Available online at www.sciencedirect.com
SCIENCE DIRECT®
Biomass and Bioenergy 26 (2004) 405–415
BIOMASS & BIOENERGY
www.elsevier.com/locate/biombioe

Potential for producing bio-fuel in the Amazon deforested areas

Ricardo Cunha da Costa*

BNDES—Banco Nacional de Desenvolvimento Econômico e Social, Av. República do Chile, 100-9° andar, Rio de Janeiro-RJ, Cep. 20139-900, Brazil

Received 21 August 2002; received in revised form 22 August 2003; accepted 28 August 2003

Abstract

This paper analyzes the possibility of producing bio-fuel in the Amazon degraded lands. The aim here is to combine environmental concerns with an improvement of local people well-being. Firstly, a historical analysis is conducted in order to figure out the major deforestation driving forces in Amazon and to help to arrive at a feasible energy choice.

Secondly, the geographical area is chosen. It is the spatial boundaries of Carajás Iron Ore Program in the southeastern Amazon where most of the deforestation has taken place in the last few decades. For this specific context, palm oil is chosen as a technological energy alternative due to its social production structure, its environmental benefits and its productivity.

A quantified analysis is realized in terms of income generation (2000–3000 US$/family/yr), job creation (200,000–300,000 families settled), land required and restored (2–3.2 million ha), and carbon emission from fossil fuel avoided (13.1 Mt C). Some recommendations related to institutional and economic barriers are proposed in order to encourage the technology penetration in the market.

Keywords: Bio-fuel; Deforested areas; Amazon; Energy; Climate change; Carbon emissions; Developing countries; Brazil

1. Introduction

In the last decades, a large number of papers about land use changes in the Amazon have been published [1–6]. The subject has received more attention since the clean development mechanism (CDM) was introduced on the global change negotiation in Kyoto in December 1997. This is the only mechanism by which industrialized countries rely on developing countries' contribution to mitigate climate change. The industrialized countries counterpart is to help and promote sustainable development in developing countries.

Most of the papers on deforestation focus on the global environment rather than local human needs. The best options usually proposed are those that avoid more deforestation and carbon emissions or impact the ecosystem less. In short, the papers on Amazon issues mainly analyze environmental damage [2,7,8], not taking duly into consideration the socio-economic framework.

The present paper addresses not only environmental concerns, but also technical, political, social and economic ones. It is true that carbon emissions from deforestation is tremendous in Brazil, but in a context where the major developing countries in the United Nations Framework on Convention Climate Chance (UNFCCC) do not accept the inclusion of forest as carbon sinks, it does not seem useful to propose

* Tel.: +55-21-2277-8653; fax: +55-21-2220-4424.
E-mail address: rcco@bndes.gov.br (R. Cunha da Costa).

0961-9534/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biombioe.2003.08.011

alternatives that are not acceptable in the near future from a political point of view.

In fact, one of the aims of this paper is to propose an economic activity in Amazon that reduces carbon emissions, not constraining directly deforestation, but rather replacing fossil fuel by bio-fuel production in degraded areas. This paper is structured as followed. The next section presents the major carbon emission sources in Brazil, as well as the technological bio-energy path adopted in the past by the country. Bio-fuel development in Brazil is discussed in order to confirm the technical feasibility of the results in the later section.

Section 3 analyzes trends in deforestation in the Amazon, seeking to identify the major driving forces. The complexity of the Amazon deforestation suggests the delimitation of the geographical area of study, which is focused where a bulk of deforestation took place in the last decades.

In Section 4, some technological energy alternatives for land restoration are analyzed regarding the local population needs. The fifth section presents the results, focusing on issues such as income generation, job creation, land requirement, and amount of carbon emission from fossil fuels avoided. Some recommendations and proposals for further developments are presented in the sixth section.

2. General framework and background

2.1. Carbon emission sources in Brazil

As distinct from the majority of the countries, the major source of carbon emissions in Brazil is land-use change rather than fossil fuel use. The findings on carbon emission from land-use change contain a high level of uncertainty, but there is no doubt that deforestation releases much more carbon into the atmosphere than does the burning of fossil fuel in Brazil.

Carbon emissions from fossil fuel are easier to estimate than those from land-use change. Intergovernmental Panel on Climate Change (IPCC) provides a relatively simple methodology to estimate carbon embodied in fossil fuel [9]. In the Brazilian First National Communication, the government published very soon the inventory of carbon emission from fossil fuel between 1990 and 1994, but it takes time to present final results on carbon emission from land-use change. [1]

Where information is not available on an official database, other sources of data are required. Depending on the method of calculation, Brazilian Amazon deforestation has emitted 150–350 million tonnes of carbon per year (Mt C/yr) since the 1980s. One of the estimations, which has been widely cited in the literature, was prepared by Houghton et al. [8]. These authors show that the annual flux of carbon from deforestation and abandonment of agricultural lands in the Brazilian Amazon was about 200 Mt C/yr. But a large deviation is accepted because of uncertainties about assumptions on biomass density, the carbon released from the decay of dead plants and the regrowth of secondary forest. "The combined effects of deforestation, abandonment, logging and fire may thus yield sources of carbon that vary between 0.1 and 0.4 Pg C yr^{-1} [8]. [2]

National sources have been more optimistic about carbon emissions from land-use change. For instance, La Rovère [10] employs IPCC's coefficients to estimate carbon emissions from land-use change. For tropical forest, he considers a mean value of 120 t C/ha released into the atmosphere, but only 70 t C/ha in the Brazilian *cerrado* (scrub vegetation) where most of the deforestation during the nineties occurred.

In Fig. 1 carbon emissions from land-use change in the last decade are higher than those from fossil fuel use even if one takes the most optimistic figures. It is important to note that a large degree of uncertainty remains in the case of carbon emissions from land-use change.

Regarding the energy sector, a natural fall in the use of non-sustainable fuel-wood consumption is observed as the economy modernizes with time. Nevertheless, fossil fuel consumption has been

[1] The government has been preparing a more accurate study on Brazilian deforestation for the National Communication. It relies on comparing recent data from satellite images with aerial photographs taken in the seventies. But, as of today, the results are not yet available on the Ministry of Science and Technology (MCT) web site.

[2] It means 100–400 Mt C/yr.

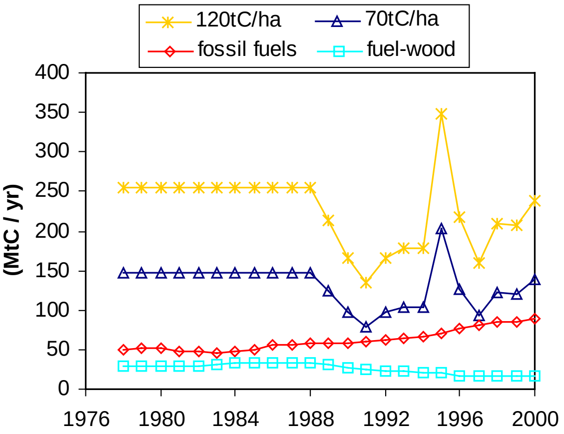

Fig. 1. Carbon emissions from land-use change and energy consumption. Sources: [10,26,27].

increasing since the early 1990s. This increase is due to low fossil fuel prices in the international market, the open-market economic policy and energy market deregulation. These facts have resulted in a reduction in the renewable market share. If this tendency remains, carbon emissions from fossil fuels should soon surpass those from deforestation [11].

Trends in carbon emissions from deforestation show a high oscillation. Annual data for the period between 1978 and 1988 is not available so an average value is shown in Fig. 1. Possibly, emissions in the beginning of the period were low. It should have increased enormously during the 1980s and it decreased significantly from the late 1980s until 1991. The explanations for the oscillation in the degree of deforestation will be discussed later.

2.2. *Bio-fuel development*

In the second half of the 1970s, in the context of increasing world oil prices, the Brazilian government decided to encourage national energy sources such as hydroelectricity and bio-fuel for the transportation sector. [3] This policy, relying on renewables, was more related to economic (balance of payment constraints) and political (energy dependence and security) issues than to environmental concerns.

Initially, two kinds of oil substitution were studied and analyzed in Brazil, one replacing Diesel by vegetable oils and the other replacing gasoline by ethanol. Instead of replacing Diesel for freight and collective passenger transport, [4] ethanol for automobiles proved less costly and the government could rely on the private sector to invest in sugar cane crops and ethanol production. The public oil company Petrobras had a important role of centralizing fuel storage and distribution, assuring as well ethanol purchase from producers.

It is considered that the Brazilian ethanol program was quite successful during the 1980s. In 1985, ethanol-car sales accounted for 96% of the automobile market. During 6 years in the 1980s, ethanol-cars represented almost 90% of auto sales. In 1989, consumers experienced the first ethanol crisis. Sugar prices increased in the international market and producers decided to address production of sugar instead of ethanol.

At the same time, the Brazilian government adopted adjustment structural policies, which implied a reduction of its role in the energy sector during the 1990s. It had become difficult to sustain high subsidies while oil prices had decreased since the second half of the 1980s. Ethanol-car production dropped drastically in the early 1990s and was practically stopped in the second half of the 1990s. In 2001, ethanol-car sales represented only 1.3% of the automobile market [12].

Fig. 2 shows that automobile bio-fuel market shares reached 50% in the late 1980s. Since then, ethanol market shares have diminished, despite the fact that the percentage of anhydrous ethanol blended to gasoline has increased. Hydrated ethanol consumption has drastically decreased because of the ethanol-car fleet retirement.

[3] Prior to the first oil price shock in 1973, the country imported almost 80% of its oil supply. Oil was the major imported product at this time. In 2000, oil imports represented 24% of the supply.

[4] In Brazil, oil refining production is constrained by Diesel. The country is obliged to export gasoline and import Diesel.

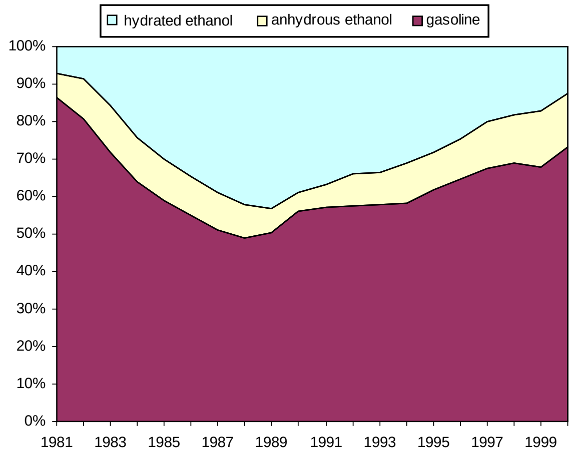

Fig. 2. Automobile fuel market share. Source: [27].

3. The Amazon deforestation

3.1. The effort to model deforestation: identifying some driving forces

Several authors have mentioned a set of major reasons driving the Amazon deforestation [1,2,4,5,13]. They are usually related to government policies and programs. The major reasons for deforestation up to the 1980s, which have been identified in the literature, can be described as the following:

1. Development of the transportation system: 60,000 km of roads had been built and 890 km of railway was built principally to transport iron ore from Carajás in the southeastern Amazon to the northern coast;
2. Settlement programs: Between 1970 and 1991, the Amazon population increased from 7.3 to 16.6 million inhabitants, but migration from the northeast of Brazil, where lands are semi-arid, accounted for 40% of this growth [6];
3. Government incentives for agriculture: Large-scale cattle ranchers had received most of the subsidies in the form of tax exemptions or privileged credits; [5] and
4. Financing large-scale projects: The Tucuruí hydropower plant investment to produce 8.4 GW from 2850 km^2 of flooded land was US$ 7.5 billion [14] while US$ 3 billion were required to build the Carajás Iron Ore Project (CIP), the world's largest high-grade iron ore deposit whose reserve is 18,000 Mt [6].

Large-scale projects usually attract a high number of non-qualified workers in the construction phase, but displace or exclude neighborhood population. Benefits and surplus are commonly transferred to big cities or overseas. [6] International public opinion exerted a high pressure on the World Bank for having financed projects that impacted the environment tremendously. In this context, the Brazilian government was, to a certain extent, left to suppress agriculture subsidies in the late 1980s. [7]

It is important to mention that the Amazon soil degrades as soon as the land is cleared [15] and it requires large fallow periods for nutrient recovery [2]. [8] Cattle ranching has been the best alternative to occupy cleared lands. During the 1980s, people believed that cattle ranching was feasible only because the government provided them with subsidies. In fact, cattle ranching has increasingly become more profitable when supplementary income comes from selling timber [1].

Another factor playing an important role in deforestation is related to land speculation. Cattle ranching has been a means of maintaining land tenure. Even if the activity is not profitable in the short term, investors can grant the return of investment by selling their properties in a context of land speculation.

Instead of criticizing political issues as illegal practices on land tenure and corruption on the administration level, it is preferred to examine the governmental programs in the Amazon in a more comprehensive socio-economic context. It is important to note that the

[5] Even in a context of high inflation, it did not take into account monetary adjustment.

[6] La Rovère and Mendes [14] affirm that in Tucuruí "the possibility of gaining construction or related employment attracted large inflows of migrants increasing the population of the immediate area six-fold. Overall the area double its population in ten years, severely straining the social infrastructure of the area and resulting in the emergence of slums (favelas)."

[7] Fearnside [1] affirms that fiscal incentives were only suspended in 1991 through Decree 153.

[8] In fact, most of it is abandoned land.

Brazilian economy was seriously affected by the second oil shock in 1979 and the Mexican financial crisis in 1982. Finally, the Brazilian economy collapsed in 1983.

During the 1980s (the "lost" decade), people coming from poor regions such as the northeast could no longer find jobs in the southeastern large cities. The standard development model postulating the natural reduction of hidden unemployment in rural areas through increasing demand for workers in large cities did not work anymore. It can be one justification for the necessity of settling people where resources are apparently available. [9]

Relying on the driving forces presented above, Reis [5] proposes an econometric model including social, economic, ecological and geographic variables such as road length, economic growth in the neighborhood areas, urban and rural population, land productivity to explain deforestation. Similarly, Pfaff [4] builds another econometric model, but his model better explains deforestation when population is excluded from the set of explained variables. Actually, he detects collinearity of population and other explained variables (bank branch locations).

The problem of his model has to do with the fact that he found a positive correlation between deforestation and soil productivity for the Amazon as a whole. In contrast, as mentioned before, other authors consider that deforestation is motivated by the fact that soil fertility decreases substantially as soon as forest is cleared and the fact that it takes a long time for land to recuperate. That is why a large amount of land is abandoned in the Amazon. Pfaff [4] could not take colonization or land titling projects into account due to the lack of data. Besides, he recognizes that "the dynamics of frontier expansion and deforestation merit further empirical work" [4].

Another problem of using econometric models on Amazon deforestation is related to the fact that these models usually rely on past information [17]. However, deforestation dynamics have changed over time. Different factors can better explain deforestation, depending on the period of analysis chosen.

Fearnside [1] requires simulation models in order to estimate the impact of environmental policies and projects mitigating deforestation. From the microeconomic point of view, "understanding how deforestation works requires quantitative estimates of effects of the profitability of beef production, roles of land speculation and land prices, incentives, small farmers, land reform, road building, logging, and soybeans." From the macroeconomic point of view, it is important to figure out the impact of inflation rate, the profitability of alternative investments, and the price of and time for transportation [1]. A general equilibrium model could take into account these questions and then evaluate the impact of the environmental policies. Nevertheless, the information required by this kind of model is not generally available on the level of the Amazon states.

The author completely agrees with Fearnside [1] about the necessity of a consistent economic framework [18]. Nevertheless, in a context where information is lacking, it is preferred to focus the analysis on a specific sector and region.

3.2. Deforestation data and trend

Since 1988, the Brazilian Space Agency (INPE—*Instituto Nacional de Pesquisas Espaciais*) has been monitoring Amazon deforestation by satellite imaging. The results have been published annually and are available on a web site [19]. Images were also taken in 1978, but there is no information available between 1978–1988. Annual deforestation for this period is usually presented as an average value. Probably, the deforestation rate was not high in the 1970s, but it increased dramatically during the 1980s.

Fig. 3 shows an important decrease of deforestation in the late 1980s. The Brazilian government believed in the effectiveness of some public policies to suppress subsidies. However, even in the beginning of the 1990s, Hurrell [16] suggested that reduction in deforestation could be related more to meteorological conditions and economic recession than to incentive reduction.

Fearnside [1] considers also that "the decline in deforestation rates from 1987 through 1991 can be best explained by Brazil's deepening economic recession over this period. Ranchers simply lacked money to invest in expanding their clearings as quickly as they had in the past. In addition, the government lacked

[9] Hurrell [16] admits that international public opinion against Brazilian programs ignores justice and equity issues.

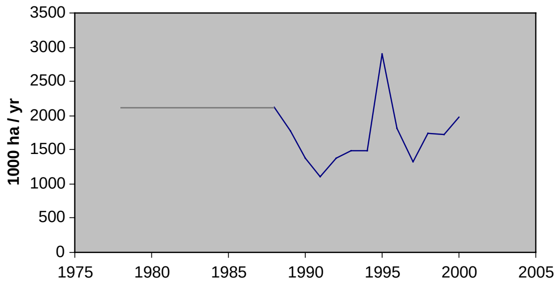

Fig. 3. Annual Amazon deforestation. Source: [19].

funds to continue building highways and establishing settlement projects."

Over the 1995–1997 period, the author identifies land speculation as one of the most significant drivers of deforestation. In fact, as soon as the Brazilian government adopted the Real economic plan constraining inflation in 1994, land prices increased tremendously. The financial market relies on this option, trying to reduce risks when economic context changes. After some time, if there is no significant economic instability, the market becomes normal. In other words, land prices decreased after some time and then deforestation rates followed the same trend between 1995 and 1997.

Despite criticisms of the Brazilian government policies and programs in the Amazon region, Nepstad et al. [3] have recognized the government regulatory efforts to increase the Amazon frontier governance. The author points out that "in the past, frontier governance has been undermined by the black market through which public lands pass into the hands of land speculators, loggers, and ranchers. In the past few years, Brazil's land reform agency (INCRA) nullified the titles of more than 20 million ha of land claims."

Others examples of improving governance are the Brazilian fire control program for Amazon [3,7] and the government plan to take effective control of access to federal lands. These actions alter, of course, the dynamic of deforestation, but econometric models relying only on past data can hardly take new facts into account.

3.3. Delimitating the area of study: the Carajás region

Although land restoration is not the best alternative to mitigate carbon emissions from deforestation, the reuse of degraded lands has been suggested for agro-forestry and biomass for energy and industry purposes [20]. Fearnside [1] considers that promoting agro-forestry among small farmers cannot combat deforestation, but it has important reasons to be supported. Nevertheless, the author points out that in the context of conflicts regarding land distribution, it is easier to distribute land in forested areas to a landless population, as occurred in the past agrarian reform programs, rather than facing the politically more difficult alternative of redistributing degraded pastureland on unproductive large landholdings [1]. However, a significant number of lands were illegally acquired and the government has tried to recover the tenure of some of them.

Therefore, attention here is focused on the spatial boundaries of the Carajás Iron Ore Program (CIP). The area specified in a study financed by the World Bank in 1994 about energy alternatives for the Carajás metallurgy pole totals 78 million ha. [10] The Carajás area includes all towns around the railway linking the Carajás mine in the southeast of the Amazon to the port in São Luís. It is important to note that the related area is in between scrub vegetation (Brazilian *cerrado*) and tropical forest. Most of the deforestation has taken place in this region, the so-called deforestation frontier.

Although the Carajás area represents only 16% of the Amazon region, almost half of the total Amazon cleared lands in 1985 (43.7 million ha) were included in the Carajás area (21 million ha). Fig. 4 shows a huge amount of fallow land in the Carajás area in 1985 (9.6 million ha), in fact it is 46% of Carajás' cleared lands. [11]

It is likely that Reis' econometric model overestimates cleared lands, since his output to total Amazon cleared lands is at least 16% higher than official figures (37.8 million ha in April 1988). However, it can be verified later that only a small fraction of Carajás fallow lands is needed to produce bio-fuel in

[10] One of the aims of the study was to estimate the producing potential of charcoal in cleared lands or managed forest for substituting coke in the pig iron industry. For more details, see La Rovère et al. [21].

[11] The amount of fallow land estimated by Reis [6] to 2010 (15.5 million ha) will be considered later to calculate the bio-fuel producing potential in deforested lands.

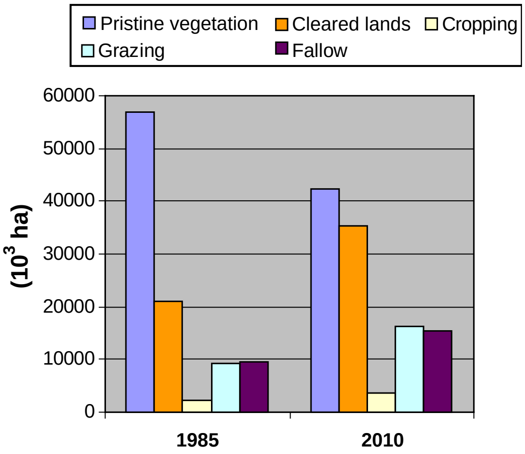

Fig. 4. Land-cover distribution in CIP (10^3 ha). Source: [26].

2010. Land requirement is not excessive even if present data is considered.

4. Technological energy alternatives for land restoration

The focus here is neither to identify the best activities concerned with avoiding deforestation nor to choose the best energy leapfrog technologies available in the market. [12] In fact, the aim is to conciliate these two issues: energy production and land restoration.

In spite of the fact that ethanol-engine technology has been diffused in Brazil, sugar cane is not an alternative for degraded lands. Besides, ethanol replaces gasoline, but Diesel and heavy fuel oil represent 76% of petroleum products consumption in the north, while gasoline is only 16%. [13] This is explained by the fact that consumer centers are sprawled in the Amazon, requiring a specific configuration for both electricity and transportation sectors. [14] In this context, three types of biomass for energy purposes in the Amazon region are identified:

- Charcoal for the steel and pig iron industry;
- Bio-fuels for transportation and electricity generation;
- Biomass waste from bio-fuel production and charcoal for power plants.

The first one has been largely mentioned in the literature [1,13,20,21]. It is not the focus here, but it can be combined with the second option in an agro-forestry framework. In fact, the second option is related to the replacement of Diesel or heavy fuel oil by vegetable oils. [15] The third alternative is merely a complementary activity, resulting from one of the two other alternatives.

Several kinds of vegetable oil have been studied in Brazil. In Table 1, seasonal and perennial crops were selected. Perennial crops have the advantage of granting continuous income during the year. Hybrid palm oil developed by *Institut de Recherches pour Huiles et Oléagineuses* (IRHO) presents the better productivity.

Aguiar and Oliveira [24] have analyzed the producing potential in the Amazon region: 70 million ha, the biggest in the world. Furthermore, the authors affirm that hybrid palm can regenerate degraded soil and control erosion.

Palm oil also presents advantages at the socio-economic level. It can be produced in a small-scale system managed in a cooperative way, as in Malaysia. This crop permits inter-planting combinations with, for example, short cycle crops such as beans,

Table 1
Oil productivity (tonnes of oil per hectare)

Seasonal crop		Perennial crop	
Soybean oil	0.35–0.45	Avocado oil	1.0–2.0
Peanut oil	0.36–1.20	Coconut oil	2.0–3.0
Sunflower oil	0.35–0.50	Palm oil	3.5–5.0
Castor oil	0.45	Hybrid palm oil	5.0–8.0

Sources [24,28].

[12] For more details, see [22].

[13] In other regions, gasoline market share varies between 25–30% in 2000 according the Brazilian Oil Agency (ANP) database [23] and conversion coefficients from the Brazilian energy balance. Five fossil fuels were considered: Diesel, heavy fuel oil, gasoline, kerosene and Liquefied Petroleum Gas.

[14] In the north, electricity is supplied mainly by oil power plants and most of power generation is isolated, not linked to the Brazilian transmission grid. Ships travel long distances to transport fossil fuels. Ships exerting an important role in the economy consume Diesel or heavy fuel oil.

[15] Diesel final cost in some places in Amazon can reach three times the national Diesel mean price [25].

corn, banana and manioc for food and to feed livestock.

Palm oil is the second international vegetable oil trade market after soybean oil and the demand has been increasing, principally in Asia. The Brazilian Bank for Social and Economic Development has financed the private sector to develop palm oil industry in Pará state. The Pará's government has been interested in participating in this project. On the one hand, subsidies are offered in the first years. On the other hand, the palm industry should first help small farmers prepare land and second should assure crop production purchase. In this phase, public interventions are required to overcome "lock in" effects, as such acceptability, learning process and minimal scale of production [17].

In summary, there are some technical, social, economic and political issues in favor of palm oil production in the Amazon degraded lands, suitable not only for energy purposes, but also for food needs.

5. Results from bio-fuel production in deforested areas

This topic relies on some of Reis' estimations to the Carajás area presented previously as fallow lands and population size. By 2010, Reis [6] projects the population will increase to 9.3 million inhabitants, while fallow lands will increase to 15.5 million ha in the Carajás area (see Fig. 4). Regarding productivity, the range from 5 to 8 t of hybrid palm oil per hectare (see Table 1) is assumed.

Relying on these three assumptions, it is easy to estimate concerning Carajás degraded lands some technical, social, economic and environmental issues as the potential for palm oil production, land requirement, number of families settled or job creation, income generated and carbon emission reduction.

The technical potential of palm oil production in Carajás degraded lands varies from 77.5 to 124 million tonnes (Mt), depending on the productivity range (5–8 t/ha). Only one fraction of this potential would be needed to replace half of the Brazilian household fuel consumption in 2010. Based on Costa [11], it would be necessary to produce 16 million tons of bio-fuel in 2010. [16]

Depending on productivity, the land requirement range is between 2 and 3.2 million ha. In other words, it corresponds to a range from 13% to 20% of fallow lands in Carajás in 2010 (15.5 million ha). From 200,000 to 300,000 families could be easily settled in this area, [17] which represents 10–15% of Carajás population in 2010.

Considering 10 ha per family [18] and a revenue range of 200–300 US$/ha/yr, only palm cropping activity could generate between 2000 and 3000 US$/family/yr. [19] Should employment vary from 200,000 to 300,000 families, total annual palm cropping revenue would be between 400 and 900 million US$ per year. Note that a large part of the income remains in the region and additional revenue can be generated from inter-planting combinations. The surplus should be invested in local activities promoting better opportunities for economic development, different from large-scale projects since the benefits of these projects go essentially to large cities or abroad.

For such levels of income, the cost of producing palm nuts varies from 2.1 to 5.1 cents per litre of crude palm oil, depending on income range (200–300 US$/ha/yr) and productivity (5–8 ton of oil/ha). [20] It should be added to palm nuts cost 19 cents, the unit cost for processing vegetable oils. [21] The Diesel national average cost is almost 35 cents (tax is not included) [23], but in certain places in Amazon the

[16] It means that the bio-fuel market share comes back to 50% of automobile fuels as in the late 1980s (see Fig. 2).

[17] The Pará's state settlement program intended to settle 100,000 families around Belém, capital of Pará, during 25–30 years in the state property lands [11].

[18] The Pará's state government considers a range of 5–10 ha per family.

[19] Palm nut output value per hectare varies from US$ 200 (national mean) to US$ 300 (northern mean). These values were calculated from town level statistics (PAM—*Produção Agrícola Municipal*). See IBGE web site: www.ibge.gov.br.

[20] 2.1×10^{-2} US$/$l$ = 200 US$/ha/yr ÷ 8000 kg of oil/ha/yr × 0.852 kg of oil/l.

[21] Based on a pilot plant project in Natal, the capital of the Rio Grande do Norte's state. The plant will produce 5600 litres of bio-fuel from castor oil per day and will cost almost US$ 1.7 millions. It was considered an interest rate of 15% p.a., 20 years of lifespan and 250 days of work per year.

cost can triple [25]. That is why bio-fuel could be cost effective in some places in the Amazon region.

Palm oil production as proposed here is not so intensive in labor (10 ha/family) if compared with other economic activities in the region. Freitas and Rosa [20] affirm that large-scale cattle ranching employs 4 workers/ha, logging 10 workers/ha and reforestation 20 workers/ha. However, it should be stressed that the purpose here is not concentrate people in small places, but rather to distribute enough land in order to assume a minimal revenue to local people.

In terms of environmental benefits, only the amount of carbon emission avoided by fossil fuel replacement was estimated. Considering the Diesel carbon emission coefficient from MCT's methodology (National Communication), 16 Mt of palm oil consumption could replace 14.4 million tones of Diesel and avoid 13.1 Mt C. According to Costa [11] business as usual scenario, it represents almost 6.5% of Brazilian fossil fuel carbon emissions in 2010.

The carbon emissions due to the oil transformation process, i.e. to transform oil in petroleum products were not included in the estimations. Yet, the amount of carbon sequestered during plant growth should have been included in the estimation, but it was not possible due to the lack of data. Certainly, it should sequester less carbon than silvicultural plantations, sustainable timber management and reduction of deforestation [13], but the palm oil option offers other benefits that pertain directly to local poor communities. Then it is not necessary to rely on economic compensation mechanisms that are unlikely to work in a context of institutional vulnerability.

6. Conclusions and recommendations

The proposal for palm oil production on the Amazon deforested lands presents both socio-economic and environmental benefits. Among the economic aspects, not only the amount of income generation should be considered, but also the fact that palm oil production relies on the available production factors such as labor and land. Furthermore, it is likely that the surplus is reinvested into the region and it reduces the necessity of the country to import Diesel. Presently, it is cost effective in some places, but the cost to distribute it in a more comprehensive framework should be better evaluated.

Among the social concerns, which usually are the most important from the developing countries' point of view, palm oil production could settle a number of families in deforested areas. This activity is structured on a small-scale framework, permitting intercropping combination. It could provide food security and poverty alleviation in rural areas. These benefits should be interpreted as direct improvement of the well-being of the local people.

Regarding environmental issues, the benefits for the local environment when land is restored should be considered. However, they were not analyzed here, but it is a visible gain for local communities, since soil restoration usually improves productivity. In fact, the focus was only the benefit for the global environment by reducing oil consumption. Even carbon sequestration, which is a natural result of palm tree growth, was not quantified here.

From the technological standpoint, palm oil contributes to alleviate some oil refining constraints. Besides, Diesel is mainly used by freight and collective transportation. In a context of more concerns on the global environment, the Amazon deforested areas seem to be a niche to start up the first experiences (pilot projects) on some high productivity bio-fuel production. On the one hand, the cost to transport Diesel to remote areas is high there and, on the other hand, it is in accordance with local energy needs, mainly for transportation and electricity.

Despite these benefits, it is clear that there are many barriers to be overcome in order to implement a project like this. Several studies have already been developed during the 1980s, but some of them were abandoned. Others continued, but they were restrained to a limited field of research. The Brazilian Agricultural Research Company EMBRAPA is one of the few active institutions doing researches and cooperating with international research centers. Nowadays, EMBRAPA sells its varieties to agro-business companies. Recently, government created an inter-ministerial group in order to study the biodiesel economic viability, since Brazil offers one of the most important potential for producing and to export bio-fuel around the world. The Ministry of Science and Technology coordinates the studies and launched in October 2002 the Brazilian Bio-fuel Programme, whose target is to replace 1.3 billion litres of Diesel up to 2005. In fact, the aim is to blend 5% of biodiesel to mineral Diesel until 2005, increasing the blend until 20% up to 2020.[22] The Ministry of Mines and Energy (MME) is another important player for biodiesel development. The Green Biodiesel Programme was launched by MME in July 2003. In the first phase, four pilot project plants were selected for producing biodiesel in Rio de Janeiro, Ceará, Piauí and Rio Grande do Norte. The plants should start up production in 2004–2005. Yet, the Eletrobras Chairman is negotiating with Acre's governor on a project for producing bio-fuel to be used in remote power generation systems in Amazon.

In the case of Amazon, not only government, but also other parts of society should be involved in bio-fuel development, mainly in some areas where governance is improving. Partners such as universities and research centers[23] should continue developing specific studies on plants adaptability in the chosen regions, impact assessment of crop inter-planting combinations, accounting studies on carbon sequestration and technological option for engines.

Some NGOs could help in this process by identifying the local population needs and the possibility that a project like this can work in practice. The context is favorable since land conflicts remain in the region and the landless and homeless movements claims are one of the main issues for the new government. In summary, the project proposed here could be integrated in the broad government agrarian reform program.

Another stakeholder that could be integrated in this network is the Brazilian oil company Petrobras. The cost to transport Diesel to some places in the Amazon region is so high that it could interest Petrobras to help the network to implement it, granting a bio-fuel market at least in the beginning of the program. It should be used as an ecological market campaign. However, Petrobras is probably risk-averse because it has supported the loss of the ethanol program.

Federal and state governments must be concerned with a project like this in order to try to eliminate "lock in" effects. Actually, Pará's governor has already promoted a partnership network with the private sector and the local communities by reducing tax fees during the first years of the implementation phase of palm oil production. For a broad project, federal government and financing agencies should be involved. In this sense, not only profits, but also risks could be shared. In a project-finance framework, bio-fuel production in the Amazon degraded lands could be profitable and could benefit both global environment and local communities.

Acknowledgements

This paper is a development of some ideas introduced in my Ph.D. thesis that supported an alternative scenario relying on biomass. A first version working paper was developed during the 2002 spring course of the Watson Institute Scholars of the Environment program. I would like to thank the professors Caroline Karp, Richard Wetzler and Steven Hamburg to encourage me to write this paper, as well as the scholars Jugal Bhurtel and Wenjun Li for the comments. Of course, the opinions expressed here are those of the author. Any remaining errors are the author's sole responsibility.

References

[1] Fearnside PM. Forests and global warming mitigation in Brazil: opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism". Biomass and Bioenergy 1999;16:171–89.

[2] Laurence WF. A crisis in the making: responses of Amazonian forests to land use and climate change. Tree 1998;13:411–5.

[3] Nepstad D, McGrath D, Alencar A, et al. Frontier governance in Amazonia. Science 2002;295:629–31.

[4] Pfaff AS. What drives deforestation in the Brazilian Amazon? Journal of Environmental Economics and Management 1999;37:26–43.

[5] Reis EJ. An econometric model of Amazon deforestation. Rio de Janeiro: IPEA; 1992.

[22] For example, some research centers that could be involved in this project are: INPA (*Instituto Nacional de Pesquisa da Amazônia*), INPE (*Instituto Nacional de Pesquisas Espaciais*), CEPEL (*Centro de Pesquisas de Energia Elétrica*), and CENPES (*Centro de Pesquisas da Petrobras*).

[23] Presently, according the Brazilian Oil Agency (ANP), there is no legal constraint to blend till 5% of bio-fuel in Diesel. For a higher percentage, technical tests are required.

[6] Reis EJ. Os impactos do pólo siderúrgico de Carajás no desflorestamento da Amazônia Brasileira. In: Perspectiva da economia brasileira 1996–1997. Rio de Janeiro: IPEA; 1996. p. 691–715.
[7] Fearnside PM. Saving tropical forests as a global warming countermeasure: an issue that divides the environmental movement. Ecological Economics 2001;39:167–84.
[8] Houghton RA, et al. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature 2000;403:301–4.
[9] La Rovère EL, Costa RC. Contabilização do Balanço de Carbono: Indicadores de Emissões de Gases de Efeito Estufa. In: Seminário sobre Monitoramento de Impactos Ambientais. Campinas, 6–8 November 2001.
[10] La Rovère EL (coord). The South North (SSN) Project: Final Report for Brazil 2001, http://www.southsouthnorth.org/frameset.asp?url=cdmprojects.asp.
[11] Costa RC. Contraintes d'environnement global et impératifs de développement á court terme: étude des conditions d'une harmonisation dans le cas du Brésil. PhD thesis. École des Hautes Études en Sciences Sociales, CIRED, Paris, 1999.
[12] ANFAVEA. Anuário Estatístico da Indústria Brasileira—2002. São Paulo, 2002, http://www.anfavea.com.br.
[13] Fearnside PM. Global warming response options in Brazil's forest sector: comparison of project-level costs and benefits. Biomass and Bioenergy 1995;8(5):309–22.
[14] La Rovère EL, Mendes FE. Tucuruí Hydropower Complex, Brazil, A WCD case study prepared as an input to the World Commission on Dams, Cap Town, www.dams.org, 2000.
[15] Pimm SL, Ayres M, Balmford A, et al. Can we defy nature's end? Science 2001;293:2207–8.
[16] Hurrell A. Brazil and the international politics of Amazonian deforestation. In: Hurrell A, Kingsbury B, editors. The international politics of the environment. Oxford University Press, Oxford, 1992. p. 398–429.
[17] Costa RC, Fallot A. Top-down versus bottom-up: coupling both modelling approaches for a prospective study on biofuels. In: Rozakis SE, Sourie J-C, editors. Comprehensive economic and spatial bio-energy modeling. Chania: Options Méditéraneennes; 2002. p. 61–76.
[18] Costa RC. Do model structure affect findings? Two energy consumption and CO_2 emissions for Brazil in 2010. Energy Policy 2001;29(10):777–85.
[19] INPE—Instituto Nacional de Pesquisas Espaciais. Monitoring of the Brazilian Amazon Forest by Satellite 1999–2000. São José dos Campos, 2001, http://www.inpe.br/Informacoes_Eventos/amz1999_2000/Prodes/index.htm.
[20] Freitas MA, Rosa LP. Strategies for reducing carbon emissions on the tropical rain forest: the case of the Brazilian Amazon. Energy Conversion and Management 1996;37(6–8):757–62.
[21] La Rovère EL, Legey LF, Costa RC et al. Estudo de alternativas energéticas para o pólo metalúrgico do programa Grande Carajás. Report for the World Bank, PPE/COPPE, Rio de Janeiro, September 1994, unpublished.
[22] Goldemberg J. Leapfrog energy technologies. Energy Policy 1998;2(10):729–41.
[23] ANP. Anuário Estatístico—2003. Rio de Janeiro, 2003, http://www.anp.gov.br.
[24] Aguiar SC, Oliveira HP. Atuação do CEPED no projeto comunidade agroenergética Tabuleiros de Valença, Bahia—Brasil. CEPED, Camaçari, 1985, unpublished.
[25] Almeida SA, Freitas MV, Di Lascio MA. Biomassa como opção energética para o desenvolvimento autosustentado de comunidades isoladas na Amazônia—o caso dos óleos vegetais. In: II Congresso Brasileiro de Planejamento Energético—UNICAMP. 12–14 December 1994. p. 625–31.
[26] MCT—Ministërio da Ciência e Tecnologia. Inventário Brasileiro das Emissões Antrópicas por Fontes e Remoções por Sumidouros de Gases Efeito Estufa não Controlados pelo Protocolo de Montreal. Comunicação Nacional, Brasília, http://www.mct.gov.br/clima/comunic_old/inventar.htm.
[27] MME—Ministério das Minas e Energia. Balanço Energético Nacional, Brasília, 2001, http://www.mme.gov.br.
[28] Pinto RN. A viabilidade econômica do diesel vegetal obtido a partir do palm oil. In: VI Congresso Brasileiro de Energia e I Seminário Latino Americano de Energia. Rio de Janeiro, 1993. p. 1117–23.