Biodiesel production and regional development in the Brazilian Savannah: an application of positive mathematical programming[1]

Produção de biodiesel e desenvolvimento regional no cerrado: uma aplicação da programação matemática positiva

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Abstract: Biofuel production has been a greatly discussed topic in Brazil. In 2004, these debates lead the country to develop new policies and implement a national program for biodiesel use and production (PNPB) with the intent to foster regional development. In this context, the present study aims to assess the impacts of the PNPB on regional development in the Tocantins state, in a region of transition between Savannah and Amazon rain forest. Ranges of socio-economic indicators were collected among smallholders who cultivate *Jatropha curcas* and *Ricinus communis*. A positive mathematical programming (PMP) was applied, at regional level, aiming at estimating the impacts of oil seed activity on resources allocation, as well, as on farm income of farmers. For this purpose, the software GAMS (General Algebraic Modeling System) was used to support the modeling simulations.

Key-words: Biodiesel; family farmers; regional development; scenarios simulation, Brazilian savannah

Resumo: A produção de biocombustíveis tem sido um tema muito discutido no Brasil. Em 2004, esse debate levou o país a desenvolver novas políticas e implantar o programa nacional de uso e produção de biodiesel (PNPB), com a intenção de promover o desenvolvimento regional. Neste contexto, o presente estudo visa avaliar os impactos do PNPB no desenvolvimento regional no estado de Tocantins, numa região de transição entre o Cerrado e a Floresta Amazônica. Uma gama de indicadores sócio-econômicos foram coletados entre os agricultores familiares que cultivam pinhão manso e mamona. A programação matemática positiva (PMP) foi aplicada, a nível regional, com o objetivo de estimar os impactos da atividade de sementes oleaginosas sobre alocação de recursos, bem como sobre o rendimento agrícola dos agricultores. Para isto, o software GAMS (General Algebraic Modeling System) foi utilizado a fim de apoiar a modelagem das simulações.

Palavras-chave: Biodiesel; agricultura familiar, desenvolvimento regional, simulação de cenários, cerrado

JEL: R28; R58.

Introduction

Global concern for the depredation and exhaustion of natural resources has led governments and scientists around the world to identify alternatives and solutions to the problem. Hayes and Nadkarni (2001) and Alier (2002), for instance, point out that this environmental problem occurs both in developed, as well as developing countries, in the urban as well as rural spaces, and are mainly a consequence of the pressure due to the current consumption and production patterns. In this context, since the beginning of 21st century, an international debate has taken shape, which is

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currently discussed at 10 out of 10 meetings on sustainable development around the world: pros and cons of biofuels (DUBOIS, 2008; FAO, 2008a; FAO, 2008c).

Regarding the pros, biofuels[4] can shift the energy matrix of a country through the usage of a cleaner and renewable source of energy. Based on this, biofuels can also bring along positive externalities like the maintenance and provision of environmental services such as carbon sequestration and reduction of carbon emission, for instance (FAO, 2008e). From the socio-economic point of view, biofuels can positively impact rural development and diversify the utilization of the local environment. For example, enhancing rural space multi-functionality, where farms are used not only for crop production, but also for eco and rural tourism and, of course, generating strategies that reduce and alleviate poverty, so-called 'pro-poor' strategies[5] (UN Energy, 2007; FAO, 2008b; FAO, 2008d).

Despite of the numerous advantages, some questions have been raised regarding the possible negative externalities generated by biofuel production. These include the decrease in local food production and supply, as well as negative impacts on environmental services and climate change (FAO, 2008a). Regarding the food supply issue, for instance, the main concern is that biofuels may compete with food crops. This competition for land becomes an issue especially when some of the crops (e.g. maize and rice), which are currently cultivated for food and feed, are redirected towards the production of biofuels. As food-oriented agricultural land is converted to biofuel production, significant negative impacts on food security can be observed, the so-called "food versus fuel" debate (FAO, 2008e; PINGALI *et al.*, 2008; COTULA *et al.*, 2008).

Therefore, in 2004, Brazil launched a biodiesel program, the National program of biodiesel use and production (PNPB), which is based on a scenario of high oil prices, a growing demand for fuels from renewable sources, and the country's comparative advantage in natural resources (NASS *et al.*, 2007). The PNPB is an Interdepartmental program of the Brazilian government and has several specific objectives such as foster the rural as well as the regional development (PNPB, 2005).

In this context, the present study aims to develop and model future scenarios based on the characteristics of family farmers who produce *Jatropha curcas* as well as *Ricinus communis* seeds, as well as of the Brazilian program of biodiesel use and production (PNPB). Thus, this study discusses the underlying theory regarding the biodiesel program scenarios considering the impacts on the oil seed activity on farm income generation, and on the supply or raw/primary material towards biodiesel production. These proposed scenarios are tested at the farm, as well as regional levels, and they focuses on integration of farmers into biodiesel chain enabling them improve their income, and also enabling the national government to fulfill three of the PNPB main targets, that are: (i) income generation; (ii) social inclusion; and (iii) rural and regional development. In other words, the study aims to simulate and analyze scenarios that seek to address specifically the very core of the research problem, i.e. the successful and effectiveness of the PNPB as a national public program.

For this purpose, the positive mathematical programming (PMP) is stated and modeled to simulate the current status of farming systems. After validating the

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4 Biofuel essentially refers to liquid fuels derived from agricultural crops used for transport and energy generation (FAO, 2008b).

5 According to Hazell and Pachauri (2006) there is a high degree of congruency between the biofuels cons arguments and the poverty reduction targets embodied the Millennium Development Goals.

models in the real situation, different scenarios under the umbrella of the PNPB are tested to show the impact on resource availability and use, as well as the economic success of the family farmers. A set of alternative or possibilities are designed to the different farming systems, in order to maintain and improve their income along with the adoption of oil seed activity. The scenarios selected, which are based on the principles of the PNPB, should fulfill some ideal qualities at farm and regional levels, such as the non negative impacts on deforestation of native forests, for example.

2. Research area

The research was carried out in Tocantins State, located in northern Brazil in a region well known as Brazilian Legal Amazon. The State is situated in a transition area, presenting climate and vegetation from Amazon rain forest (15% of the territory) and Cerrado (85% of the territory). This transition area, so-called Ecotone zone, is the home to traditional communities (family agriculture, indigenous, as well as, quilombolas) and comprises rich biodiversity, which is responsible for numerous environmental services. For this reason, scientific studies and research in the area are extremely important. Often they are focused on understanding the different farming systems and their connections to the local economy and the very diverse environment.

Data collection necessary to create the database was formed through a comprehensive survey, which was carried out between April and September 2008 in two sub-study regions within Tocantins State. In one sub-study region, *Ricinus communis* (castor bean and also well known as mamona in Brazil) oil seed cultivated and in the other sub study-region *Jatropha curcas* (well known as pinhão manso in Brazil) is cultivated.

Specific questionnaires were applied to smallholders, who were randomly selected: 27 in the case of *Jatropha curcas* producers; 24 in the case of *Jatropha curcas* non-producers; 25 in the case of *Ricinus communis* producers; and 25 in the case of *Ricinus communis* non-producers. The selection of smallholders followed statistical procedures and that the sample can be considered representative since it comprises more than 90% of small-scale oil seed producers in the region in question at the time the research was carried out.

3. Methodological aspects

3.1. Model concept

In the present study, one model was established, which deals with small-scale farming systems and includes farm, household, as well as off-farm activities. Therefore, the objective function is to maximize the family income and the impact of different scenarios is determined by the results of model applications under "with and without" scenario development. The differences between future development scenarios, which comprises different biodiesel policies (such as the price of raw/primary material; and the oil seed productivity) - and without them - are the impact of the tested scenarios.

Based on this, the model concept can be explained in five steps, which are applied to test the impacts of different biodiesel policy scenarios on family, as well as farm income: (1) construction of the basic models to describe the farming systems (4 farming systems at small-scale level). The description includes the availability and use of family resources, farm activities, and parameters reflecting economic success, such as farm and family income. The parameters in this model are the average values for the farmers in each farming systems; (2) validation of the model by verification between the models results and the empirical data from the survey analyses. Resource availability, level of use, farm activities and economic success are used as parameters for validation; (3) calibration of the model to achieve the highest possible level of model fit (ability to reflect the real situation); (4) application to different biodiesel policy scenarios; and (5) comparing the basic model with the result of the models with the scenarios. The difference between them is the impact of the several scenarios.

3.2. Positive Mathematical Programming (PMP)[6]

Agricultural regional models can be used to analyze effects of policy changes for different agricultural industries and the agricultural sector as a whole. Moreover, agricultural regional models can conduct policy experiments in order to analyze policy alternatives before a decision is taken and put into operation. In this context, the Positive Mathematical Programming (PMP) approach uses the farmer's crop allocation in the base year to generate self-calibrating models of agricultural production and resource use, consistent with economic theory. While the PMP approach is unconventional in that it employs both programming constraints and "positive" inferences from the base-year crop allocations, it automatically calibrates models using minimal data, and without using "flexibility" constraints. The resulting models are therefore considered more flexible in their response to policy changes.

LP models have the tendency to overspecialize and as a consequence they will not reproduce the observed activity levels. Overspecialization usually occurs because by definition the standard LP model contains a linear objective function and marginal profit is constant. As a result the model will use fixed inputs for the most profitable activities. Overspecialization could be avoided by adding more constraints to the model. However, in aggregated models the number of empirically justified constraints is relatively small compared to the number of activities. Moreover, additional constraints will burden the models' flexibility to react to exogenous shocks. Using the method of PMP, the parameters of a non-linear objective function can be specified in such a way that the model calibrates almost exactly to the observed activity levels. Based on this, PMP calibrates to observed activity levels in three steps. In the first step a primal LP model is extended and reformulated as a constrained LP model as follows:

$$\max Z = \sum_{j=1}^{n} P_j X_j - C_j X_j \tag{1}$$

Subject to:

[6] This section is based on Howitt (1995), Helming (2005), as well as on Umstätter (1999).

$$\sum_{j}^{n} a_{ij} X_j \leq b_i \qquad \forall i \qquad [\pi_i] \tag{2}$$

$$X_j \leq X_j^* + \varepsilon \qquad \forall j \qquad [\pi_j^1] \tag{3}$$

$$X_j \geq 0 \qquad \forall j \tag{4}$$

Where P_j is the price per unit of the j^{th} output activity in regional farm; C_j is the cost per unit of j^{th} input in regional farm; X_j^* is the observed activity level j in the regional farm; ε is a very small positive number; π_i is the shadow price of the fixed inputs; π_j^1 is the shadow price associated with the calibration constraint.

The calibration constraint (3), included in the first step of the PMP approach, states that activity levels cannot exceed observed activity levels in the base year plus a very small perturbation ε. The perturbation variable ε enables more fixed inputs to be allocated to the preferable activities than are actually observed in the base year, given the input-output coefficient of fixed input *i* per activity p(a_{pi}). As a result preferable activities are constrained first by the calibration constraint (3). Because more fixed inputs are allocated to preferable activities, fewer fixed inputs (than actually observed) are allocated to the marginal activity as the availability of fixed inputs is restricted by constraint (2). This means that the activity level of the marginal activity will be below the observed activity level and the shadow price of the corresponding activity constraint (3) will be zero, given the input-output coefficient of fixed *i* input per activity *m*(a_{mi}). This means that a marginal increase in the availability of fixed inputs only increases the level of the marginal activity. Hence, the shadow price of fixed inputs is determined by the profit of the marginal activity.

Mathematically shadow prices of the fixed input constraint and the calibration constraint can be derived from the Kuhn-Tucker conditions. If one assumes that all variables X_j are non-zero and all constraints on fixed inputs are binding, the shadow prices can be formulated as:

$$\pi_p^1 = P_p - C_p - \sum_i a_{pi} \pi_i \tag{5}$$

$$\pi_m^1 = 0 \tag{6}$$

$$\pi_i = \sum_m (P_m - C_m)(a_{mi})^{-1} \tag{7}$$

Where π_p^1 is the shadow price on the calibration constraint of the preferable activity and π_m^1 is the shadow price on the calibration constraint of the marginal activity. Shadow price π_p^1 provides the contribution to the objective function Z (revenue minus variable costs) if the preferable activity increases marginally. Equation (5) shows that the shadow price π_p^1 equals revenue minus variable costs minus the (shadow) costs of the fixed input *i* per unit. In the literature shadow price

π_p^1 is also referred to as unobserved costs. It equals unobserved costs of remaining fixed inputs not included in *i*.

In the second step of the PMP calibration procedure, total marginal costs per activity are assumed equal to the sum of observed and unobserved costs per activity. By applying the First Order Conditions (FOC) for a competitive equilibrium we can derive the parameters of a non-linear variable costs function. Any type of non-linear costs function with the required properties can be used in principle. Here, one could use a quadratic costs function that looks as follows:

$$c(X_j) = kk_j + \alpha_j X_j + 0.5\beta_j X_j^2 \qquad (8)$$

Where kk_j, α_j and β_j are parameters of the costs function to be calculated.

In the third step of the calibration procedure the linear unit costs term, $C_j X_j$, in the objective function (1) is replaced by the above-mentioned quadratic total variable costs function: $c(X_j)$. In its standard form the final primal non-linear programming problem can be formulated as:

$$\max Z = \sum_{j=1}^{n} P_j X_j - kk_j - \alpha_j X_j - 0.5\beta_j X_j^2 \qquad (9)$$

Subject to:

$$\sum_{j}^{n} a_{ij} X_j \leq b_i \qquad \forall i \qquad [\pi_i] \qquad (10)$$

$$X_j \geq 0 \qquad \forall j \qquad (11)$$

Note that the calibration constraint (3) has been removed. The model will almost exactly calibrate to the observed activity levels.

3.3. Farm modeling

A farming system consists of the full range of activities available to the individuals in a particular set of small-scale or large-scale farm units. In this context, household members select from among these options, which are essentially strategies, those activities that best contribute to achieving the household production targets, in order to their social reproduction and/or economic success. Thus, a well designed model reflects these choices by selecting a combination of activities that is feasible, given a set of fixed farm constraints that optimize a particular objective, while achieving other goals, such as security in food supply, or accessing new markets, for instance.

Thus, the main idea behind the process of modeling at the farm level is based on the philosophy that the best way to analyze limited resource farms is to comprehend the relationships and interactions integral to them. As such, impacts of modified production scenarios are shaped by the constraints on these farming systems. For this reason therefore, the issue of farm composition is of immense importance and must be explicitly incorporated in the modeling process (BLAIR, 2007). To deal with such a complex set of factors as the farming systems, modeling is undertaken utilizing the LP method as an appropriate tool. In the first instance, models for the four farming systems attempt to reflect the scenario as closely as possible to the actual one experienced by farmers in these farming systems. The basic model of each farming system describes the group through technical coefficients, resource constraints and a set of activities based on the results of the field surveys carried out in the year of 2008. The results of the model were estimated using the software GAMS (Generalized Algebraic Modeling System) and presented later on.

3.3.1. The basic model

The annual basic model of each farming system was constructed by utilizing the average of each group. This means all parameters in the model represent average figures. The model itself consists of the objective function and constraints, and thus seeks to capture the main farm activities with are primarily crop and oil seed production, off-farm activities, labor hiring activities, land hiring activities, household consumption from the farm, household expenditures, credit activities for crop and livestock purposes, sales activities and the resulting annual cash scenario from these activities.

So, in the first instance a static model will be applied and compared with survey data at a fixed point in time. A comparative static model would then be used to establish a number of scenarios aiming at better comprehending the impacts of biodiesel policies on the adoption of oil seed activity by farmers, and therefore the impacts on their farm income. In order to reflect a realistic scenario, very careful attention was paid to the selection of activities captured in the model. A critical balance had to be arrived at with respect to the temptation of including every conceivable activity in the model against the need for an adequately representative model that is not too burdened by a large number of activities that are insignificant in the context of the observed patterns in the study area (ABU SHABAN, 2007; BLAIR, 2007). This being the underlying criteria then in activity selection, only those activities that are on average undertaken by each farming system were selected.

3.3.1.1. Objective function

The role of the objective function herein is to maximize the most significant component of family income in small-scale farming systems, subject to resource availability and other constraints, over a period of one year. The family income is maximized through the value of the main agricultural activities found in the average farm, along with off-farm income and production costs. Based on this, the mathematical structure of the static LP model of the present study is presented as follows:

$$\max Z = \sum_{j=1}^{n} P_j X_j - C_j X_j \quad (12)$$

Subject to:

$$\sum_{j}^{n} a_{ij} X_j \leq b_i \qquad \forall i \qquad [\pi_i] \quad (13)$$

$$X_j \geq 0 \qquad \forall j \quad (14)$$

Where:

Z = the objective function;
X_j = the level of activity j;
P_j = the price per unit of the j^{th} output activity;
C_j = the cost per unit of j^{th} input;
n = number of activities;
m = number of resources and constraints;
b_i = amount of i^{th} resource available
a_{ij} = technical coefficient (amount of i^{th} input required to produce one unit of j^{th} activity)
π_i = variable associated with restriction (13), is defined as the shadow price of fixed input i[7].

Therefore, the components of the objective function to small-scale LP model are as follows: (i) the variable costs of crops and livestock per unit of land and head, respectively, excluding hired labor and hired land costs; (ii) the average sale prices of crops which are used to calculate the revenue of farm products; (iii) household consumption of farm products, which has zero value in the objective function and has be forced in by respective conditions in the right hand side (equation); (iv) hired labor costs are determined by the average wage per man-day observed in the study area; (v) off-farm activities is determined by the average wage (seasonal) and salary (permanent) per man-day as reported by households; and (vi) interest for credit was established as the average interest rate of formal credit (PRONAF) as reported by farming households.

3.3.1.2. Constraints

Constraints on resources are a basic feature of the farming systems. Based on this, constraints in the basic models represent the resource situation of the average farm in each farming system handled in this study. Farmers are supposed to achieve

[7] The shadow price of a fixed input provides the increase in the objective function if the input could be made less restrictive marginally (HELMING, 2005).

their goals through using their limited resources in different activities. Therefore, the different options of productions and farm activities contribute to the maximization of the objective function by using these limited resources. In this context, these resource constraints include the following:

Land: The average arable land areas owned by the farmers were used as the upper limit of land constraints. As land, in the region in question, is not separated by type of farm activities, i.e. different farm activities compete for land use, these resource was not divided into different farm activity patterns. In addition, the land rented by farmers also has its upper limit according to the survey results.

Labor: Two forms of labor sources are identifiable, and they include family and hired labor. Family labor capacity was calculated using man-equivalent and based on the assumption that working capacity for one year is 290 days for a family member. The family labor was distributed among farm and off-farm activities, and the option of hiring labor was restricted by upper limit.

Household consumption and household expenditure: Two sources of food supply were considered, i.e. from own farm subsistence and from markets. This shows the interdependence of production and consumption of subsistence and market. Thus, this made it possible for farmers to decide on crop and livestock production through consumption preferences. Food consumption is based on family requirements of food products that are produced on farm. Constraint relating to other family expenses on the household was also considered.

Cash balance: It covers the cash coming in and out from farm and off-farm activities. The in cash flow includes cash coming from selling crops and livestock products and the income from off-farm activities, while the cash out flow includes the costs of crop and livestock production, household expenditure and hiring labor cost.

Credit: One source of credit was considered that was the formal credit. Informal credit was not included as it was used for other family purposes rather than to be invested on farming.

3.3.1.3. Activities

Family activities are diversifying into activities done on farm, off-farm and household, regarding small-scale farming systems. Those activities include crop production and selling its products, livestock production and selling its products, household consumption from farm and household expenditures on market, labor use on farm, off-farm activities, and hiring labor.

Oil seed production: Oil seed activity is the main research target of the present study. The activity is exerted by families in just two of farming systems at small-scale level. In this context, the purpose herein is also to understand the impacts of biodiesel policies on the adoption of *Ricinus communis* and *Jatropha curcas* by those who, so far, have not do adopt it. More than that, the objective is to understand the impacts of those policies on family income due to the oil seed activity adoption.

Crop production: Four different crops are cultivated on small-scale farming systems for self-consumption, as well as to be traded at local markets: maize, rice, cassava, and beans. These mentioned crops contribute significantly to the family income and household food consumption.

Livestock production: It is major farm activity amongst the four small-scale farming systems. In this context, the livestock represented in the model is cattle, which is the main livestock in the region.

Sales and consumption*:* This involves the selling, purchasing and subsistence consumption activities. Sales and consumption have direct consequences for the cash flows to the farm and the family. Further still, they indicate the degree of production orientation in terms of subsistence or market production. The activities assume a perfect demand and supply of crops, livestock and other products. Prices of products are assumed to be the same, irrespective of land used in production whether improved or not.

Labor activities: Allocation of family labor in farm and off-farm activity is included in per activity bases in one year. Family labor was given in man-day for farm activities. Off-farm activity includes seasonal and permanent jobs, and they were expressed in man-days and were computed for a whole year. The activity of hiring labor was also included in the model.

Capital and Household expenditure: One type of credits was considered in the model; the formal one. The interest rate was assumed to be 4.5% provided by the National Program of Family Agriculture Strengthening (PRONAF). Collateral is needed to obtain such a credit; the interest cost was included in the activities on the yearly basis. Household expenditure was given in aggregated figure, and that was covered in a yearly basis.

3.3.2. Calibration and validation of the model

The process of model building or indeed the theorizing about farming systems as is the case in LP modeling would require validation. In a model building one starts out with assumptions or hypotheses about farmer objectives and subjective constraints, and bases the predictions and prescriptions on these. Validation therefore involves the comparison of the model predictions with what farmers are actually doing. Wide deviations of the model results from this actual state may indicate that the initial assumptions were wrong and therefore would require modification. It can be alternatively concluded as well that the assumptions were not at all wrong, but the farmers are operating in an inefficient way and it is their management practices that need to be changed. As such, if the model predictions present results similar to the actual state or scenario, it cannot be concluded certainly that the initial assumptions were correct. It is only through testing and validation over a range of circumstances can confidence be strengthened regarding the results of the model.

It therefore follows, with actual scenario, and secondly through further testing which may involve essentially sensitivity analysis. This sensitivity analysis involved some degree of calibration. The obvious reason for the calibration exercise was to integrate a measure of realism in the model that war sorely absent when the model was left to select freely. It was found, for instance, that households consistently stipulated a minimum amount of land for each crop. When these preferences were ignored, the model presented highly unrealistic results for the amount of resources available to the households. As such an attempt was made to integrate these preferences in the model, which presented much more realistic and acceptable results for the purpose of this study. Therefore, in the first run of the model, free selection between different activities on the available resources was allowed. The model, as expected, run towards an overspecialization, and thus did not select some crops in different farming systems, since no profit is generated from these activities. This outcome does not reflect the real situation of the farmers since they do have part of their production diverted to self-consumption. Therefore, it should be calibrated to represent the real situation in a better way. In this context, the model was calibrated in order to select these crop activities regardless of maximizing profit objective.

Thus, the analysis that follows must be taken in light of this fact. Table 1 give an overview of how farm, off-farm and family income from the model, compared with survey data in 2008.

Table 1: Farm, off-farm and family income results from the basic model compared with the survey data

Parameters (R$)	RC producers			RC non-producers			JC producers			JC non-producers		
	survey	Basic model	Δ%	survey	Basic model	Δ%	survey	Basic model	Δ%	survey	Basic model	Δ%
Farm income	3844	3708	(4)	4220	3877	(8)	8154	8259	1	3973	4370	9
Off-farm income	6033	5493	(8)	6619	6618	-	6109	6052	(1)	5509	5114	(7)
Family income	9878	9201	(7)	10840	10495	(3)	14263	14311	-	9482	9484	-

Source: research results (2010).

Notes: RC = *Ricinus communis*; JC = *Jatropha curcas*. Differences between survey and model results are in percentage. Figures in parenthesis represent negative deviation from survey data in percentage terms, while positive figures represent positive deviations in percentage terms.

As one can notice, farm income of basic model is very similar to family income capture in the survey. Some slight differences can be seem in the case of *Ricinus communis* producers group, as well as in the case of *Ricinus communis* non-producers group, where the farm income is lower than the farming income captured in the survey (4% and 8%, respectively); and in the case of *Jatropha curcas* producers group, as well as of *Jatropha curcas* non-producers group, where farm income of basic model is higher than the farming income captured in the survey (1% and 9%, respectively). Off-farm income of basic model is lower than the farming income captured in the survey in the all groups, except in the case of *Ricinus communis* non-producers group. Nevertheless, alike farm income, off-farm income figures are very similar to those capture in the survey, and the results therefore can be considered within the range of the standard error of the mean (SE).

Family income of basic model is lower than the farming income captured in the survey in the *Ricinus communis* producers group, and in the *Ricinus communis* non-producers group (7% and 3%, respectively), and no difference is seem to *Jatropha curcas* producers group, as well as of *Jatropha curcas* non-producers group. The differences are as expected and lie in the range of the mean standard error. In this context, the gap between the basic model and reality can exist since the model assumes perfect knowledge of the farmers and that their decisions are made suddenly with no lag in time (KITCHAICHAROEN, 2003). Moreover, according to Abu Shaban (2007), this indicates the ability of the model to reflect the real situation of farming systems in the research region. For both groups, the results of the basic model indicate that the resource allocation and use from the basic model is similar to that of the survey results. The optimal model results show an alternation in the land devoted to some crops, depending on the farming system in question. Nevertheless, this difference in land allocation, per crop, is as expected since the model takes into account perfect knowledge of the farmers regarding optimal solutions, as mentioned previously. In the *Ricinus communis* producers group, for instance, the area used for maize and rice cultivation is higher than the average of that from the survey result. On the other hand, the area used for cassava and bean cultivation from the basic model is lower than the average of that from the survey result. Similar trend can be seen when one considers the other farming systems. These small differences were accepted since they are very small figures and do not affect the validity of the model (ABU SHABAN, 2007).

The use of other resources present figures close to the survey results (Table 2). The land devoted to oil seed activity, for instance, is the same in the model when compared to the survey results. This was reached through model calibration, since the farmers keep contracts with biodiesel companies and therefore the land was already compromised to this activity. Grass land also presents the same result in the model when compared to reality due to the fact that livestock represents the major farm activity in all small-scale farming systems and therefore the resource land is fully demanded in this case. The model did not allow for hiring labor in. This is due to the availability of the family labor where labor was not considered as restricting variable. However, in the survey data, hiring labor was of minor importance for farmers in the research region. Both comparisons proved the ability of the model to reflect the farming family situations in the study region. The credit requirement in the model of the *Ricinus communis* producers, as well as the *Jatropha curcas* producers group, was not very different from the actual farmer's practices, even though it was slightly lower for both groups. Data on credit in general was not easily accessed and the suspicious therefore, is that formal credit was overtaken in the survey data. In summary, from the results of farm, off-farm and family income, as well as resource use and a combination of farm activities, the basic model of each group presents and adequate approximation to the actual farmer's practices. Based on this, one can be assured about the model robustness, since both comparisons proved the ability of the model to reflect the farming family situations in the study region in question. Hence, these basic models are hereby used as the basis for the analysis of impacts resulting from the suggested scenarios to follow in the subsequent section.

Table 2: Resource use from the basic model compared with the survey data

Parameters	RC producers		RC non-producers		JC producers		JC non-producers	
	Survey	Basic model	survey	Basic model	Survey	Basic model	survey	Basic model
Cultivated land (ha)	4.6	4.6	2.4	2.4	5.5	5.5	2.9	2.9
Maize (ha)	1.2	1.6	0.6	0.6	0.9	1.3	0.9	0.8
Rice (ha)	0.4	0.6	0.7	0.9	0.9	0.8	0.9	0.8
Cassava (ha)	0.5	0.3	1	0.8	0.7	0.6	0.9	1.2
Bean (ha)	0.5	0.1	0.2	0.1	0.4	0.2	0.2	0.1
Oil seed (ha)	2	2	-	-	2.6	2.6	-	-
Grassland (ha)	0.6	0.6	0.8	0.8	0.8	0.8	0.8	0.8
Labor (MD)	377	340	354	320	419	419	381	345
Hired Labor (MD)	27	-	34	-	26	-	37	0
Rented land (ha)	4	4	8	8	7.4	7.4	4.2	4.2
Credit (R$)	2500	2215	2000	2000	3000	2320	1800	1800

Source: research results (2010).
Notes: RC = *Ricinus communis*; JC = *Jatropha curcas*.

4. Results and discussion

According to Sterman (1988), the output of an optimization model is a description of the best way to accomplish some target. Optimization models do no tell you what will happen in a certain situation. Instead, they tell you what to do in order to make the best of the situation. On the other hand, the purpose of a simulation model is to portrait the real system so that its behavior can be analyzed. So, while optimization models are prescriptive, simulation models are descriptive. Moreover, simulation model do not estimate what should be done to reach a particular target, but instead clarifies what would happen in a given situation. Hence, the purpose of simulations may be predicting how systems might behave in the future under assumed conditions or policy changes. In other words, simulation models are “what if” instruments. This distinction made, the task of simulating future scenarios are addressed.

4.1. Scenarios simulation at regional level

There is often a difference between the impact analyses of farm and regional needs (DOPPLER, 2004). Impact analyses at farm level have explained the impacts of biodiesel policy changes on the oil seed activity, as well as on the farm and family incomes, especially towards the economic success of families in the region in question. It, however, did not consider the impacts of policy changes on oil seed activity, as well as in the farm income at regional level.

Therefore, the impact analyses at regional level is extremely important aiming at better understanding the role of the biodiesel policy changes in the regional development. All those analyses will be tested under different scenarios reflecting different oil seed pricing policies and different levels of oil seed productivity. Thus, impacts on the change in biodiesel policies, as a result of applying those scenarios, will be assessed. For this purpose, not a LP model, but a positive mathematical programming (PMP) model will be applied, since according to the literature this method seems to fit better to regional simulation analysis (HOWITT, 1995; UMSTÄTTER, 1999; BAUER and KASNAKOGLU, 1990).

4.1.1. Description of scenarios

As mentioned previously, the scenarios established in the present study are based on the Brazilian program of biodiesel use and production (PNPB), as well as the current scenario of biodiesel demand and supply in the country. In this context, 2 different scenarios were proposed at regional level: (1) changes in the productivity of raw/primary material; and (2) changes in the price of raw/primary material (oil seeds). In this context, the scenarios herein are built based on the current situation where: productivity of *Ricinus communis* is 127 kg per hectare, and productivity of *Jatropha curcas* is 1038 kg per hectare (average for ten-year production based on the ratio of the first year productivity); price of R$0.75 per kg for *Ricinus communis*, and price of R$0.35 per kg for *Jatropha curcas*.

Therefore, the scenarios include: (i) the minimum productivity expected by the biodiesel company, i.e. 600 kg per hectare for *Ricinus communis*, and 2444 kg per hectare for *Jatropha curcas* (average for ten-year production); (ii) productivity above the minimum expected, i.e. 1200 kg per hectare for *Ricinus communis*, and 3476 kg per hectare for *Jatropha curcas* (average for ten-year production); (iii) price 25% higher compared to the current situation (basic model); and (iv) price 50% higher compared to the current situation (basic model).

The gross margin was estimated as a *proxy* for farm income since the major part of crop production is traded at market, and only a small part is used for self-consumption.

4.1.2. Results of scenarios simulation at regional level

The results from the different scenarios simulation can be seen in the forthcoming Table 3, which contain the results from the calibration LP model, the base PMP model and the PMP scenarios. So, first of all, an analysis of resource allocation is done, especially regarding the resource land. Thereafter, the farm income, hereby represented by the gross margin, is estimated.

The results from the small-scale regional modeling show an alternation of land devoted to the oil seed activity. When the price of the oil seed activity rises 25% compared to the current/baseline price, and the productivity remains at the current level, the land diverted to *Ricinus communis* diminishes, whereas the land diverted to *Jatropha curcas* activity increases. Moreover, when the price of oil seeds rises 50% compared to the basic model, the situation becomes clearer and the results point towards the *Jatropha curcas* production in detriment to *Ricinus communis* activity. However, when the productivity of oil seed per hectare becomes the minimum expected by the biodiesel companies (the price remaining at the current level), the land devoted to *Ricinus communis* increases, and whereas the land devoted to *Jatropha curcas* production diminishes. In addition, when the productivity becomes above the minimum expected by the biodiesel companies, the land devoted for *Ricinus* becomes even higher, 4.8 hectares, compared to 3.9 hectares devoted to *Jatropha* activity.

The competition for the resource land between oil seed activity and conventional crops can be seen especially in scenarios 2a and 2b, when some of crops are not cultivated anymore. Therefore, the results suggest that the national biodiesel program should focuses on the oil seed price in the case of *Jatropha curcas* activity, and on oil seed productivity in the case of *Ricinus communis* activity. Nevertheless, as one can see in the Table 5, the total gross margin, hereby as a *proxy* for farm income, constantly increases from scenario 1a to scenario 2b.

So, as one could observe, the results presented hitherto suggest that the current oil seed price, plus the low oil seed productivity in the region in question might jeopardize the regional targets of the Brazilian program of biodiesel use and production (PNPB), especially regarding the social inclusion, income (and job) generation, as well as the supply of raw/primary material towards the biodiesel production. One way to avoid this situation is to focus on the quality of the oil seed, as well as the technical assistance to farmers, which might lead to an important increase in the productivity of the oil seed activity. Another important solution relies on a combination of aggressive biodiesel policy and market equilibrium, i.e. with the constant increase in the percentage of biodiesel blend (B's), the prices of oil seed may rise, mainly due to the inelastic supply of raw/primary material in the short run. Therefore, a policy that integrates higher prices and higher productivities may include family farmers in the biodiesel chain; generate income and jobs in rural spaces, leading therefore to a sustainable regional development.

Table 3: Small-scale regional modeling simulation

	Calibration LP	Base PMP	Scenario PMP1a	Scenario PMP1b	Scenario PMP2a	Scenario PMP2b
Total GM (R$)	5625.5	3662.1	4567.6	5533.3	6196.4	9454.8
Average GM (R$/ha)						
Maize	325.8	246	289.7	316.7	409.2	-
Rice	300	247.1	280.8	307.8	400.3	-
Cassava	623.5	395.4	429.1	456.1	548.6	731.2
Bean	88	82.6	116.3	143.3	-	-
Ricinus	52.5	49.2	98.8	138.5	379.8	787.5
Jatropha	3.3	183.3	346.7	477.5	582.5	945.8
Livestock	1450	751.6	785.3	812.3	904.8	1087.5
Area (ha)						
Maize	0.9	0.9	0.7	0.6	0.4	-
Rice	0.7	0.7	0.6	0.5	0.3	-
Cassava	1	1	0.9	0.8	0.6	0.2
Bean	0.4	0.4	0.2	0.1	-	-
Ricinus	2	2	1.2	0.6	3	4.8
Jatropha	2.6	2.6	3.9	5	3.9	3.9
Livestock	3	3	2.8	2.7	2.3	1.6

Source: research results (2010).

Notes: Scenario 1a: price 25% higher and current productivity; Scenario 1b: price 50% higher and current productivity; Scenario 2a: current price and minimum productivity expected by the biodiesel company; Scenario 2b: current price and productivity above the minimum expected.

Conclusions

The income generation, the supply of raw/primary material towards biodiesel production, and the regional development are some of the main PNPB targets, stated by the Brazilian government during the year of 2004. However, to become a reality, those targets need to be comprised by changes in the current biodiesel policy in the country, i.e. the improvement in the quality of oil seeds, as well as in the technical assistance to farmers seem to be crucial factors to generate higher yields in the field. In addition, prices paid by the biodiesel companies to the farmers for the oil seeds is one the main complaints by the latter, even suggesting that some of the farmers may cease the production in case the current price remains constant in the following years.

Based on this, it is imperative that the Brazilian government focuses on a broader biodiesel policy that aims to overcome these shortcomings. As the results from scenarios simulation demonstrate, the economic success of farmers, as well as the regional development demands an effort in order to guarantee the continuation of the oil seed activity and, at the same time, the income and job generation in the region in question. More than that, if the Brazilian government wishes the PNPB to be a successful public program, and therefore fulfill the targets stated previously, they should also empower local and regional agencies aiming at enabling them to foster the regional oil seed activity, i.e. select the proper vegetable oil specie, indicate the proper areas for cultivation (economic-ecological zones), monitor and enforce the contracts between companies and family farmers, etc.

The regional development of one of the poorest regions of the country (northern Brazil) needs special attention. The reality of family farming in northern Brazil follows the diversity of the country, and thus, completely different from other regions. These differences, along with the natural endemic characteristics to the region, make the development of the state of Tocantins a challenge, especially when one talks about biodiesel and oilseed production by family farmers. Only a more critical look at regional differences will allow PNPB meets its goals of social inclusion and income generation in the field in the context of sustainable development. Based on this, we strongly suggest that other studies be carried out, aiming at better understanding the relationship between family farmers and the Brazilian biodiesel chain.

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