

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 production.

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 20-20-20¹. To achieve energy and climate goals,

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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

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* Linn - 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%.

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

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	Aptitude Classes (score)			
	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, Chimoiio, Quelimane, Tete, Nanpula, Pemba)	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	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)

Local accesses	Inaccessible zone	Do not allow vehicles (cars, tractors, trucks) to circulate at normal speeds at any time of the year	city 50-100 km Allow vehicles (cars, tractors, trucks) to circulate at normal speeds for much of the year	Allow the circulation of vehicles (cars, tractors, trucks) at normal speeds at any time of the year
Electric network	Non-existent and very remote (>50km)	Non-existent and remote (50-20km)	Not existing but close (<20km)	Already existing
Other support infrastructures	Network of main support services (workshops, petrol stations, factors of production, oil extraction factory,...) very remote (>50 km) and incomplete	Network of main support services (workshops, petrol stations, factors of production, oil extraction factory,...) remote (50-20 km) and incomplete	Main support network (workshops, petrol stations, factors of production, oil extraction factory,...) remote (50-20 km) or incomplete	Network of main support services (workshops, petrol stations, factors of production, oil extraction factory,...) close and complete
Land availability without DUAT assigned	Areas/Zones of parks and natural and / or landscape reserves, and fragile areas	Areas/Zones of reduced land availability without DUAT	Areas of medium land availability without DUAT	Areas of high land availability without DUAT

- 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	Aptitude Classes (score)			
	Without Aptitude (0)	Reduced Aptitude (1)	Moderate Aptitude (2)	High Aptitude (3)
Climate	All the others Climate types	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

		very intense and frequent droughts, annual R<600 mm, annual T < 22°C	months: R<60mm), annual R 600-1000 mm, annual T 22°C-26°C	(1-3 dry months), annual R> 1000 mm, annual T > 26°C
Soils	Soils with prolonged flooding or flooding periods and very low fertility	Heavy soils without prolonged flooding / flooding periods and low fertility	Sandy soils with poor fertility and low water storage capacity and moderate fertility	Frank soils with good fertility and medium to high water storage capacity and high fertility
Vegetable cover	Very dense and dense forest	Dense tree/shrub forest and/or sparse forest. Requiring intense selective deforestation	Grass and bush savanna. Requiring removal of shrubs and heavy harrowing for soil regularization	Clean of vegetation. Only requiring simple disc harrow
Land availability, ownership and restrictions	Land with very good agricultural aptitude. Use for food crops	Reduced availability (spot within a circle of radius of 15/20 km and with <5 to 8,000ha) and/or reduced ownership (20-25 years) and/or with doubts about the possibility of using it for JCL	Moderate availability (15,000 to 25,000 hectares within the ideal circle) and/or average ownership (25-35 years) and without any restrictions on use	Abundant availability (> 25,000 hectares within an ideal circle), lasting tenure (> 35 years) and without any restrictions on use
Agricultural infrastructure and improvements	Absence of infrastructure and agricultural improvements. Without "people" and without agricultural "past"	Absence of infrastructure and agricultural improvements. With "people" and agricultural "past"	Existence of a more or less operational agricultural infrastructure, with "people" and "past", or even with some activity already started	Existence of a good operational agricultural infrastructure, with "people", "past" and activity
Water resources	Absence of surface (rivers and dams) and ground water	Absence of surface water (rivers and dams). Presence of ground water, need to drill holes and pumping.	Surface waters (rivers and dams) existing but not functional throughout the year. Need to carry out works /	Surface water (rivers and dams) abundant, which never dry, and easy and immediate

			improvements	capture/pumping.
People and Population	Area without or with very low population density (<10 people/km ²) in the vicinity	Area with low and / or high population density, and / or relatively dispersed, and / or unbalanced age pyramid, and / or people without work habits and agricultural and / or industrial training	Area with average population density but relatively dispersed, and / or unbalanced age pyramid, and / or people without work habits and agricultural and / or industrial training	Area with medium and relatively concentrated population density, balanced age pyramid, people with work habits and agricultural and / or industrial training

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.

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

The following Fig.1 is an exemplary scheme of the calculation procedure from variables to final scenarios using the GIS structure and multicriteria analysis.

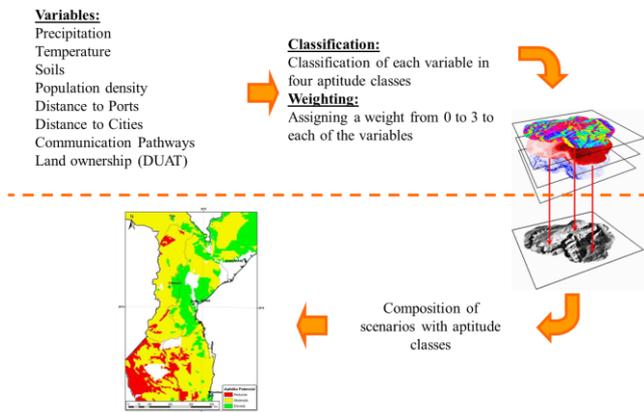


Fig. 1 - Steps of applying the model in a GIS framework to obtain aptitude class maps

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 (eg 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 (eg 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).

Table V – Variables and weighs of a hypothetical scenario

Variables	weight
Precipitation [<i>Pre</i>]	1.5
Temperature [<i>Temp</i>]	0.5
Soil Resources[<i>SR</i>]	1.0
Population Density [<i>PopD</i>]	2.0
Distance to Ports [<i>DPort</i>]	2.0
Distance to City [<i>DC</i>]	2.0
Communication Ways [<i>CW</i>]	1.0
Land Wonership [<i>LW</i>]	0.0
Total	10.0

We get the following weighted average equation:

$$\text{weighted average} = (1.5 \times Pre + 0.5 \times Temp + SR + 2.0 \times PopD + 2.0 \times Dport + 2.0 \times DC + CW) / 10.0$$

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).

Table VI – Variables and weighs of the three studied scenarios

Variables	Scenario 1	Scenario 2	Scenario 3
Precipitation [<i>Pre</i>]	1,0	0,0	1,0
Temperature [<i>Temp</i>]	1,0	0,0	1,0
Soil Resources[<i>SR</i>]	1,0	0,0	1,0
Population Density	0,0	1,0	1,0

[<i>PopD</i>]			
Distance to Ports [<i>DPort</i>]	0,0	1,0	1,0
Distance to City [<i>DC</i>]	0,0	1,0	1,0
Communication Ways [<i>CW</i>]	0,0	1,0	1,0
Land Wonership [<i>LW</i>]	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.

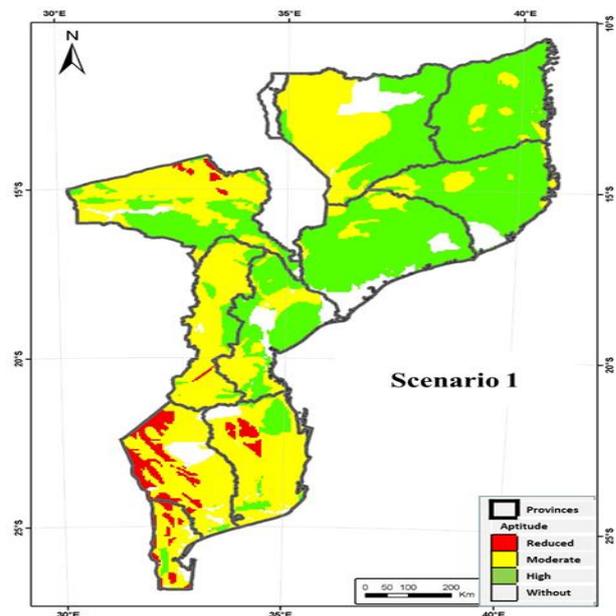


Figure 2 – Scenario1 map (pedoclimatic variables)

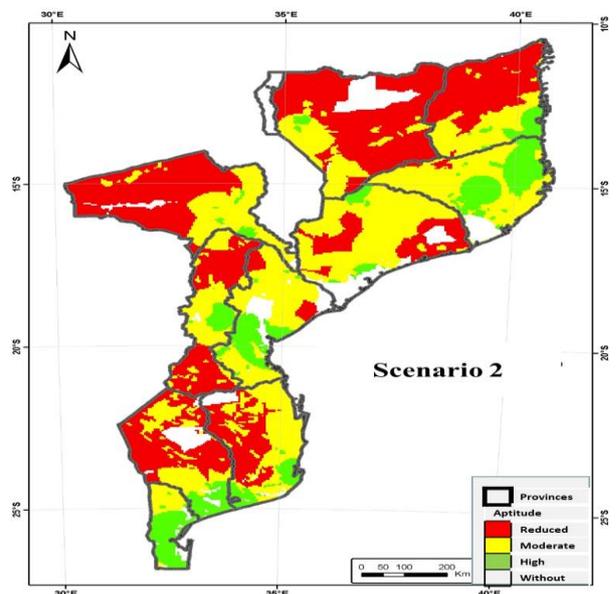


Figure 3 - Scenario 2 map (social and logistics variables)

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

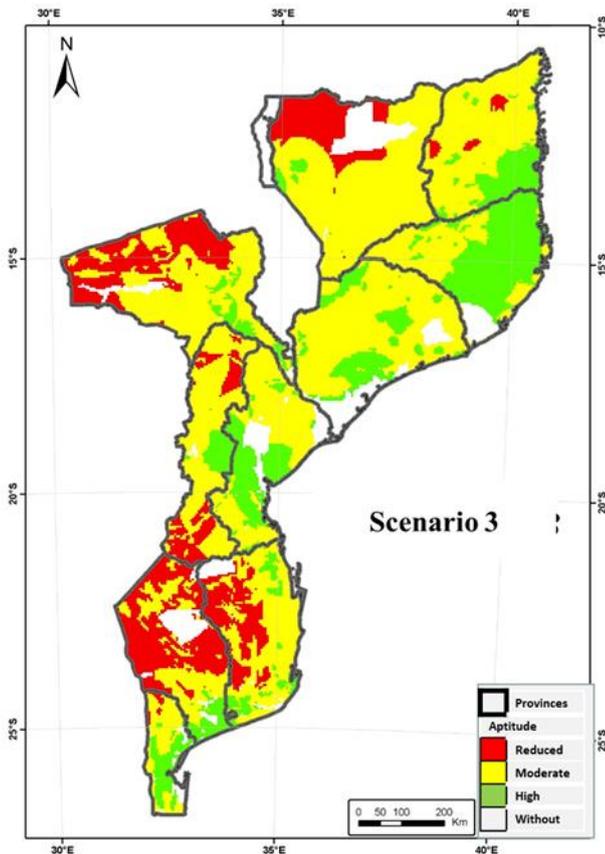


Figure 4 - Scenario3 map (all variables)

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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