A Model to Determine Aptitude of Mozambique territory for cultivating and processing *Jatropha curcas* L. as a bioenergy crop

José Castro Coelho, Pedro Mateus

**Abstract**— GALP Energia’s Biofuels Business Development Unit considered it necessary to create a GIS-based model for identifying and assessing areas to support decision-making on the implementation of *Jatropha curcas* Linn (JCL) projects in Mozambique. From this need/challenge was born the present methodological proposal for the first prototype of the model. In summary, the identification and subsequent choice of new areas for JCL planting is structured in two phases, which consider: Phase 1 - Macro-scale assessment of the logistics conditions of the sites, from the perspective of the industrial component. This first set of variables includes the qualitative assessment of the following 5 variables: Regional/national connections to the sea port; Local accesses; Electric network; Other support infrastructures; Land availability without DUAT assigned. The appraisal of each of these variables is made according to a scale of four levels of aptitude (High, Moderate, Reduced and Without aptitude), considering their impact on the ease and/or cost of installing and operating industrial units; Phase 2 - assessment of the agroecological skills of the sites for culture, at the micro scale and from the agronomic perspective. This second set of variables includes the qualitative assessment of the following 7 variables: Climate; Soils; Vegetable Cover; Land availability, ownership and restrictions; Agricultural infrastructure and improvements; Water resources; People and population (availability of man-power). The assessment of each of these variables is made on a four-level fitness scale in view of their impact on the ease and/or cost of setting up and operating JCL plantations.

**Index Terms**— Agroecological Zoning, Bioenergy, *Jatropha curcas* L., Multicriteria analysis.

I. INTRODUCTION

The exponential growth of energy demand worldwide, the depletion of oil reserves and the severe pollutants problems caused by industry that favors greenhouse effect, evidence the need to increase the supply of biofuels.

According to this, the new energy strategy for Europe from 2011 to 2020 has been discussed in European Union (EU) institutions [1]-[3] This strategy has to be in line with the “Lisbon Treaty” to guide long-term emission-reduction goals, the so-called 20–20–20. To achieve energy and climate goals, the potential of bioenergy is a key issue. The European Parliament has placed special emphasis on the design of a biomass policy to foment a market for this agricultural and forestry product in order to promote biofuels in Europe. In this regard, the share of biofuel production was up 8% between 2010 and 2011, reaching 16,027,000 t [4]. Nevertheless, the EU is far from being the major world producer of biofuel [5].

This sets a new overview for studying non-edible oilseeds species for biodiesel production. An alternative is barbados nut or piñon (*Jatropha curcas* - JCL) crop, perennial bush that is native from Mexico and Central America, grows in most of tropical countries, and it is considered like one of the non-conventional oilseed crops with great expectations for obtaining biodiesel.

The JCL seeds have an outstanding characteristic: their high oil content allows converting it to liquid biofuel, and also the shell can be transformed into biogas and biofertilizers. JCL is a green option to reforest degraded soils and to control erosion, as well as an option to diversify agricultural systems. On the other hand, in several scientific and technical studies [6]-[10] it is reported a wide variation in yields, due lack of study of plant’s genetics, the agronomic handling, as well to the misunderstanding that exists in some countries in the field of zones with best agroecological ability to set the crop. The agroecological zoning (AEZ) refers to a division of land surface and weather into smaller units that have similar characteristics related to its ability, potential yield and environmental impact. However, previous AEZ studies have been conducted with the use of biophysical and ecological datasets to the neglect of equally important socio-economic variables.

In this context, the Portuguese main company of fuel energy (GALP Energia)’s and its “Biofuels Business Development Unit” considered it necessary to create a GIS-based model for identifying and assessing areas to support decision-making on the implementation of JCL (agricultural and industrial) projects in Mozambique. From this need/challenge was born the present methodological proposal and the first prototype of the model.

Therefore, this research is conducted at the Mozambique national level to estimate suitable agricultural areas/zones for JCL crop in Mozambique by application of socio-economic variables in conjunction with widely employed biophysical and ecological variables. The objective of this study is to provide an up-to-date, GIS based agricultural land suitability renewable energy share to 20% of final energy consumption and to increase energy efficiency by 20%.

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José Castro Coelho, *Department of Sciences and Engineering of Biosystems, School of Agriculture - University of Lisbon*, Lisboa, Portugal, Phone No. +351 21 365 3177.

Pedro Mateus, Biofuels Development Unit, Galp Energia, Lisboa, Portugal, Phone No. +351 217 240 407.

1 The emission reduction goals, the 20–20–20, are the following: to reduce greenhouse gas emissions by 20% compared to 1990 levels, to increase the
assessment for determining suitable agricultural areas/zones for JCL in Mozambique. Biophysical, ecological and socio-economic factors assumed to influence agricultural land use were assembled and the weights of their respective contributions to land suitability for agricultural uses were assessed using analytic hierarchical process. This study used the four levels [highly suitable (3), moderately suitable (2), marginally suitable (1) and unsuitable (0)] suitability classes commonly used by the Food and Agricultural Organization [11]-[12].

II. THE CONCEPTUAL MODEL AND ITS VARIABLES

In summary, the identification model and subsequent choice of new areas for JCL planting is structured in two phases, which consider:

* Phase 1 - Macro-scale assessment of the logistics conditions of the areas/zones, from the perspective of the aptitude for implementing an agro-industrial project. This first set of variables includes the qualitative assessment of the following 5 variables: Regional/national connections to the sea port; Local accesses; Electric network; Other support infrastructures; Land availability without DUAT assigned2 (Table I).

A complex decision problem is decomposed into its constituent criteria. The criteria are therefore prioritized according to their relative importance within each level. The appraisal of each of these variables is made according to a scale of four levels of aptitude (High, Moderate, Reduced and Without Aptitude), considering its impact on the ease and/or cost of installation and operation of industrial units, which is presented in the following table.

Table I - Macro assessment, first phase (variables and aptitude classes to consider and appreciate)

| Variables                                         | Without Aptitude (0) | Reduced Aptitude (1) | Moderate Aptitude (2) | High Aptitude (3) |
|---------------------------------------------------|----------------------|---------------------|-----------------------|-------------------|
| Regional/national connections to the nearest sea port (Maputo, Beira or Nacala) city (Maputo, Xai-Xai, Inhambane, Beira, Chimoio, Quelimane, Tete, Nanpula, Penha) | Area/Zone without paved roads and railways. Distance to the nearest sea port > 250 km. Distance to the nearest city > 150 km | Area/Zone with remote connections (>50 km) to main paved roads and/or railways. Distance to the nearest sea port 250-120 km. Distance to the nearest city 150-100 km | Areas with close connections (<50 km) to main paved roads and/or railways. If the distance is more than 100km, the existence of the railway gains more relevance. Distance to the nearest sea port 250-120 km. Distance to the nearest city 150-00 km | Area with close connections (<50 km) to main national asphalted roads and/or railway. Distance to the nearest sea port < 120 km. Distance to the nearest city < 50 km |

2 DUAT – Direito de Uso e Aproveitamento da Terra (right to use and benefit from land)

* Phase 2 - assessment of the agroecological skills of the sites for culture, at the micro scale and from the agronomic perspective. This second set of variables includes the qualitative appreciation of the following 7 variables: Climate; Soils; Vegetable Cover; Land availability, ownership and restrictions; Agricultural infrastructure and improvements; Water resources; People and population (availability of man-power). The assessment of each of these variables will be made on a four-level aptitude scale, with a view to their impact on the ease and/or cost of setting up and operating JCL plantations (Table II).

Table II - Micro assessment, second phase (variables and aptitude classes to consider and appreciate)

| Variables | Without Aptitude (0) | Reduced Aptitude (1) | Moderate Aptitude (2) | High Aptitude (3) |
|-----------|----------------------|---------------------|-----------------------|-------------------|
| Climate | Steppe semi-arid climate (Bs). Marked water deficiency (4-6 dry months). | Rainy tropical savanna climate (Aw). Moderate water deficiency (3-4 dry) | Tropical monsoon (Am) and altitude (Cw) climates. Water deficiencies are low | |

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### Soils

| Soils | very intense and frequent droughts, annual R < 600 mm, annual T < 22°C | months: R <600(mm), annual R 600-1000 mm, annual T 22°C-26°C | (1-3 dry months), annual R > 1000 mm, annual T > 26°C |
|-------|---------------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------|

### Vegetative Cover

| People and Populatio n | Sandy soils with poor fertility and low water storage capacity and moderate fertility | Sandy soils with good fertility and medium to high water storage capacity and high fertility |
|------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|

### Land availability, ownership and restriction s

| People and Populatio n | Absence of “past” for food crops | People and Populatio n |
|------------------------|----------------------------------|-----------------------|

### Agricultural infrastructure and improvements

| People and Populatio n | Absence of “past” and agricultural improvements | People and Populatio n |
|------------------------|-----------------------------------------------|-----------------------|

| People and Populatio n | Reduced availability (spot within a circle of radius of 15/20 km and with <5,800ha) and/or reduced ownership (20-25 years) and/or with doubts about the possibility of using it for JCL | People and Populatio n |
|------------------------|-------------------------------------------------|-----------------------|

| People and Populatio n | Absence of agricultural productivity and infrastructural requirements for food crops | People and Populatio n |
|------------------------|----------------------------------------------------------------------------------|-----------------------|

### Water resources

| People and Populatio n | Absence of surface water (rivers and dams) | People and Populatio n |
|------------------------|--------------------------------------------|-----------------------|

| People and Populatio n | Absence of surface water (rivers and dams) | People and Populatio n |
|------------------------|--------------------------------------------|-----------------------|

### III. THE GIS PLATFORM

The proposed model has a markedly spatial use where the main objective is the geographical characterization of the aptitude for the implantation of an agro-industrial project of JCL in Mozambique. The expected end result is a thematic map of Mozambique classified by four aptitude classes: high, moderate, reduced and without aptitude (which means exclusion of the area).

The tool used for cartography elaboration was ArcMap GIS Software, which consists of computer mapping system that relates locations with agroclimatic, social, infrastructures/logistic, etc., information equal, in this case, to *Jatropha curcas* crop and industrial project requirements.

One way to implement the model in a GIS framework is to construct a cartographic model consisting of a collection of maps recorded on a common cartographic basis, where each map refers/retracts to a variable and on which mathematical operations can be performed. The common cartographic base is an indispensable requirement to ensure that any point (coordinate) has exactly the same geographical location on all maps. The cartographic basis that we have used came from [13]-[15].

Maps are raster in shape, meaning that a grid where the pixel is the base processing unit and defines the accuracy of the map defines space. Performing algebraic operations on one or more maps at the same time is called map algebra. With map algebra, it is possible to establish a set of mathematical functions that allow processing the various maps contained in the GIS cartographic base.

Designing scenarios that represent different alternatives and points of view on how best to characterize fitness is achieved with multicriteria analysis. Multicriteria analysis consists of assigning different weights to the model variables so that the addition of the variables reflects their importance. It can be done by percentages, weighted average, and other methods, but the central idea is that the user/modeller has the ability to differentiate variables by their importance as well as perform sensitivity analyses on variables.
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The following Fig.1 is an exemplary scheme of the calculation procedure from variables to final scenarios using the GIS structure and multicriteria analysis.

![Fig. 1 - Steps of applying the model in a GIS framework to obtain aptitude class maps](image)

**Classification and appreciation of the base variables**

The proposed conceptual model presents two sets of variables for macro and micro evaluation. Some of these variables are easily mapped because information already exists or is directly derived from existing data (e.g. precipitation, seaport links, roads and railways, etc.) while other variables are more difficult to map because no information is available and/or because they require field work (e.g. agricultural infrastructure and improvements, electricity grid, etc.).

The first step in building the GIS database is to define which variables will give rise to maps. This step is closely linked to the ability to obtain relevant information from a variety of sources.

To create a first approximation to the case study of Mozambique, we were able to obtain cartographic information for the following variables: precipitation, temperature, pedological resources, population density, distance to ports, distance to cities, roads, railways and land tenure.

Therefore, and although this list includes variables that we previously considered in the conceptual model to belong to the 1st and 2nd evaluation phases, we will consider them, from this point on, as the basic variables for obtaining aptitude maps at macro, or national scale.

**Construction of maps with valuation of base variables**

After defining the base variables, it is necessary to digitize and construct the maps, in this case in raster format. There is no general rule for this, and in each case, the solution adopted depends on the type and detail of the information available.

The base variable maps were obtained by:
- Precipitation - digitizing a map [13] with a scale of - 1:12,000,000;
- Temperature - digitization of a map [13] with a scale of 1:12,000,000;
- Pedological features - digitizing a map [13] with a scale of 1:6,000,000;
- Population density - digitization of a map [13] with a scale of - 1:6,000,000;
- Distance to ports - buffer analysis based on seaport location [13];
- Distance to cities - spatial analysis (buffer) based on city location [14];
- Communication routes - Spatial analysis (buffer) based on the road and rail network [14];
- Land title - digitalization of two maps: one with location of areas occupied by reserves and natural parks2; and another with localization of areas without DUAT assigned [15].

Sorting is a simple task of reclassifying previously obtained maps by directly assigning each pixel a score based on the following closed scale (Table III).

**Table III – Aptitude weighs and classes**

| Weighs | Aptitude classes |
|--------|------------------|
| 0      | Without Aptitude |
| 1      | Reduced Aptitude |
| 2      | Moderate Aptitude|
| 3      | High Aptitude    |

We emphasize the fact that the base variable maps may not include the “without-aptitude” class, because the origin and/or nature of the information for the definition of this class may not be represented there. For example, the soil variable map contains the georeferenced information of soils and their characteristics, but by itself does not tell us enough about the occurrence and intensity of soaking problems in a given location - which is a condition of exclusion of this site for the cultivation of JCL - as it may be related to the topography of the land and/or the hydrographic network. It makes no sense, therefore, to include in the same map two sources of information with different characteristics (e.g. soil and topography), and it is preferable to make this correction only at the end of the calculations.

**Multicriteria Analysis**

As mentioned, multicriteria analysis is a way of creating scenarios by assigning weights to variables. The method used in this case study was the weighted average, where the user uses the following closed weight scale (Table IV).

**Table IV – Relevance weighs and classes**

| Weighs | Relevance classes |
|--------|-------------------|
| 0      | Not relevant at all|
| 0.5    | Little relevance  |
| 1      | Relevant          |
| 1.5    | High relevance    |
| 2      | Very high relevance|

This scale makes it easy to identify, according to the user's perception, which variables are most relevant for the construction of a given scenario. It is a simple scale that aims to give the user the ability to, in the extreme, neglect or duplicate the effect of a given variable.

The baseline or general suitability/aptitude scenario was constructed by assigning weight 1 to all variables, and reflects
the equal importance given to all variables. Alternative or specific suitability scenarios are obtained by applying an algebraic equation that will calculate the weighted average resulting from the weights assigned in the multicriteria analysis.

If we consider the following weighting scenario as an example (Table V).

| Variables               | Weight |
|-------------------------|--------|
| Precipitation [Pre]     | 1.5    |
| Temperature [Temp]      | 0.5    |
| Soil Resources [SR]     | 1.0    |
| Population Density [PopD]| 2.0  |
| Distance to Ports [DPort]| 2.0  |
| Distance to City [DC]   | 2.0    |
| Communication Ways [CW] | 1.0    |
| Land Ownership [LW]     | 0.0    |

We get the following weighted average equation:

\[
\text{weighted average} = \frac{(1.5 \times \text{Pre} + 0.5 \times \text{Temp} + 2.0 \times \text{SR} + 2.0 \times \text{PopD} + 2.0 \times \text{DPort} + 2.0 \times \text{DC} + 1.0 \times \text{CW})}{10.0}
\]

which will be applied to each pixel.

In the end, we will get a map where each pixel is scored between 0 and 3, which corresponds to its aptitude class.

In correcting the scenario maps, we removed the excluded areas (without aptitude) and reclassified the map legend from initial quantitative value, between 0 and 3, to a qualitative value of aptitude class (low, moderate, high). It is more versatile to remove exclusion areas in the end because it avoids recalculating the scenario when identifying new areas.

After the correction, we obtained the final maps of the macro location scenarios that will support the decision on which regions of interest for the implementation of agro-industrial bioenergy projects. Once the target regions are identified and classified at the macro scale, the next step will be to identify and classify the variables of the second phase of the model that require additional and detailed field work of micro localization.

IV. THE FIRST OUTPUTS OF THE MODEL

As we have said before, the sought and expected end result of each “run” of the model is a thematic map of Mozambique classified by four skill levels: high, moderate, low and no aptitude/exclusion.

To rehearse the model we decided to build and run the following 3 scenarios (Table VI).

| Variables               | Scenario 1 | Scenario 2 | Scenario 3 |
|-------------------------|------------|------------|------------|
| Precipitation [Pre]     | 1.0        | 0.0        | 1.0        |
| Temperature [Temp]      | 1.0        | 0.0        | 1.0        |
| Soil Resources [SR]     | 1.0        | 0.0        | 1.0        |
| Population Density [PopD]| 0.0        | 1.0        | 1.0        |

The first two scenarios give us a partial view of the territory's ability to implement the Jatropha project: Scenario 1 refers to soil and climate conditions and Scenario 2 refers to logistics conditions. Scenario 3, which we may call the general scenario, considers all 8 variables and gives them equal weight or importance.

The following Fig 2, 3 and 4 show the final maps for the three scenarios.

![Scenario 1 map (pedoclimatic variables)](image1)

![Scenario 2 map (social and logistics variables)](image2)
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V. CONCLUSION

The model proved to be easy, robust and useful to use. However, the scenarios tested lack the adjustment of the weights of importance to be attributed to the various variables. A practical and appropriate way to achieve this would be to form a group of experts and ask each one to assign a score/class of importance to each variable, in order to obtain a weighted average score for each one.

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