land use and land cover that may be considered in the business-as-usual scenario.

Finally, the simulation platform will moves households around on the landscape and changes how they act with the environment depending on a pre-defined set of responses (making choice and change endogenous in similar fashion to the elasticities of CGE models) and scenarios (e.g., infrastructure investment).

Overall **this can be considered as a partial equilibrium land use change model**. That means that while we focus on details of land use and household economics, and has increasingly quantified links to the overall economy, some aspects of the economy, such as GDP or national labor markets (and even physical attributes such as land degradation), will be included exogenously.

Outputs & Variables

These results are spatially explicit and will be presented in the form of maps or database aggregated over administrative units (province or districts) or raster map representing the output value in a pixel or cell.

The proposed models, and the underlying modeling platform, will be designed to be flexible and address a number of different policy and investment questions over time. **The model will run annually, starting from 2016 and covering the two next decades**. A twenty years projection is a standard time frame in land use change modeling, and does allow meeting policy expectations on middle to long term strategic planning activities and enable to simulate in the meantime climate change scenarios (usually in a long to very long term, 2050-2080). However, longer time frame simulations above 20 years are likely to produce uncertain or unrealistic figures.

We first started the building process by selecting a number of Strategic Output Variables (SOVs) that answer pressing problems and serve to demonstrate the capacity of the models to provide useful results (see Table 1 below). We can also add SOVs and sub-models to the platform at a later date. For example, there is no commercial logging model yet slated for inclusion, but this could be added.

Key variables that are related to, or can be proxied by, forest cover – mainly biodiversity and carbon – will be calculated through the projected change in the land use land cover variable.

Table 1. Output variables and resolution for simulation

Output variables	**Spatial ganularity**	**Time resolution (Annual)**	**Source of data for historical values**
Household distribution	Raster map (250 m)	2016 to 2036	INE/MTC locations of villages and cities
Household density	Administrative units (province / district)	2016 to 2036	INE census in 1997 and 2007
Food and cash crop production	Administrative units (province / district)	2016 to 2036	Household surveys (AIS, 2015 and IOF 2015)
Household income	Administrative units (province / district)	2016 to 2036	Household surveys (AIS, 2015 and IOF 2015)
Crop areas	Administrative units (province / district)	2016 to 2036	Household surveys (AIS, 2015 and IOF 2015)
Land use and land cover	Raster map (250 or 30 m)	2016 to 2036	National land use land cover map 2016
Deforestation threat	Raster map (250 or 30 m)	2016 to 2036	Historical deforestation analysis

Scenarios

Each of the SOVs will vary according to the different scenario. For example, in an analysis of infrastructure spending we would see the impact of that program on the "location of households". In other words, there will be an algorithm embedded in the model that estimates the changes in household location in a region due to the quality of infrastructure.

Here we present the narrative of two scenarios: business as usual and alternative scenarios. The focus will be put in the business as usual scenario, with current infrastructure network and planned projects.

Table 2. Possible scenarios for the LANDSIM model

Scenario	Description
Business as Usual	Model will be run without change to key policies and in the absence of unknown government investment. The focus of the GoM so far has been on national or international-scale infrastructure (e.g., corridors with South-Africa and Zimbabwe, Ports, or EN1 linking Maputo to the North of the country). More recently, a shift has been observed toward rural infrastructure. For instance, the World Bank and the European Union are planning to invest in rural infrastructure upgrading in Zambezia. This could have major impacts on smallholder livelihood as it would improve access to markets and government services. Model run with all planned rural infrastructure investments successfully implemented based on roads and infrastructure development database from ANE.
Alternative Scenario	Model will be run with large-scale additional infrastructure investment linked to mega-projects, in particular Oil & Gas expected growth. The investment projects on road infrastructure to be used for simulations will be defined based on the outcomes of PNDT consultation and strategic plan activities, that are expected to be carried out during the implementation phase of LAUREL prototype.

Additionally **we will evaluate the impact for climate change scenarios**. The model will run to include projected climate change impacts (see initial technical description for further detail). The link will be conducted through the crop model and the impact on crop yields. LANDSIM can also be easily adapted to be a tool to analyze policies to achieve Mozambique Nationally Determined Contribution in the land use sector such as the Country Forest Reference Level, notably by overlaying the land use & land cover map produce by LANDSIM with carbon maps and data (emissions factors).

It **would also allow the linkage with REDD+ national mechanism**. The impact of the national REDD+ strategy, or of the policy and investment interventions in the two pilot jurisdictional REDD+ landscapes of North Zambézia (Zambézia Integrated Landscape Management Program) and Cabo Delgado could be assessed with the LANDSIM platform as an adaptive management tool to fine tune already planned interventions.

In future efforts we can **use the model to analyze the impact of several key strategy identified in the National Plan for Territorial Development - PNDT**. The PNDT is a major planning exercise underway by the Mozambican government. We will work with the PNDT team to adjust the LANDSIM model so that it estimate the impact of those plans on economic development, rural household welfare, and the environment (see below for further detail in policy context integration).

Finally, the LANDSIM model **can be adapted to analyze the impacts of other World Bank projects**. A specific landscape where the interaction between investments in infrastructure and natural resources will be very strong in the coming years is the southern-part of the country between Maputo and Ponta d'Ouro at the South-African border. The construction of a bridge in Maputo over the Rio Espirito Santo and the tarring of the road toward the border will open a new corridor for development, especially in terms of tourism. This area also homes the Maputo Special Reserve and the Ponta d'Ouro Marine Reserve where the World Bank is investing a lot through the Mozbio program. The LANDSIM platform can help analyze the consequences of this infrastructure investment.

2.2 Integration into the on-going policy context

During the first (May) and second (September) missions we developed a strong relationship between the LAUREL team and the Team at DINOTER leading the PNDT. The anticipated elements and timetable of coordination of the LAUREL work with the PNDT preparation process is presented in the table below.

In addition, the LAUREL team conducted introductory discussions with the incoming Technical Advisor to DINOTER on PNDT, and highlighted the importance of PNDT and LAUREL teams establishing open communications and strong coordination. Finally, all data collected and collated by LAUREL will be shared with he PNDT consultants.

Current information on the PNDT process is provided in the LAUREL October Aide-Mémoire.

Table 3. Linkages between LAUREL & PNDT

FASE DO PNDT	**LAUREL contributions**	**Use of LAUREL contributions by PNDT consulting team**
FASE PRELIMINAR	Presentation of detailed methodology to Seminário de Lançamento do PNDT and/or to Encontro técnico	Definir no inception report como os cenários LANDSIM serão utilizados na Proposta de Modelo Territorial
FASE 1 - DIAGNÓSTICO NACIONAL	Estimates of land degradation	Utilização dos resultados da avaliação da degradação dos solos na definição de Modelo Territorial
FASE 2 - PRIMERA PROPOSTA DE MODELO TERRITORIAL	First set of runs of LANDSIM-P results	- Discutir os resultados do LANDSIM-P em um workshop de consulta pública - Utilização dos resultados do LANDSIM-P (cenário de referência) na definição de Modelo Territorial - Definição de cenários alternativos a serem analisados nas próximas séries de LANDSIM-P
FASE 3 - PROPOSTA DO PLANO	Second set of runs of LANDSIM-P results	- Utilização dos resultados do LANDSIM-P (cenários alternativos) na definição de Modelo Territorial - Discutir os resultados do LANDSIM-P em um workshop de consulta pública
FASE 4 - ENTREGA DA VERSÃO FINAL DO PNDT	Final version of running LANDSIM-P	

2.3 Encouraging local partnerships

Our planned approach to establishing continuity in the use of the LANDSIM tool as well as building local capacity and becoming effective in the policy arena is to partner with two key institutions (more can be contemplated in the future). The two keys institutions are: DINOTER and Universidade Eduardo Mondlane.

We have established a significant line of communication with DINOTER, in particular Lucas Combesi, who traveled with the team on a field trip in September and has attended all the workshops put on by the team.

UEM is a well-established institution with several opportunities for collaboration. For example, the SECOSUD II project, with which we have an emerging partnership, is housed within UEM. We have met with several UEM professors and established preliminary collaboration. The team will be visiting UEM to formalize ties in early 2018.

3.Technical description LANDSIM

This section describes the individual models or components presented above in more in-depth fashion[11].

3.1 Population modeling

Mozambique has an estimated population of 25 million. This population is estimated to increase to around 40 million or so by the year 2040. While there are several excellent population projections for Mozambique, including estimates of rural to urban migration, it is important that we internalize the ability to project population so that we are able to accommodate a broader range of scenarios.

There is a well-established connection between population growth and environmental degradation[12], so in the first step of our simulation model, we will build a model to project the rural populations of Mozambique[13]. We will set up a suite of population projection models that project population growth, based on fecundity and mortality rates, and finally in-and out migration. At a last step the migration patterns between Provinces and to and from urban areas will be balanced within a population matrix – the matrix will control the numbers of people, making sure that those leaving and arriving match.

There are several population projections, not least of which is produced by the *Instituto Nacional de Estatistica* (INE) that has projections at the level of *District* through to 2040[14]. Another exemplary projection, made worldwide and at country level 100-meter resolution is the WorldPop work conducted by the University of Southampton[15] for 2010 and 2015 reference year (United Nations statistics). We will check our numbers against the estimates made by INE and the WorldPop project to validate our results.

Estimating population

The population models are currently being built and programmed into DINAMICA EGO.

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[11] The household models are still in the design phase. Details about household characteristics and spatial variation are available (see discussion below and Annex I & II), but the elasticities and responses to change (IF:THEN sequences) are still being created**.**

[12] Kalipeni, E. 1992. Population growth and environmental degradation in Malawi. *Africa Insight* vol.22 273-282.

[13] Urban population growth will be included exogenously in the prototype of the platform. Data on Urban growth is available from GoM statistics. The key urban centers are Nampula, Beira, and Maputo City.

[14] http://www.ine.gov.mz/estatisticas/estatisticas-demograficas-e-indicadores-sociais

[15] Lloyd, C. A. Sorichetta & A. Taterm. 2017. High resolution global gridded data for use in population studies. *Scientific Data*. www.nature.com/scientificdata. http://www.worldpop.org.uk/

With two points in time – data available to us though the INE – the simplest model for projecting population is by calculating the crude "r", or growth rate[16]. Using the following equation and the 1997/2007 population data by *Posto Administrativo*, we will calculate a crude growth rate at a fine scale that can then be used to extrapolate population.

$Pt = P0 * e^{rt}$ where:

> Pt is the population the last year
> P0 is the population in year 1
> e is the natural logarithmic constant
> ^{r} is the unknown annual rate of growth
> ^{t} is the number of years between Pt and P0

A deeper accounting of population will include the details of natural changes in population plus in and out-migration, such that:

$Pt = P0 + (P0*FR – P0*MR+ INmg - Omg)$

> Pt is the population the last year
> P0 is the population in year 1
> FR is the fecundity rate (variable over time)
> MR is the mortality rate (variable over time)
> INmg is the rate of in-migration (variable over time)
> Omg is the rate of out-migration (variable over time)

This calculation allows us to make use of a population matrix that tracks the movement of people between Provinces. INE population data contains a detailed description of population movement between and within provinces. In the prototype, however, we will not seek to incorporate this detail since it is as yet unclear whether in-migration from different regions significantly alters production practices and resource use – i.e., households arriving into a region conduct themselves in a similar manner to those already there. Therefore, we will assume that in-migration provides no change in household activities -- although it does increase pressure on resources and affects markets -- and out-migration reduces available labor, but in compensation provides the opportunity for remittances (see discussion about migration below).

Spatial population allocation model

The spatial population allocation model is currently being built and programmed into DINAMICA EGO.

[16] http://www.columbia.edu/itc/hs/pubhealth/modules/demography/populationRates.html

Both urban and rural population density and size affect farm size, wealth, the demand for off-farm labor and many other factors[17]. Here will we begin by allocating the density according to established estimates for Administrative Posts from the INE population data. Allowable density within a pixel and changes to that number will be determined and input exogenously.

We will rank cells according to a probability ranking of having population and then allocate the population (essentially filling the most desirable cells first). As population grows it can either fill empty cells or should there be no local options, would migrate out. Ranking will serve as a tool for the initial location of the population, but then also as a means to identify where population will move to.

The ranking function for the cells will be based on a spatially explicit analysis of proximate variables that affect current population distribution and including, but is not limited to the variables in the following equation.

CellRank = *f*(road density, neighboring population, soil, distance to water, distance to urban area, villages, topography, rainfall, etc).

We will calibrate and validate our spatial model based on available rural population maps[18,19,20], as well as by using demographic data.

Migration and the rural/urban interface

Migration is a key element of population change and indeed household dynamics in Mozambique. The Southern African Migration Project[21] notes that remittances have been an important contribution to household welfare in Southern Mozambique (Gaza, Inhambane, and Maputo provinces) but that increasing competition for those jobs may affect overall household returns. Even so, in 2000 Mozambican made up almost 20% of mine workers in South Africa[22]. However, only some members of the household migrate. 80 % of rural household do not move, but when available send household members away to seek work.

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[17] Ricker-Gilbert, J., Ch. Jumbe, & J. Chamberlin. 2014. How does population density influence agricultural intensification and productivity? Evidence from Malawi. *Food Policy* 48:114–128

[18] http://documents.worldbank.org/curated/en/367391472117815229/pdf/107996-WP-P155269-PUBLIC-MeasuringRuralAccessweb.pdf

[19] http://sedac.ciesin.columbia.edu/data/collection/gpw-v3

[20] https://reliefweb.int/map/world/global-population-density-estimates-2015

[21] South African Migration Project (SAMP). 2006. *Migration and Development in Mozambique: Poverty, Inequality and Survival*. Migration Policy Series No 43. 33pgs.

[22] International Organization for Migration. *Briefing Note on HIV and Labour Migration in Mozambique*. www.iom.org.za

Figure 2. Households in Gaza - 2017

We will model the migration – essentially labor supply and demand -- through push and pull factors.[23] **Push factors** are when the household falls out of sustainable equilibrium (see below in HH model section for detailed description) and must either migrate to another nearby pixel – as in the example of when a new family unit is created – or will send some of its labor force to either temporary work, in for example the mines of South Africa. In the push conditions the household has fallen below a threshold level of income or consumption and seeks to reallocate labor. It is important to note that not all labor that can be allocated by the household to non-farm labor can be accommodated. If, for example, the labor supply from a region increases suddenly because of drought, in which case all households would be seeking to reallocate labor, then there will either be a reduction in the labor price, and thus remittances, or simply excess unallocated formal labor, in which case the labor and consumption requirements are returned to the household. **Push factors are created endogenously** within the household lifecycle and through exogenous changes such as drought or ill health.

Pull factors are those whereby the demand for labor is apparent and the value of that labor exceeds that offered in agricultural production within the household cycle. Though often informal, this labor movement and opportunity is a common aspect of household with access to urban labor.[24] Examples include, but are not limited to: mining, urban labor, mega-project labor. These can be categorized within the Service, Manufacturing and Government components of the economy. In the first phase of the simulation platform, **pull factors will be included exogenously**. Labor demand will be a factor of

[23] In the subsequent phases, we may also consider using Gravity-type spatial interaction models that would project population movement exogenously for the platform. See: Garcia. A., D. Pindolia, K. Lopiano & A. Tatem. 2015. Modeling internal migration flows in sub-Saharan Africa using census microdata. *Migration Studies* 3:89-110

[24] Davila, J., E. Kyrou, T. Nunez & J. Sumich. 2008. *Urbanization and Municipal Development in Mozambique: Urban Poverty and Urban-Rural Linkages*. World Bank Report. Development Planning Unit, University of London. 117 pgs.

urban growth as well as overall population growth. It will be disaggregated by economic sector (Agriculture, Manufacture, & Service). Projections of urban growth and sector change are available from Government and international economic projections.[25] They will be accessed and incorporated into the models exogenously.

With only a few households having access to salaried work, we will not assume that there are perfect labor markets. Instead markets will be described as thin, which implies that even if someone wishes to work, either by looking for work close-by or by migrating to find a job, there is no certainty this will be successful. A monte-carlo approach will be use to imbue the choice to look for work, or the chance of finding it and thus remittances to the household, with an element of risk of success. Labor markets will change according to growth in the domestic economy, growth in regional labor markets, and the type of employment generated. For example, an increase in the GNP due mainly to Gas production, may not result a commensurate increase in labor demand in industry, because skilled labor can be imported, but may have regional increases in the peri-urban agricultural production and increases in the service sectors. These details will be included as the models are built. To begin, and keeping with the process of simple to complex, we will simply match rural labor supply from households to estimated labor demand and quantify excess or shortages.

3.2 Crop yield modeling

Crop yields will be estimated using the SARRA-H crop model and its spatial component SARRA-O. The model is particularly suited to respond to global issues such as climate change and food security. The SARRA-O model was developed by LAUREL team members at CIRAD and AGRHYMET[26] as part of the FP7 EU Stimulating Innovation for Global Agricultural Monitoring (SIGMA) project and has been successfully tested during the 2015 and 2016 growing seasons by AGRHYMET in West Africa.

In LAUREL, the crop model will be applied to estimate crop yield and to forecast the impacts of climate change.[27] The SARRA-O crop model uses satellite based daily rainfall estimates (e.g. TAMSAT, CHIRPS), 10 days climatic data estimates (e.g. ECMWF for PET, Rg, Tmin, Tmax) and a soil map (e.g. FAO, 13 soil types) as input to simulate potential yields of the main staple crops (i.e. soybean, maize and rice). Main variables and features are presented in figure 3.

[25] World Bank. 2016. *Mozambique Economic Update: Facing Hard Choices*. 32 pgs.

[26] Castets, M., Baron, C., Traoré, S.B., Jahel, C., Agali, A., Degenne, P., Songoti, H. and Lo Seen, D., 2017. A spatialized crop model for operational food security early warning in West Africa. In preparation for *Environmental Modelling and Software*.

[27] Jahel C., Baron C., Vall E., Karambiri M., Castets M., Coulibaly K., Bégué A., Lo Seen D., 2016. Spatial modelling of agro-ecosystemdynamics across scales: A case in the cotton region of West-Burkina Faso, *Agricultural Systems*, http://dx.doi.org/10.1016/j.agsy.2016.05.016

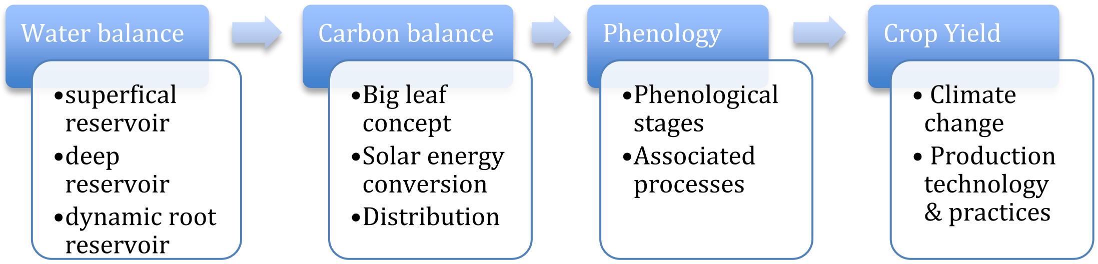

Figure 3. Simplified depiction of SARRA-H crop model process

Crop model spatialization for Mozambique will be carried out using the Ocelet Spatial Dynamics Modeling language and simulation platform.[28] This model will then be adapted and incorporated into the overall LANDSIM platform.

The model can take also into account cultural practices and technology adoption to simulate crop cycle dynamics and crop yield at harvest time. We will determine the exact mix of technology adoption practices during the final scenario design. The sowing date is determined by cultural practices, crop variety, and cycle duration, soil moisture.

The yield forecasting capability of the model in farming environment was verified against maize yield during year 2014 on a dataset comprising about 80 plots (R^2~0.8, slope ~ 0.8), and tested again for year 2015 and 2016 (R^2~0.85, slope ~ 0.76, see Fig. X3).

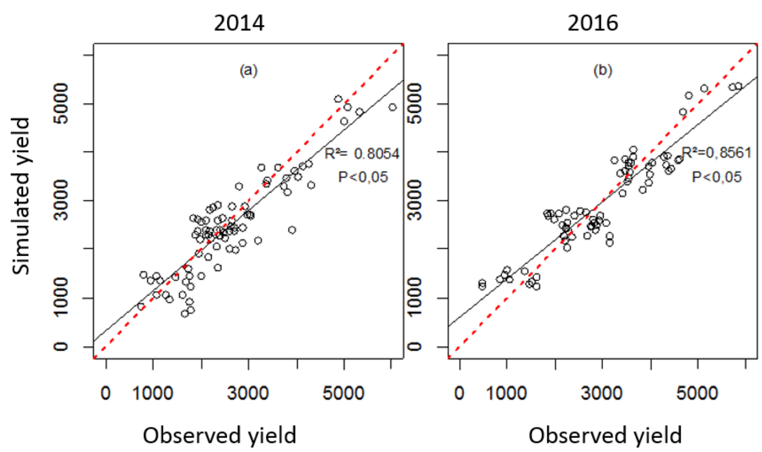

Figure 4. Correlation between simulated yield by SARRA-O and observed farmer's yield for maize in 2014 (left) and 2016 (right)

For LAUREL and integration into the LANDSIM platform, **SARRA-O will first be adapted to maize – the main crop in Mozambique - and then extended to other selected crops**, including but not limited to, soybean, rain-fed rice and sugar-cane, adopting the FAO Single crop coefficient (Kc) approach when necessary, to define water stress index.

[28] Degenne P., Lo Seen D., 2016. Ocelet: Simulating processes of landscape changes using interaction graphs. *SoftwareX*, 5:89-95. http://dx.doi.org/10.1016/j.softx.2016.05.002

For a selected number of crops, yield and/or water stress index maps[29] for Mozambique will be generated for the last 30 years, for 4 general fertility levels, within 3.7 km grid cells, using TAMSAT and ECMWF rainfall and meteorological input data. These **maps can be used offline by LANDSIM to have access to a large variety of situations that may be needed for simulating the different scenarios**. This will also allow verifying the consistency of crop yield simulations with crop statistics at national level, and at sub-national levels when possible.

3.3 Household, land and resource use modeling

The household models are still in the design phase. Details about household characteristics and spatial variation are available (see discussion below and Annex I & II), but the elasticities and responses to change (IF:THEN sequences) are being created.

Background on household models

The main modules are the population system dynamics and household or agent based like[30] model. An important reason for using the agent-based like household model as the cornerstone for the land use projections is that we are able to include what might be considered as illogical, or second best, decisions. In most models of a national economy, and in particular, in Computable General Equilibrium (CGE) models,[31] actors are assumed to respond in profit-maximizing ways. This may not be the case with household sometimes choosing what are often described as sub-optimal decision paths that may be risk mitigation strategies. Furthermore, in CGE models factors of production (labor, land & capital) are placed in large "pools" and not spatially disaggregated to a fine *landscape* scale as we intend to perform within LAUREL program.[32]

Each populated raster cell within a defined zone will then contain a certain number of household units that will act as collective type of agent. Thus, the core engine of the LANDSIM will be an agent based like model (ABM, see more detailed discussion

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[29] For each 3.7 km cell of the map, the pixel value gives the yield (in kg/ha) or water stress index that can be reached with given crop and cultivation conditions.

[30] We use the term agent based like model because while we adhere to the basic concept of an agent based model – whereby we are simulating the actions of autonomous agents – we are simplifying those actions to a significant degree for the goal of developing a nationally relevant platform. We will include randomness in selected variables through a Monte-Carlo Approach.

[31] The benefits of CGE models are they have a formal structure for simulating a market economy, including land, labor and capital, they have endogenous choices of prices and markets, and they formally account for all changes within the economy through a social accounting matrix. Although our model begins as a partial equilibrium model, we take guidance from the CGE architecture, in particular the SAM and internal elasticities, to be relevant at a national scale and to create endogeneity in the model, respectively.

[32] CGE models for Mozambique tend to divide the country into three sections – North, Central and South.

below). In this case, an agent is a discrete individual located in space that has the ability of making decisions based on other agent reactions and its surrounding environment. The agent has attributes (history, capabilities, preferences, etc.) and objectives. ABMs can be designed primarily as deliberative or reactive architecture systems. As deliberative systems, the agents have an internal model of the environment and the decisions are made through logical reasoning.

We begin the modeling exercise by designing a representative household which objectives are both linked to reproduction (through risk minimizing on food access) and profit maximization.

A draft system of equations is used to set up the main variables of the first household model and the first rules for the decision process. (See Annex I for details).

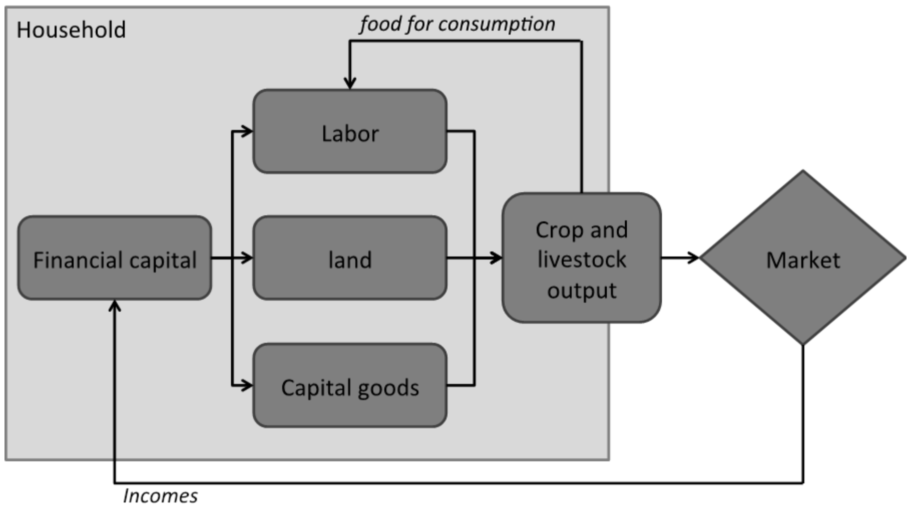

Figure 5. Simple representation of household model

Introducing complexity into the household architecture

Once this first household model is developed and allow generating household output values aggregated at district/province (income, food and cash crop production, etc.) as well as landscape/cell level (crop areas). we will then introduce complexity into the system.

Complexity will be introduced in the household decision process, with its ties to the local and national economies (see dedicated section below), and through spatial variation in farming systems and ecology. As part of the ecological complexity we will introduce linkages to crop yield models to account for spatial distribution of crop yields according to the plant (crop) and biophysical variation (mainly climatic variation along the historical period). Also, level of land degradation on a particular area will be connected to the household model through changes in food production (change in potential yields), with eventual tuning of farming systems decision rules (see example appendices I).

Internal complexity within the household decision is an additional set of rules that reflect a decision set for the households/agent. According to their state, these attributes will change the potential agent strategy towards production and land use. The agent will be reactive and, as such, s/he will behave to stay and produce or move to nearby areas after a sojourn time or due to displacement by external drivers such as land availability,[33] protected areas, or DUATs granted to commercial agricultural companies, or infrastructure access.[34]

The agent will also be able to intensify or diversify agricultural production, i.e. change practices, due to internal (such as incomes) and external stimuli (such as policies, market access). The agent population is dynamic depending on growth and migration rates that will affect available labor. Agent agricultural production will depend on projected agricultural yield (see crop yield model and spatial variation in production). Finally, a household agent can fail if production falls below a certain threshold due to, for example, climate stress or if market prices do not allow the household agent to reproduce its farming system. In this case, the household will either reduce its farming activities, migrate away or will require social safety nets.

We will assess food security needs and conditions for households whenever households face system shocks their use of natural resources changes. For example, climate change or low incomes due to low market prices can alter household production decisions, perhaps by reducing cultivated land or downgrading to lower work productivity practices, or by forcing out-migration of selected household members. In the latter case, this will reduce the time that can be devoted to productive on farm activities. This has implications for food security within each household and then the decisions process on what should be cultivated (more land for staple crops than cash crops). These factors can be affected by access to infrastructure or health facilities and are therefore tied to major investment policies for both development and conservation. The household models react to change and generate quantifiable changes in production, consumption, labor availability and other measurable variables.

Spatial variation in the household model

There is significant spatial variation in, ecology and economics, with resulting variation in both production practices and market prices, in Mozambique.

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[33] Tanner, C. 2002. *Law Making in an African Context: The 1997 Mozambican Land Law*. FAO Legal Papers Online #26. 62 pgs.

[34] Dear, C. and S. McCool. 2010. Causes and Consequences of Displacement Decision-making in Banhine National Park, Mozambique. *Conservation and Society* 8(2): 103-111. Walker, M. 2015. Producing Gorongosa: Space and the Environmental Politics of Degradation in Mozambique. *Conservation and Society* 13(2): 129-140.

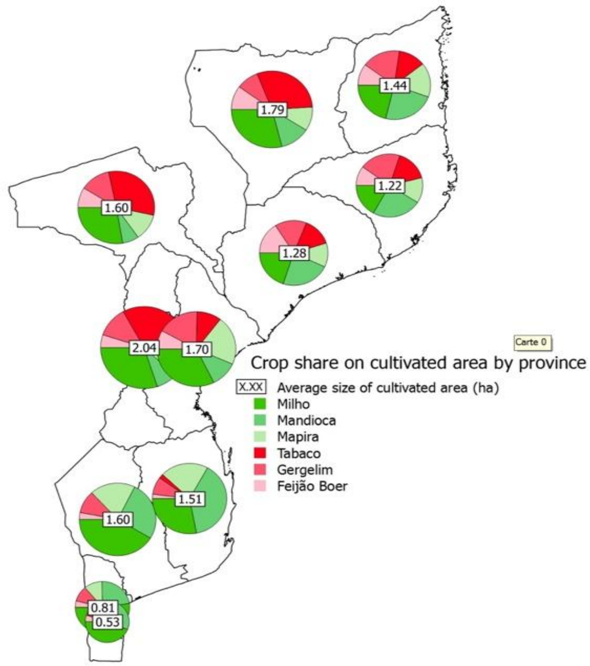

Figure 6. Example of spatial variability in crop area and production

Many national level studies separate the country along three ecological zones: North, Central & South. We will first develop input variability at the Provincial level. This allows us a political division that helps with data collection (preferred scale in national statistics) and also with policy relevant scenarios and results. Indeed, two Provinces in Mozambique, Nampula and Zambezia, are disproportionately rural and responsible for intractable poverty and slower growth.[35]

Annex II presents a set of tables that form the basis for the spatial differentiation of farming systems at the provincial level. As we mine the massive amounts of data available from several surveys (see section 3 "dataset requirements") we will move from the simple spatialization to a more complex representation of household choice and farming systems. The LANDSIM engine incorporates a series of algorithms to spatialize and update maps for input factors and SOVs as well as summarize outputs per country provinces.

3.4 Integration into the national and regional economy

These linkages are in the design phase and completion and details are currently part of the project workflow. For the most part, in the prototype the households will interact exogenously with the overall economy. Ideas presented below represent our thinking and experience, but <u>are not final</u>.

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[35] World Bank. 2016. *Accelerating Poverty Reduction in Mozambique: Challenges and Opportunities*. (Para 7, page 11) 54 pgs.

In 1998, Mozambique was one of the first heavily indebted countries to apply and receive debt restructuring and relief. This opportunity has since been squandered as it has been on a debt-financed public spending spree that focused heavily on government owned companies and Mega-project investments. As mentioned above, there has been some reduction in poverty associated with economic growth but not enough. Regardless, these households interact, some more or some less, with regional and national economy, and policy decisions affect their choices.

We will follow the economic linkages path set in the development of CGE models.[36] But different from the CGE models, which fit an economy into a prescribed matrix (called a social accounting matrix) and theoretical framework (including, for example, perfect competition), we will create a version of the matrix and set of theoretical assumptions over time by building the models from the bottom up. This design will help us overcome some of the problems in integrating partial and general equilibrium models and develop flexible plans[37] for addressing the hurdles of integration.[38] We will also not deliver a complete CGE since some of the connections will be exogenous (described below), making the platform a partial equilibrium model.

For example, our first cut at integrating the household economy with the regional and national economies will be as exogenous actors. That is households will act as price takers in the market and will not influence prices. Prices, discussed in more detail below, will be generated with nationally determined statistics and then assumed constant or vary according to exogenous projection. The projections will be taken from the literature or made with simple assumptions. As the model development continues, endogenous links will be incorporated where possible. The first example of which is the impact of local agricultural production on local agricultural markets, where households may play a role in driving prices.

Figure 6 shows a graphic representation of the Mozambican economy and the relationship of the rural households to the rest of the economy. In this case we begin with an increasing population that is allocated between rural and urban households. Rural households are then allocated in space by the process described above in the density model. Like in the household models, and in a simple version of a CGE, we will be developing equilibrium equations for the economy, whereby, for example, agricultural

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[36] Diao, X. & J. Thurlow. 2010. *A Recursive Dynamic Computable General Equilibrium Model*. Chapter 2 pgs 17-50. Arndt. C, P. Chinowsky, K. STrzepek & J. Thurlow. 2012. Climate change growth and infrastructure investment: The case of Mozambique. *Review of Development Economics* 16:463-475. Arndt, C. H. Jensen & F. Tarp. 2000. Structural characteristics of the economy of Mozambique: A SAM-based analysis. *Review of Development Economics* 4:292-306. Jones, S. and F. Tarp. 2016. Mozambique: Growth Experience through an Employment Lens. In *Africa's Lions*, H. Bhorat and F. Tarp eds. Brookings Institution Press, Washington, D.C. 282 pgs.

[37] It is important to note that developing these linkages is part of the project workflow. Many of the solutions are not yet built, but will be completed as the linkages section is built. Furthermore, integration of endogeneity in the model and national economic integration are subject to programming constraints within this project and may not be included in the first phase.

[38] Flores, R. 2008. *Are CGE Models Still Useful in Economic Policy Making*? Ensaios Economicos #674. Fundacao Getulio Vargas 12 pgs. (His answer is yes, they are still useful).

consumption is equal to household production, commercial agricultural production and imports.

The industrial and service sectors will be exogenous forecasts that can be taken from the development literature or, in the absence of reasonable data, projected out in a linear manner with sensitivity analysis. The model then grows the population allocates in space, produces and consumes goods – engaging in the agricultural sector or migrating out to the industrial and services sectors as urban households.

We will also determine the linkages between household decisions and government investment and policy decisions. A decision to invest, for example, in infrastructure may result in an in-migration pressure to secure transportation and markets access. This will have both economic production and resource degradation consequences for the region. We will quantify this relationship as part of the overall rural population dynamics to demonstrate the complexity of impacts of development investments.

Prices will be included in two formats. First we will use collect prices for the model for crops or input variables at a predetermined location - usually the nearest large urban market. Then we apply a transport cost friction surface or decay function that decreases the farm gate price down to the zero over space. These friction surfaces for prices are common in landscape modeling. In addition, and as part of the household market linkages, we will be building endogeneity into the model. Endogeneity – the ability of the model to respond to changes in internal variables – will be included in some aspects of the model. Traditionally these responses are embedded through the use of elasticities, which are programmed responses to change. For example, if the price of corn increases then there will be set increase in supply, and that percent change is the elasticity.[39]

It is also the case that rural and even peri-urban households do not have access to perfect information. That is there is some uncertainty or lack of availability about the price information in agricultural markets. This is often the case for rural farmers who are subject to predatory pricing by middlemen, who serve as important but sometimes abusive links to formal product markets. In our model, we will describe a relationship between information and the likelihood of producing for commercial markets – i.e., even if there is a high price the households without information may not capture that price and therefore may choose subsistence production.

There is also going to be competition for land during the development process. For example, some key commercial crops for possible expansion in Mozambique are sugar cane, cotton, tobacco, sesame, and pigeon pea. The expected area for commercial crops will, at first, be generated as a reflection of expected growth rates in production volume. These growth rates will be taken from the literature or generated with simple assumptions (e.g., linear growth project from past growth rates). The same applies for Timber

[39] Detailed elasticities for all choices are difficult to calculate, so simulation models, including CGE models, make assumptions about elasticities. See for example, Jones, S. and F. Tarp. 2016. Mozambique: Growth Experience through an Employment Lens. In *Africa's Lions*, H. Bhorat and F. Tarp eds. Brookings Institution Press, Washington, D.C. 282 pgs.

Plantation expansion but which also may be mega-project investment. These expansions will be modeled as exogenous change in the land use model that (1) removes land from production; (2) competes for regional markets with household production; (3) may serve as a technology hubs; (4) displace households.

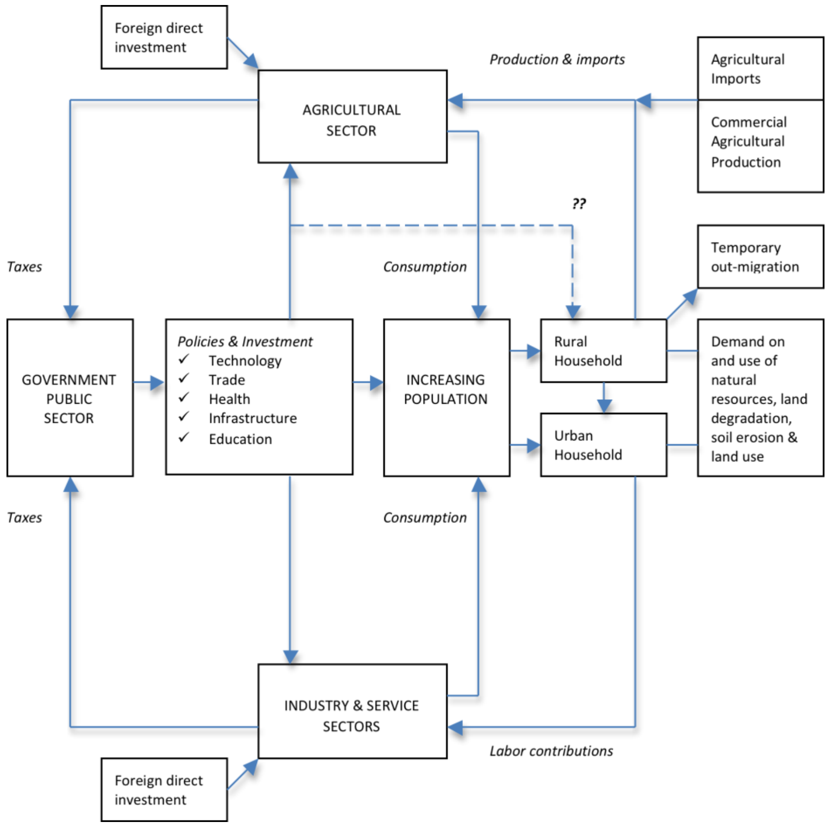

Figure 7. Simplified conceptual model of Mozambican economy with linkages for rural and urban households and natural resources

In summary, the links to the local and regional markets and economies will begin almost completely in isolation, in other words all other aspects of the economy will be exogenous projections in which the households act. As with the household models themselves, once we have established the simple connections we will then build more complex interactions into the platform.

3.5 Integration of climate change scenarios

Flood and drought are the two most important climate change risks,[40,41] and are the main causes of variation of food production and economy and impact on food security in the

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[40] Suit, K. & V. Choudhary. 2015. *Mozambique: Agricultural Sector Risk Assessment*. World Bank Report # 96289-MZ103 pgs.

last 30 years in Mozambique[42]. Climate change risk in Mozambique include also a likely increase in the frequency and intensity of. Furthermore, without improvements in agricultural technology and the continued dependency on rain-fed agriculture, it is possible that the process of land degradation will continue with attendant impacts on overall crop production and household welfare.

Indeed, a 2012 study by the National Institution for Disaster Management on Climate Change impact on Agriculture sector [43], projected average yield changes -- variable by eco-region and scenario – and showed that maize, the most important household crop in Mozambique saw estimated yield changes from a 4.36 % drop to a 6.37 % increase. and a 17.38% drop for Millet in a dry scenario to a 0.09% drop for Cassava in a wet scenario. The authors used the CliCrop model and four climate-change models (CISRO30_AR GLOBAL DRY; NCARC_A2 GLOBAL WET; IPSL_AR MOZ.WET; & UKMO1_A1B MOZ.DRY).

Climate change in Mozambique may lead to increase occurrence and severity of droughts, floods and cyclones, making it a country directly in the path of change. Overall, and unsurprisingly, these changes are expected to have a negative impact on economic development, though perhaps not an insurmountable one.[44]

The impact of future climate change and climate variability on agriculture will be analyzed using one crop model (SARRA-O) that is driven will be driven by meteorological data generated by General Circulation Model outputs.

Different General Circulation Models (GCM) can then be used to simulate these scenarios.[45] The effects of climate change on crop yield will be studied based on the climate projections proposed in the IPCC's Climate Change 2014 - Fifth Assessment Report (AR5). **Two Representative Concentration Pathways: RCP2.6 and RCP8.5 will be used.** Scenario RCP2.6 implies a drastic global reduction of GHG, whereas RCP8.5 is the most pessimistic scenario that is caused by the continuation of present trends (see Fig. 5). Besides, the simulation will also include the protocol defined in the 2010 World Bank study on Mozambique which used 4 climate projections.

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[41] *Atlas for Disaster Preparedness and response in the Limpopo Basin*. INGC, Universidade Eduardo Mondlane & FEWSNET. 99 pgs.

[42] Baez, J., J. Nijhoff, G. Elabed, A. Thiebaud & C. da Matta. 2016. *Why is Agriculture not more effective in reducing Poverty in Mozambique? Understanding the Constraints to Productivity and market-based Agriculture*. World Bank. 54 pgs. At only 0.26, Mozambique's growth elasticity of poverty reduction is half that of the rest of sub-Saharan Africa (Para 34, pg 29.)

[43] Brito R. Holman E. 2012. Responding to Climate Change in Mozambique. Theme 6 : Agriculture. National Institue for Disaster Management (INGC), 29p.

[44] Arndt, C., P. Chinowsky, K. Strzepek & J. Thurlow. 2012. Climate change, growth and infrastructure investment: The case of Mozambique. *Review of Development Economics* 16:463-475.

[45] Cervigni, R. L. Rikard, J. Neumann, & K. Strzepek. 2015. *Enhancing the Climate Resilience of Africa's Infrastructure : The Power and Water Sectors*. Africa Development Forum; Washington, DC; World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/21875 License: CC BY 3.0 IGO.

The Fifth Assessment Report (IPCC AR5, 2015) includes an extensive chapter dedicated to Africa in which the observed climate trends and projections are described. A huge work is actually being done with partners to evaluate impacts of many GCM and scenarios on yields simulated by the SARRA-O crop model, in West Africa, the outputs of this study will be analyzed and compared to others studies to determine which up to date scenario and GCM will be the most adapted to this study on Mozambique.
These activities will also include the CGM models from the ECRAI program available on the Climate projection data warehouse[46] or the Climate Change Knowledge Portal.[47] The outputs of the GCMs include precipitation, temperature, global radiation and potential evapotranspiration on 0.5°x0.5° grid cells for the whole world.

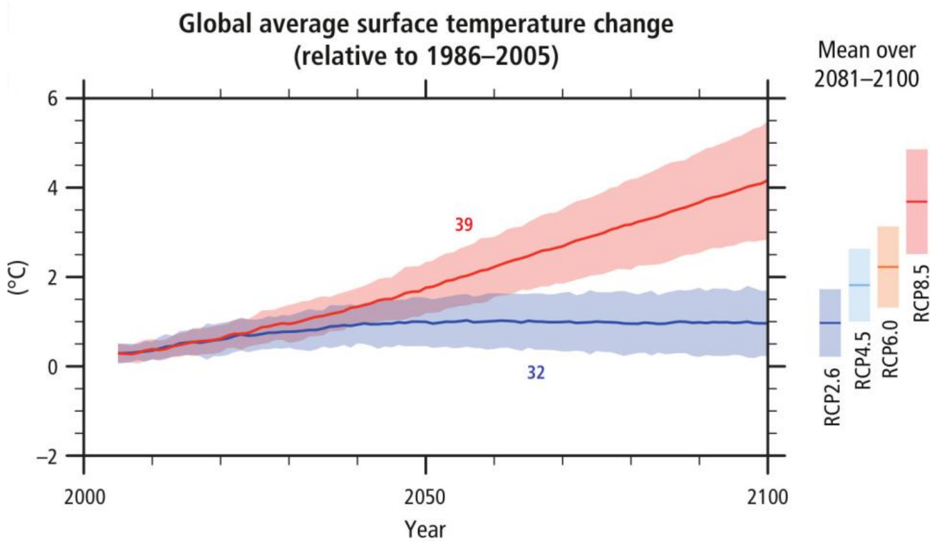

Figure 8. Global average surface temperature change from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Taken from IPCC's Fifth Assessment Report (AR5), Climate Change 2014 - Summary for Policymakers

The model SARRA-O is already equipped to allow such analyses, as it has already been used for this type of studies.[48] The time frame of the analysis will be 2016-2036. . SARRA-O will then be used to simulate future yields and/or water stress for crops that are already cultivated in MZ. It may also be used to test crops that may be better adapted to future climates in the different land use and land cover change scenarios implemented in LANDSIM.

[46] http://www.indecon.com/iecweb/ClimateProjectionData.html
[47] http://sdwebx.worldbank.org/climateportal/
[48] Oettli P., Sultan B., Baron C., Vrac M., 2011, "Are regional climate models relevant for crop yield prediction in West Africa". Environmental Research Letters, Vol 6, pp014008. http://stacks.iop.org/1748-9326/6/014008

3.6 Software to be used in LANDSIM

Two software, or modeling platforms, will be used to develop and design the LANDSIM prototype: Dinamica and Ocelet. Both are modeling environments with tremendous capacity to solve complex land use change problems.

Dinamica

DINAMICA EGO is a freeware for environmental modeling (www.dinamicaego.com). This modeling platform allows the design from very simple spatial models to very complex dynamic ones. Applications of Dinamica EGO include, but are not limited to: simulation of urban growth and intra-dynamics; land-use change; agricultural expansion; fire; deforestation; forest sector dynamics; the cattle ranching sector; analyses of opportunity cost of reducing deforestation and carbon supply curves; and the effectiveness of protected areas.

DINAMICA EGO is a flexible modeling tool that can be run from the desktop to a high performance computer. Thanks to its innovative techniques the software provides a complete solution for calibrating, running, and validating complex landscape simulation models.

DINAMICA EGO has made important contributions to more than 150 peer review papers by scholars worldwide and it is widely used by governmental organizations and planning bodies.

A full list of citations is available at: http://csr.ufmg.br/dinamica/publications/

Dinamica EGO favors usability, flexibility and performance, optimizing speed and computer resources. The software interface allows designing models using an intuitive and user-friendly graphical programming language. Users build models by simply dragging geo-processing operators and connecting them to represent the model visual diagram. While this simplicity facilitates newcomers' learning, sophisticated and powerful features address the challenges posed by expert modelers.

Advanced features include nested iterations, multi-transitions, dynamic feedbacks, multi-region approach, decision processes for bifurcating and joining execution pipelines, a complete series of spatial algorithms for the analysis and simulation of space-time phenomena, model wizard, and high performance computing with a 64-bit native and multiprocessor architecture that handles large raster datasets.

See: www.csr.ufmg.br/dinamica/dokuwiki/doku.php?id=wizard

Dinamica EGO also allows the user to break up the model into sub-models to simplify design and enhance communication, or to design new operators that can be stored in the software library or exchanged using an online repository. In addition, Dinamica EGO enables map operation combining raster maps in any geographic projection, spatial resolution, or extent, making it truly multiple resolution and multi-scale software. The software environment also allows the online coupling with R studio taking fully advantage of Dinamica EGO high performance and R vast statistics capabilities in one integrated modeling environment.

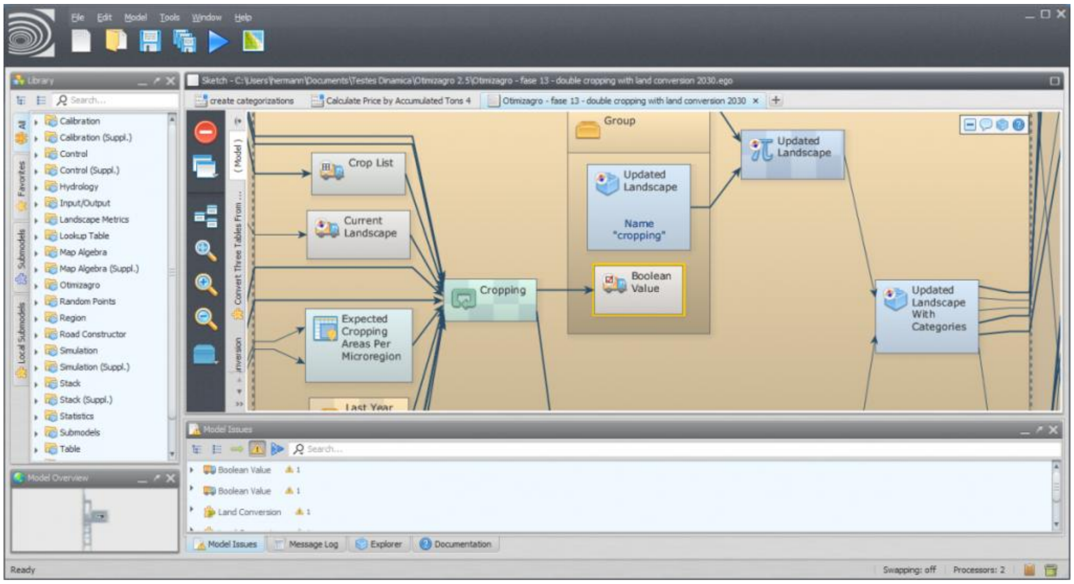

Figure 9. DINAMICA EGO graphic interface showing model coupling and aggregation

The software environment, developed mainly in C++ and Java, contains a series of algorithms called operators. Dinamica EGO operators include the most common spatial algorithms available in commercial GIS, and a series of algorithms especially designed for spatial simulations, including cellular automata transition functions, and calibration and validation methods. A special class of operator is the "container" that can envelop a series of operators and other containers, for example, to control the model dataflow, such as the Repeat operator. Operators, including containers, are sequenced in a graph form to establish a visual data flow.

Ocelet

Ocelet is language and simulation environment for modeling spatial dynamics (Degenne and Lo Seen, 2016[49]). This innovative model allows us to solve a given problem using interaction graphs. Given the generic nature of interaction graphs, Ocelet can be used in a wide range of applications involving multi-disciplinary issues. For example, Ocelet has been successfully used for experimenting land use policy simulation scenarios in a

[49] Degenne P., Lo Seen D., 2016, Ocelet: Simulating processes of landscape changes using interaction graphs, *SoftwareX*, 5:89-95.

participatory approach[50], studying farming systems evolution from plot to regional scale[51], and modeling mangrove coastline changes[52].

Figure 10. Google Earth outputs example from Ocelet on land cover change in an agricultural landscape

A graph is a mathematical concept represented by a set of objects (nodes), some of which are linked (through arcs). Interaction graphs are graphs with (interaction) functions defined on the arcs that can be executed during time steps to make the system change. Each process involves entities (some of which are spatial and distributed in space) that are in interaction with each other. Tools are provided to easily build graphs from several data sources, and Ocelet being a programming language, also offers substantial expressive power to the modeller during model building.

An interesting feature of this language is to facilitate the handling of spatial information. Ocelet proposes the use of "datafacers" which are data interfaces to the main types of data formats, especially spatial data, like ESRI Shapefiles or PostGIS databases, from which spatial entities together with selected attribute data can be easily imported and incorporated in graphs.

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[50] Lestrelin G, Augusseau X, David D, Lagabrielle E, Lo Seen D, Bourgoin J. et al. *Collaborative landscape research in Reunion Island: Participatory modelling and spatial simulation to foster dialogue and knowledge integration*. In: International association for landscape ecology (IALE) 2013 European congress: Changing European landscapes, Manchester (UK), 09–12 September; 2013.

[51] Jahel C, Baron C, Vall E, Karambini M, Castets M, Coulibaly K, Bégué A, Lo Seen D. Spatial modelling of agro-ecosystem dynamics across scales: A case in the cotton region of West-Burkina Faso. *Agricultural Systems* 2016

[52] C. Proisy, P. Degenne, E.J. Anthony, U. Berger, E. Blanchard, F. Fromard, et al. 2016. A multiscale simulation approach for linking mangrove dynamics to coastal processes using remote sensing observations A. Vila-Concejo, E. Bruce, D.M. Kennedy, R.J. McCarroll (Eds.), Proceedings of the 14th International coastal symposium (Sydney, Australia). *Journal of Coastal Research*, Special Issue, No. 75, Coconut Creek (Florida) (2016), pp. 810–814 ISSN 0749-0208

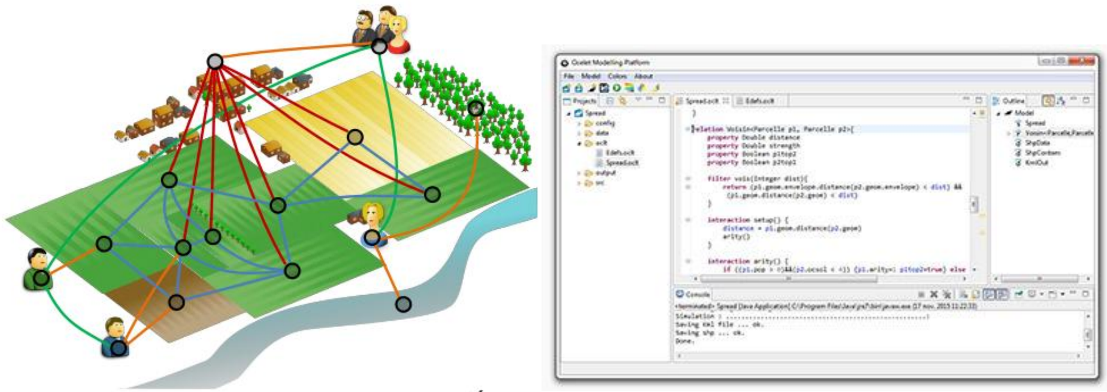

Figure 11. Illustration of Ocelet modeling platform and graph interaction

Ocelet offer to modelers as large as possible capacity of expression, with (a) no predefined representation of space and the possibility to mix more than one (grid, vector, continuous), and (b) no predefined form of relationship, where most modelling tools have their own relationship meta-model (e.g. agent-population hierarchy, topological adjacency neighborhood) which can sometimes be constraining for the modeling exercise. We believe that having only one same generic concept to hold any kind of interaction, with the support of a domain specific language, is a good compromise between capacity of expression and ease of use. It also provides appropriate concepts and associated tools to help modelers integrate points of views from different scientific disciplines into one same model.

4.Program implementation

4.1 Data requirements

The LAUREL team has made good progress in identifying and obtaining various data layers that are needed for the two LAUREL components. The data mobilization effort so far has relied on MOZGIS, the Inter-Agency GIS portal for Mozambique supported by Ministry of Transport (MTC).

Remaining data mobilization that is critical to enabling the work to progress on the two LAUREL components consists of the data layers itemized in Table below. The LAUREL team has met with key technical contact persons in relevant Government institutions to agree on the steps indicated in the Table to enable access to the sought data bases.

Table 4. Remaining Key Data Mobilization Plan

Data Content	**Source/Agency**	**Agreed plan and timetable for access**
Forests license and concessions	DINAF	20 October
Transport – digital spatial inventory, existing and planned	MTC	TBD
Agricultural statistics - SIMA : commodity prices in Excel File by market place	DINAS	Already shared
Agricultural statistics - SDAE: crop acreage and production data per district	DINAS	TBD
Other production and consumption surveys: AIS 2015 : Inquérito Agricola Integrado - Agrarian Integrated Survey IOF 2015 - Inquerito ao Orcamento Familiar — household budget survey - 2014/15.	DINAS	 Already shared Already shared
National Soil map	IIAM	Already shared
Land use and Land change points database	MRV Unit	To be shared with the LAUREL team in October 7/November 7 2017

Land use and land cover map 2016	MRV Unit	To be finalized 7 December 2017 and shared with the Laurel team
Roads and Infrastructure development	ANE	To set a VC with ANE
Population Migration	INE	20 October
Demographic and Health Survey – 2011 and 2013	INE and MISAU	20 October
Natural Hazards Risk Zones	INGC	24 October

4.2 Capacity building and training

As mentioned in the TOR we will be conducting training in both land use modeling on-site in Mozambique. For instance, these will be week-long programs that follow our established course – we have given DINAMICA EGO training in more than 10 countries.

While the schedule is flexible, we currently expect to hold these training courses in early to mid-2018.

The key steps to local partnerships and provide useful training sessions in 2018 are:

- Formalize partnership with UEM and establish connection to professors and students (already underway with Prof. Jose Rafael, Prof. Ivan Rename, SECOSUD project, and others).
- Conduct training courses at UEM, as described in the TOR, open for any interested parties.

4.3 Work plan and delivery schedule

The table below presents the general work plan and delivery schedule.

Table 5. LAUREL prototype development work plan and delivery schedule

Module	Activities	**1st Tech report** Dec. 2017	**2nd Tech Report** April 2018	**3rd Tech report** Nov. 2018
Population	Population projection	X		
	Spatial population allocation model	X		
Crop	First run of selected crop and potential yields	X		
	Adding crops		X	
	Integration of climate change scenarios			X
Household and land use	Design of household typology and attributes	X		
	Design of household rules and functioning	X		
	First implementation of household model		X	
	Final implementation of household model			X
Land	Final Land use and land cover change		X	
	Final Land degradation		X	
National economy	Draft linkage or regional to national economy		X	
	Final linkage of regional to national economy			X
LANDSIM simulation	Draft business as usual scenarios outputs		X	
	Final scenarios (BAU and other) outputs			X
General activities	Setting up collaboration with stakeholders	X	X	
	Workshop		X	X
	Training sessions		X	X

ANNEX I: Household model

A draft formal description of the household model

The household model is mainly an extended farming system model that includes non-farming expenses and incomes in the decision-making process. The model is based on 4 main variables (land capital, labour access, financial capital and capital goods) that may change according to the interaction between the previous state of the system and context evolution (prices, policies…).

The model is designed to show changes in land use (farmland expansion or reduction) and in household strategy towards production (subsistence vs commercial). These changes will depend on external factors (weather, policies, prices…) and evolution of household assets (land, labour, capital goods, crop repartition on the farmland…).

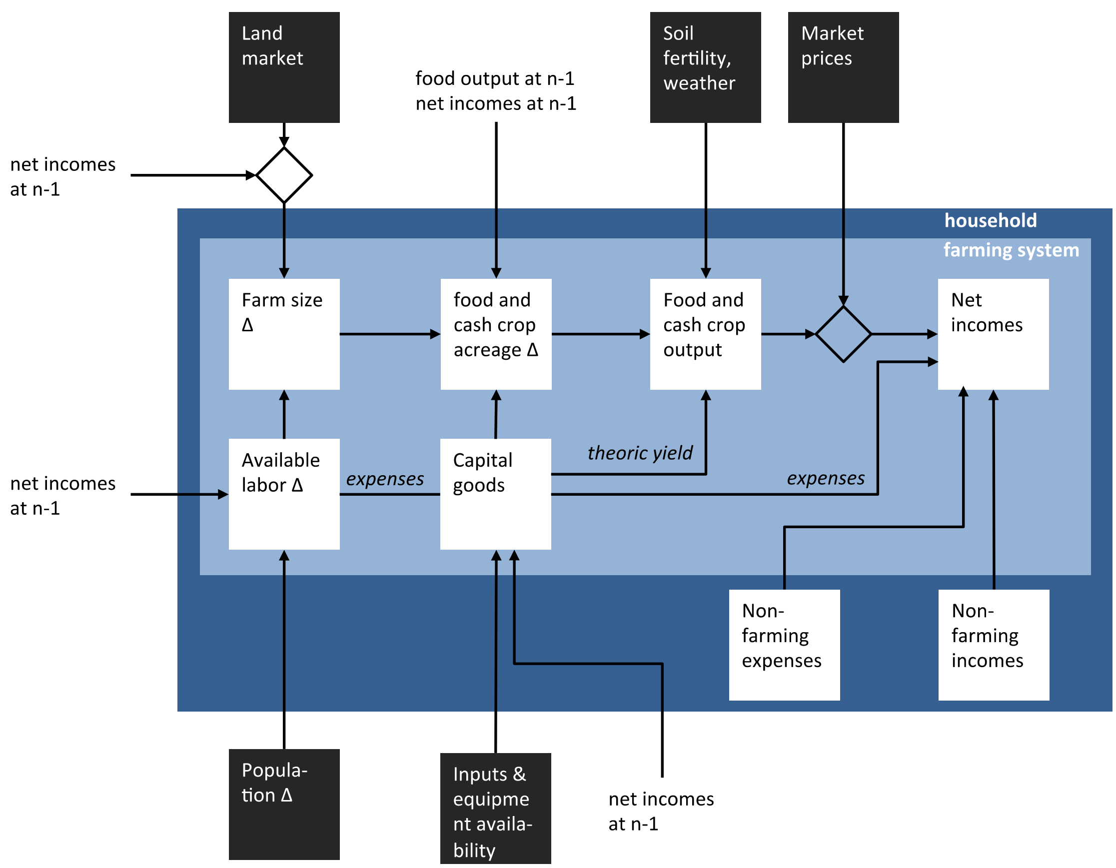

Figure A1. Household model sub-modules and links with external factors

2. Main variables and relationships

2.1 Labour

Labour represents the workforce inside the farming system. In this model, we consider the total available workforce (WA).

The total available workforce is equal to the sum of the household workforce (WH) and the waged workforce (WW). The household workforce will be initially defined by the available statistical data on household (household survey). The household workforce may vary through time (birth, death, migration… => which model?). The use of waged workforce will depend on the household assets (incomes level and incomes repartition) and external factor (availability of labour outside the household => model?).

WA = WH+WW
WH = (statistical data on population).fn(population model)
WW = fn(household incomes, population model)

2.2 Land

The farming system land (LT) is the sum of land used for each crop (staple crop acreage LS, cash crop acreage LC), land for livestock (LB) and fallow (LF).

Considering a farming system with 2 staple crops and 1 cash crops:

$$LT = \sum(LS_1, LS_2, LC_1, LB, LF)$$

2.3 Financial capital

At each turn n, the household model has a financial capital K that is the sum of farming incomes (IF) and non-farming incomes (INF) minus farming expenses (EF) and non-farming expenses (ENF). K_n is equivalent to the net income at the end of the fiscal year (turn) n.

$$K = IF+INF-(EF+ENF)$$

2.4 Capital goods and services

Capital goods are the tools and inputs used for the farming activities. Their use impacts the work productivity (less necessary workforce) and the theoretical yields (expected yields in optimal external conditions). We also include in this category the use of services that encompasses equipment (*e.g.*, rented plough ≠ from waged labour). Goods and services also impact the household income through their consumption (or amortization).

For the model purpose, we will specify household's capital goods and services use through categorisation (or level) in order to have discrete states of input and equipment use. First level will describe the most limited access to tools and inputs: all work is done with the help of basic tools (machete, axe, digging stick, hoe) and no inputs (pesticides, fertilizers) are used. The higher level will correlate with access to high-end tools (tractors) and inputs.

In order to do this categorisation we need to:

- ✓ Assess tools, inputs and services uses by farming system type (data in household survey and TIA survey) in order to model bundle of capital goods
- ✓ Assess costs, gain of productivity (work productivity and crop/livestock yield) for each category.

Capital goods and services also need to be context-specific. For instance, farming systems with a use of irrigation do not necessarily rely on the same package of tools, inputs and services that rain-fed system in forest area.

Moreover, we expect that farming systems with a high level of equipment or an intensive use of inputs and services will have a strong commercial strategy while low capital goods will be strongly linked to subsistence farming strategy.

3. Decision-making process within the household model

The sequence of decision within the household is the following:

1. Farm size variation
2. Land attribution repartition
3. Marketing decision
4. Net income uses (repartition amongst household needs)
5. Estimation of available labour

3.1 Farm size variation

The Farm size variation will depend on cash available to access land (land market model?) and the comparison between the available workforce and the necessary workforce to maintain the farming system.

Land market and access to new land

how to model land market? Does it even reflect reality? => case of collective management of land, case of low population density, etc

Decision process of land expansion (or reduction) through the comparison with the necessary workforce

Definition of the necessary workforce. The necessary workforce (WN) is the sum of each specific workforce necessary for each crop and livestock activities in the farming system in order to reach the theoretical yield for each of these activities (= optimal yield regarding material conditions – see 3.4. capital goods).

$$WN = \sum(WS_x\ WC_x,\ WB_x)$$
$$WS_x = LS_x.WS_x*$$
$$WC_x = LC_x.WC_x*$$
$$WL_x = SB_x.WB_x*$$

WS_x is the workforce necessary for the staple crop S_x, WC_x is the workforce necessary for the cash crop C_x and WB_x is the workforce necessary for the livestock B_x. WC_x is the multiplication of the necessary workforce for the cash crop x on 1 ha (WC_1*, a constant linked to the level of capital goods) by the land allocation for the cash crop x in the farming system (LC_x). WB is the multiplication of the necessary workforce for 10 heads of the livestock x (WB_x*) computed to the actual livestock size (SB_x).

- *WB* <=> 10 heads = arbitrary, to be adapted to existing data*
- *WC* vary in time (e.g., more weeding activity in plots at year 2 than year 1 in the case of slash and burn practises)*

Set of rules for the decision process: comparison of WA and WN and outcomes.

1) At turn n, WA is inferior to WN. The household does not have access to enough workforces in order to maintain all its activities. The household will decrease its farmland to match its available workforce. The acreage of the less profitable cash crop will be reduced proportionally to the available workforce of this crop. Profitability defined through the ratio (activity income)/(activity necessary workforce) (see below farmland repartition).

   If WA<WN,
   $WC_n=WC_{n-1}+(WA-WN)$
   $LC_n=WC_n/WC*$

- *Case WC_{n-1} < (WA-WN) => then less profitable cash crop = exit and second less profitable cash crop with acreage reduction. And so on*

2) At turn n, WA is superior to WN. In the case that the household has no food access issue, the new land goes to the most profitable cash crop (ranking through income/workforce ratio). In the case the household has food access issue, the new land goes to the main staple crop (according to household typology). For food access estimation, see farmland repartition decision process making below.

   Case 1: no food problem => new land to more profitable cash crop

LC_n= (WA-WN)/WC*

Case 2: food problem => new land to main staple crop
LS_n = (WA-WN)/WS*

- *Criteria ∂? WA>WN+∂, where ∂ is a number of supplementary day of work needed so that change is considered possible*
- *Define if ∂: existing data on farming system expansion*
- *Case livestock missing*

3.2 Farmland repartition

The farmland repartition decision process refers to the repartition of land use for each farming activity at each turn n. This decision process depends on the household food access, which is linked to the household own food output and, in case of the household's food production is lower than its needs, to the household incomes that can be attributed to food.

The household food access criteria will be based on the province's average household staple crops output (FA) as, according to available data, household tend to produce more than their actual needs. The decision process will be based on the comparison between this food access criteria and the household staple crop output (OS_x, for the quantity produced of staple crop S_x) at turn n-1. If the food access value is superior to the staple crop output, then the household will attribute more land for its main staple crop (staple crop ranking through initial production output). On the contrary, if the food access value is inferior to the staple crop output, the household will then attribute more land to cash crop (expansion of the more profitable cash crop).

Case of 2 staple crops, S_1 and S_2 and 2 cash crops C_1 and C_2:

If $(\sum(OS_{n-1}))/WH \leq FA_{n-1}/WH$,
$LS_{1,n} = (FA-LS_{2,n-1}) / YS_{1,n-1}$
If $LS_{1,n} > LT-(LS_2+LC_1+LC_2)$,
$LS_{1,n} = LT-LS_2$

If $(\sum(OS_{n-1}))/WH > FA/WH$,

Rank staple crop using (OS_x/WH), Staple crop with the highest output variation from initial situation, reduction using the theoretical yield LS= (FA-$LS_{x,n-1}$)/YS*

The system calculates then the remaining land for cash crop

$\sum(LC_x) = LT-\sum(LS_x,LF\ldots)$

Finally, the system allocates land to cash crop based on the ratio income/necessary workforce.

$$LC_1=\sum(LC_x).(IC_1/WC_1)/(\sum IC_x/\sum WC_x)$$
$$LC_2=\sum(LC_x).(IC_2/WC_2)/(\sum IC_x/\sum WC_x)$$

- at initial stage, cropland repartition according to IAS data
- link between soil fertility and crop allocation not represented here
- what about introduction of new varieties and suppression of old ones?
- case of disappearance of crops, can reappear in favourable context => selection through random function, based on initial state or neighbouring more profitable cash crop, …?

3.3. Marketing decision

The household does not only sell cash crops and livestock. Staple crops can also be sold. In order to model that we set another variable than the food access criteria (FA), which reflects household practices regarding food production at the province scale. FA is always superior to the household food needs (FN), which is the quantity of staple crops needed by the whole household for the whole year. If the staple crops output is superior to the household food needs, then the surplus can be sold on the market (MS for marketable staple crop).

If $\sum(OS_x) > FN$,
$MS = \sum(OS_x)-FN$

- aggregate presentation, needs to be done for each staple crops (means to determine FN for each staple crops)

3.4. Net income definition and uses

Farming incomes (IF) are the sum of the marketable output for each crop and livestock (respectively MS, MC, ML) multiplied by their market price at turn n (respectively PS, PC, PL).

Farming expenses (EF) are the sum of costs linked to waged labour (HWW), tools (amortization, renting), inputs and services uses (respectively HE, HI and HJ).

Non-farming incomes and expenses (INF and ENF) will be inferred from the household survey database using a ratio between the total income or expenses of the household and the part of its incomes or expenses coming from outside the farming system.

$$K = IF+INF - (EF+ENF)$$
$$IF = \sum(MS.PS,MC.PC,ML.PL)$$

$EF = \sum(HWW, HE, HI, HJ)$
$INF = fn(\text{statistical data})$
$ENF = fn(\text{statistical data})$

A key element to specify is the household's reinvestment strategy of incomes. Reinvestment behaviour will be defined through 1) the household budget survey database, which will give us elements to specify repartition of expenditures amongst the household and through 2) the household typology, which will help us to identify potential development trajectories for each household/farming system.

However, in order to set a coherent model, we can already set household reproduction (purchase food for the household member if the food production is not enough, non-farming expenses – more than that: school, phone, bicycle…) and farming system reproduction (necessity to spare enough funds on net income so as to maintain the level of capital goods even if the farming system is expanding) as 1st and 2nd use of incomes. Analysis of existing data will help which type of investments come next (farming vs non-farming activities).

3.5. Estimation of available labour

use of waged labour to be linked with a certain level of income

3.6. Change of capital goods level

idem link investment in farming system and level of incomes

ANNEX II: Household typology and attributes

A preliminary exercise of designing household typology and attributes has been performed using recently collected household surveys database and is presented below.

In addition to the dataset presented above, several recent publications on the economics of agricultural production in Mozambique are available and provide adequate description of the variation in production practices. Furthermore, ETC Terra and members of the LAUREL team have considerable experience in the economic of crop production in Mozambique, with a particular focus on Zambezia.

Below are selected tables and maps of input data to be used in the modeling of the households.

Number of households, people/hh & Area farmed

Province	Number*	Person/household**	Category	Av. Area farmed***	Category
Niassa	225,151	4.30	1	1.79	3
Cabo Delgado	339,816	4.00	1	1.44	2
Nampula	829,642	4.00	1	1.22	2
Zambezia	828,801	4.20	1	1.28	2
Tete	376,150	4.50	2	1.60	2
Manica	265,486	5.00	3	2.04	3
Sofala	271,249	4.80	3	1.70	3
Inhambane	269,310	4.40	2	1.51	2
Gaza	216,771	4.90	3	1.60	2
Maputo	150,706	4.50	2	0.81	1
Maputo City	54,715	4.90	3	0.53	1

*Source: INE Censo Agro Pecuario 2010 / Quadro 1.1 - Número de explorações agro-pecuárias por província segundo o tipo
Value of attributes per each province
Categories are from 1 to 3 minor to major. Le 1 représentant la catégorie qui représente le moins l'attribut.
**Source: Recenseamento Geral Da População E Habitação 2007
***Source: Source: INE Censo Agro Pecuario 2010

Percent acreage per crop

Province	Maize	Cassava	S_mapira	Tobaco	Sesame	Peas	Total
Niassa	28,93%	12,40%	10,33%	30,17%	8,68%	9,50%	100,00%
Cabo Delgado	21,23%	22,91%	16,20%	12,29%	17,32%	10,06%	100,00%
Nampula	17,01%	23,71%	13,40%	16,49%	19,59%	9,79%	100,00%
Zambezia	19,80%	22,84%	12,18%	13,71%	15,23%	16,24%	100,00%
Tete	27,76%	6,94%	12,24%	31,84%	12,65%	8,57%	100,00%
Manica	29,79%	7,88%	13,70%	31,16%	11,99%	5,48%	100,00%
Sofala	32,11%	11,47%	21,10%	10,09%	17,43%	7,80%	100,00%
Inhambane	28,06%	38,85%	20,86%	2,16%	7,91%	2,16%	100,00%
Gaza	40,97%	26,39%	18,75%	0,00%	10,42%	3,47%	100,00%
Maputo	53,01%	22,89%	10,84%	0,00%	9,64%	3,61%	100,00%

Maputo City	44,07%	33,90%	5,08%	0,00%	11,86%	5,08%	100,00%

Source: INE Censo Agro Pecuario 2010

Ratio (by acreage) of food/cash crops

Province	Food Crop	Cash crop	Ratio	Catégories
Niassa	51,65%	48,35%	1,07	1
Cabo Delgado	60,34%	39,66%	1,52	2
Nampula	54,12%	45,88%	1,18	1
Zambezia	54,82%	45,18%	1,21	1
Tete	46,94%	53,06%	0,88	1
Manica	51,37%	48,63%	1,06	1
Sofala	64,68%	35,32%	1,83	2
Inhambane	87,77%	12,23%	7,18	3
Gaza	86,11%	13,89%	6,20	3
Maputo	86,75%	13,25%	6,55	3
Maputo City	83,05%	16,95%	4,90	3

Source: INE Censo Agro Pecuario 2010

Livestock: number of bovine per household

Province	Head cattle	Bovine/household	Catégories
Niassa	14,252	0.063	1
Cabo Delgado	9,641	0.028	1
Nampula	50,476	0.061	1
Zambezia	13,940	0.017	1
Tete	318,911	0.848	2
Manica	157,437	0.593	2
Sofala	57,743	0.213	2
Inhambane	185,923	0.690	2
Gaza	312,981	1.444	3
Maputo	138,549	0.919	2
Maputo City	17,191	0.314	2

Yields of cultivated crops (kg/ha)

Province	Milho	Mandioca	Mapira	Tabaco	Gergelim	Feijao boer
Niassa	751	5,517	462	1,242	396	1,327
Cabo Delgado	751	5,517	462	1,242	396	1,327
Nampula	751	5,517	462	1,242	396	1,327
Zambezia	751	5,517	462	1,242	396	1,327
Tete	751	5,517	462	1,242	396	1,327
Manica	751	5,517	462	1,242	396	1,327
Sofala	751	5,517	462	1,242	396	1,327
Inhambane	751	5,517	462	1,242	396	1,327
Gaza	751	5,517	462	1,242	396	1,327
Maputo	751	5,517	462	1,242	396	1,327

Maputo City	751	5,517	462	1,242	396	1,327

Source: FAO Stat

Labor days needed per ha by crop

Labor	Milho	Mandioca	Mapira	Tabaco	Gergelim	Feijao boer
Days/ha	65.9	60.1	53.0	0.0	159.0	29.2

Données ZIMLP - Mémento

Agricultural input use

Province	No. HH	Pesticide incidence by Province	% HH using pesticides	Cat.
Niassa	225 151	10 541	4,68%	2
Cabo Delgado	339 816	15 813	4,65%	2
Nampula	829 642	8 491	1,02%	1
Zambezia	828 801	1 047	0,13%	1
Tete	376 150	34 357	9,13%	3
Manica	265 486	4 245	1,60%	1
Sofala	271 249	1 482	0,55%	1
Inhambane	269 310	5 265	1,95%	1
Gaza	216 771	4 237	1,95%	1
Maputo	150 706	2 441	1,62%	1
Maputo City	54 715	5 275	9,64%	3

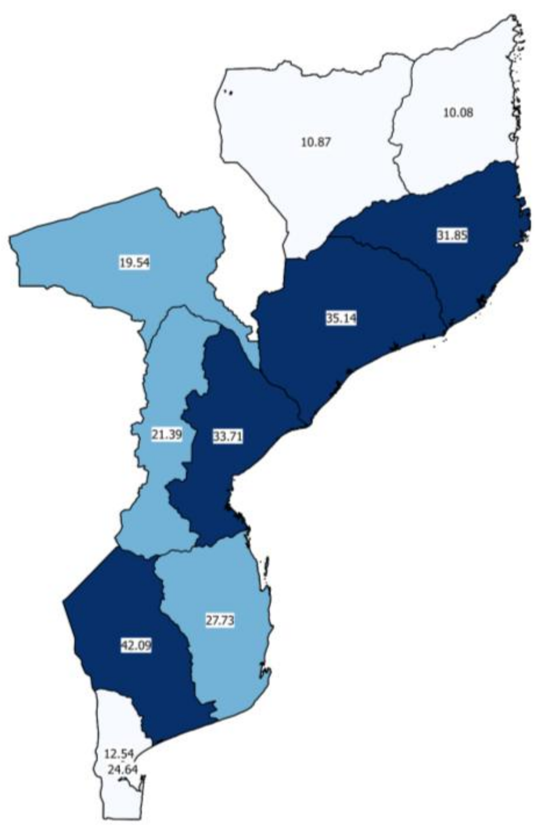

Figure 1. Percentage of households using rotating cultivation by Province

Kcal produced per ha & consumed per household

Province	Maize	Cassava	Mapira	Total Kcal	Total kcal/HH/year	Comparison	Cat
Niassa	1,917,839	2 648 000	379 817	4 945 656	2 425 093	2,04	3
Cabo Delgado	1 041 113	3 618 933	440 588	5 100 633	2 255 901	2,26	3
Nampula	904 124	4 060 267	395 010	5 359 400	2 255 901	2,38	3
Zambezia	1 068 510	3 972 000	364 624	5 405 134	2 368 696	2,28	3
Tete	1 863 044	1 500 533	455 780	3 819 357	2 537 888	1,50	2
Manica	2 383 600	2 030 133	607 707	5 021 440	2 819 876	1,78	2
Sofala	1 917 839	2 206 667	698 863	4 823 369	2 707 081	1,78	2
Inhambane	1 068 510	4 766 400	440 588	6 275 498	2 481 491	2,53	3
Gaza	1 616 464	3 354 133	410 202	5 380 800	2 763 479	1,95	3
Maputo	1 205 499	1 677 067	136 734	3 019 299	2 537 888	1,19	1
Maputo City	712 340	1 765 333	45 578	2 523 252	2 763 479	0,91	1

Source: FAO Stat / USDA

Local markets prices for selected crops (USD/Ton)

Province	Milho	Mandioca	Mapira	Tabaco	Gergelim	Feijao boer
Niassa	212,25	231,10	189,95	474,30	1028,80	802,00
Cabo Delgado	212,25	231,10	189,95	474,30	1028,80	802,00
Nampula	212,25	231,10	189,95	474,30	1028,80	802,00
Zambezia	212,25	231,10	189,95	474,30	1028,80	802,00
Tete	212,25	231,10	189,95	474,30	1028,80	802,00
Manica	212,25	231,10	189,95	474,30	1028,80	802,00
Sofala	212,25	231,10	189,95	474,30	1028,80	802,00
Inhambane	212,25	231,10	189,95	474,30	1028,80	802,00
Gaza	212,25	231,10	189,95	474,30	1028,80	802,00
Maputo	212,25	231,10	189,95	474,30	1028,80	802,00
Maputo City	212,25	231,10	189,95	474,30	1028,80	802,00

Source: FAO Stat

Incomes from cash crops

Province	I_Tabaco	I_gergelim	I_feijao boer	I_Total	Cat.
Niassa	430,10	85,55	244,72	760,37	3
Cabo Delgado	129,62	126,29	191,52	447,43	2
Nampula	188,54	154,81	202,16	545,50	2
Zambezia	159,08	122,22	340,48	621,77	2
Tete	459,56	126,29	223,44	809,29	3
Manica	536,15	142,58	170,24	848,97	3
Sofala	129,62	154,81	180,88	465,31	2
Inhambane	17,68	44,81	31,92	94,41	1
Gaza	0,00	61,11	53,20	114,31	1
Maputo	0,00	32,59	31,92	64,51	1
Maputo City	0,00	28,52	31,92	60,44	1

Estimated incomes from agriculture

Province	HH Income from agriculture
Niassa	12 984
Cabo Delgado	4 452
Nampula	2 112
Zambezia	6 288
Tete	17 364
Manica	3 360
Sofala	2 460
Inhambane	1 068
Gaza	1 008
Maputo	1 812
Maputo City	564

Source: *Relatório Final Do Inquérito Ao Orçamento Familiar - Iof-2014/15 Quadr0 3.1 Receitas Mensais (Inclui Transferências Em Espécie) Por Agregado Familiar Por Províncias, (Em Meticais A Preços Correntes) Segundo Fontes De Receitas. Moçambique, 2014/15*