African Journal of Biotechnology Vol. 8 (4), pp. 515-523, 18 February, 2009
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2009 Academic Journals

Review

Opportunities and challenges for the international trade of *Jatropha curcas*-derived biofuel from developing countries

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Accepted 7 January, 2009

The interest on non-food energy crops is increasing, and among these *Jatropha curcas* has been highlighted as a possible source of biodiesel due to its characteristics of growing on barren, eroded lands under harsh climatic conditions, demanding low moisture and in resulting productive harvests. In face of the promising international biofuel market, several African and Asian countries are seizing biodiesel trade opportunities through exploitation of the benefits of large-scale production and trade of Jatropha though little is known about the agronomics of this crop for biofuel production. Thus, the study aimed at analyzing the challenges and opportunities of large-scale Jatropha cultivation in developing countries for biodiesel export. The Strategic Niche Management framework was applied to analyze socio-technological experiments of Jatropha cultivation in India, as a case-study because this country is currently the world leader in cultivating Jatropha on industrial scale and it has similar edapho-climatic conditions and cultural characteristics with some African countries. Therefore, before engaging into large-scale cultivation of Jatropha in developing countries considerable experiments ought to be made with the participation of all stakeholders. Furthermore, for developed markets access biofuel-producing countries would require certification systems which take into account certain specific environmental, social, and agricultural production practices.

Key words: Jatropha cultivation, strategic niche management, biofuel trade, India, Africa.

INTRODUCTION

The sharp increase in the price of the petroleum products, the finite nature of fossil fuels, and growing environmental concerns especially related to greenhouse gas emissions and health and safety considerations are forcing the search for new energy sources and alternative ways to power the world's motor vehicles. Biofuels are defined here as organic fuels derived from biomass that can be processed into liquid fuels for either transport or heating purposes, which may offer a promising alternative. They can be made from purpose-grown energy crops, as well as multipurpose plantations and by-products such as residues and wastes (FAO, 2007).

This work focuses on one type of liquid biofuel produced from purpose-grown crops: biodiesel that is derived from seeds such as rapeseed, sunflower, soy, palm, coconut or jatropha, by reaction of the oil with methanol or ethanol. Biodiesel can either be burnt directly in diesel engines or blended with diesel derived from fossil fuels (Peskett et al., 2007).

The new global interest in biofuels has already translated into rapidly expanding international biofuel markets. Several developed and developing countries are establishing regulatory frameworks for biofuels, including blending targets. For instance, the European Union's (EU) goal of 10% blends of biofuels in fuel transport by 2020 (Peskett et al., 2007). They are also providing kinds of subsidies and incentives to support nascent biofuel industries. These developments are expected to spur a sustained worldwide demand and supply of biofuels in

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the years to come (ICTSD, 2006).

Arguably their greatest appeal lies in their potential to reduce greenhouse gas (GHG) emissions by partial replacement of oil as a transport fuel. According to Faaij (2004), because the demand for transportation fuels is so large, biofuels offer farmers in all countries-rich and poor-huge market opportunities. This could help countries meet their commitments under the Kyoto Protocol and mitigate the effects of climate change. Still in relation to the demand for bio-energy, the greenhouse gas emission reduction is important as it is the guarantee that biomass produced in other part of the world is supplied on a sustainable way.

According to Dufey (2007), in economic terms today's high oil prices make biofuels from the most efficient producer countries competitive and these are largely developing nations. Further driving forces behind biofuel market development include the promotion of greater energy security, currency savings through a reduced oil bill, rural development, and poverty reduction. These factors combine to place biofuels at the top of today's policy agendas. So, the biofuels business is booming, with implications for agriculture and energy, environment, development and trade. Getting the best from them will require the right combination of markets, incentives and institutions at the local, national and international levels. As markets for biofuels grow, so too will their international trade.

For Faaij (2004), international bioenergy trade is the result of combination of these drivers and the regional diversity like climate, availability of water, soil conditions, population density, stage of development and agricultural production methods. Actually, the raw materials or feedstock being exploited commercially by the biodiesel countries constitute the edible fatty oils derived from rapeseed, soybean, coconut and palm (Korbitz, 1999). Some authors argue that the use of such edible oil to produce biodiesel in developing countries is not feasible since the majority of these, which are potential biofuel producers already have a shortage of edible oil and can not afford to divert any of its existing harvest of vegetable oil for biodiesel production, inedible oil produced from trees such as *Jatropha curcas*, that can grow on barren, eroded lands under harsh climatic conditions such as desert soils unfit for food or feed production, could be a source of choice for biodiesel under present circumstances (Francis et al., 2005; Azam et al., 2005). Depending on the specific agricultural, environmental, economic and energetic conditions that countries have, biofuels can provide different options. However, policies play an important role in the development of bioenergy trade. The profitability of biofuels will depend on a range of factors including energy demand (which is growing) and other markets for feedstocks (e.g. food), by-products and traditional fossil fuels. It is generally assumed that increased biofuel production and trade will raise the price of feedstock, but that the effects may vary markedly across crops (ICTSD, 2006).

Peskett et al. (2007), argue that notwithstanding the differences between different production systems, feedstocks, or historical patterns of agricultural production and poverty levels, the economics of biofuels production show that in general, the economies of scale are important in biofuels production. Like all major technological innovations in human history, the transition to a low-carbon energy regime will create benefits and burdens. Though biofuels present both promises and perils, they have very promising prospects and could in fact be a key component of the future world's energy system. However, without the development of biomass resources (through energy crops) and a well functioning biofuel market that can assure a reliable and lasting supply, those ambitions may not be met.

In the face of this promising market, several African and Asian countries are seizing biodiesel trade opportunities through exploitation of the benefits of large-scale production and trade of fast growing, drought resistant feedstock of jatropha tree seeds, although few is known about the energy and greenhouse gas balance, and the environmental, land use and socio-economic impact of jatropha agricultural production system. Therefore, considering large-scale jatropha biodiesel production, it is required in answering the following questions:

- How can jatropha biodiesel produced in developing countries be accepted by the potential international market? Should be any concerns about cultivating jatropha in large extension?

This study aims to analyze the implications of large-scale jatropha cultivation in developing countries for biodiesel export. For this purpose we explore the developments in India, because it is the leader when it comes to cultivating Jatropha on an industrial scale and has similar cultural and edapho-climatic characteristics with some African countries. The questions we want to address in this study are: which are the opportunities and challenges for jatropha biodiesel production for developing countries? What has been made so far? What are the major difficulties developing countries will face to establish locally an export-oriented biofuel production?

STRATEGIC NICHE MANAGEMENT AS ANALYTICAL TOOL

The introduction of sustainable technologies is not an easy task. Experience shows that this is usually a complex and protracted process with high likelihood of failure even though they promise superior performance compared to incumbent technologies (Caniëls and Romijn, 2006). This is explained by the fact that technologies are always part of a broad and complex system - a socio-technological (ST) regime, which consists of manifold interacting technological and societal elements.

Hoogma et al. (2002) defined the socio-technological regime as “the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures”. In turn, the regime is embedded in a wider context – the landscape, which consists of material and immaterial societal factors. Van der Laak et al. (2007), points that systems are locked in through technological, institutional and social path dependency, resulting in a variety of barriers for new innovations such as the lack of a fuel infrastructure, the lack of clear government regulations or fierce competition with a network of incumbent actors that do not support the innovation. Moreover, new technologies often suffer from limited technological and economic performance compared to the dominant design, which has already profited from decades of dedicated research and development. Yet new technologies often do get support on the basis of expectations about future performance improvements. In addition, Eijck and Romijn (2006), say that innovations with radically new features especially those that aim to improve environmental and social equity-related sustainability, do not rub well with extant socio-technological regime characteristics that reinforce the importance of short-term economic benefit alone. Simultaneous adaptations in all major parameters of the regime are thus required for such technologies to be successfully developed, introduced to the market and adopted widely.
Levinthal (1998), argue that although expectations about future performance of new technologies can create a niche for R&D it is not sufficient. Rather for successful technology introduction in society, experimentation and testing in niche markets is a fundamental step in the innovation process.

However, there is a limit to the adaptability of the regime itself because regime change is conditioned by landscape factors. This can result in powerful inertia that can prevent new sustainable technologies from gaining ground, let alone from unseating incumbent ones.

In order to address these problems, the SNM approach advocates the creation of niches: protected spaces in which new technologies are given opportunities to incubate and mature through gradual experimentation and learning by actor networks of producers, researchers, users, governmental and other organizations (Eijck and Romijn, 2006). This multi-level perspective – landscape, regime and niche – is adopted in SNM to analyze the potential of emerging transition processes and their dynamics. SNM framework has proven useful for analysis of success and failure factors in the introduction of specific radical innovations, such as wind energy, biomass, public transport systems and food production. By identifying the major characteristics and developments at each level and tracing their effects to the other levels through niche creation process, it is possible to gain insight into the constellation of major forces that push for, and hold back, the development of new supply chain of sustainable technologies.

For this study, it was used the multi-level perspective of socio-technological (ST) system proposed by Geels (2002), supplemented by a geographical boundary suiting Jatropha biodiesel production projects (Figure 1). In this perspective, the emerging technology appears on the niche level, constituting niche ST-systems and describing the relation between the three processes of niche creation which are: ‘network formation’, ‘learning’ and ‘stabilization and convergence of expectations’.

Actors, relations, institutions and physical artifacts connected to entrenched technologies belong to the regime level, and determine the normal way to provide society with products and services.

There is also a higher landscape level containing issues not under control of separate regimes and niches, for example, societal concerns, general politics and general economic situation. However, the landscape can be influenced by regime changes in the long run.

High quality niche creation processes are characterized by a wide and interconnected actor network, by extensive experimentation and learning on several subjects – not merely about the new technology itself, but also about user acceptance, economic aspects, required infrastructure, and by expectations that are gradually stabilizing and becoming more specific (Eijck and Romijn, 2006).

The first process is voicing and shaping of expectations is meant to match the promises held out by the innovation and the stakeholders’ expectations about it, with the needs in society that the innovation is meant to satisfy (Kemp et al., 1998). Firms, users, policymakers, entrepreneurs and other relevant actors participate in projects on the basis of expectations. Articulating expectations is important to attract attention and resources as well as new actors, in particular when the technology is still in early development and functionality and performance are still unclear.

The process of voicing and shaping of expectations is considered to be good when (a) an increasing number of participants share the same expectations (expectations are converging), and (b) the expectations are based on tangible results from experiments (Van Der Laak et al., 2007).

The second process of niche creation revolves around experimentation-based learning about technological and environmental possibilities and constraints of the innovation, about the discovery of specific application domains and its uses in these domains, about its acceptability by social groups and individuals, about policies to regulate or promote it, and so on. At the same time, social actors themselves change their views and align their expecta-

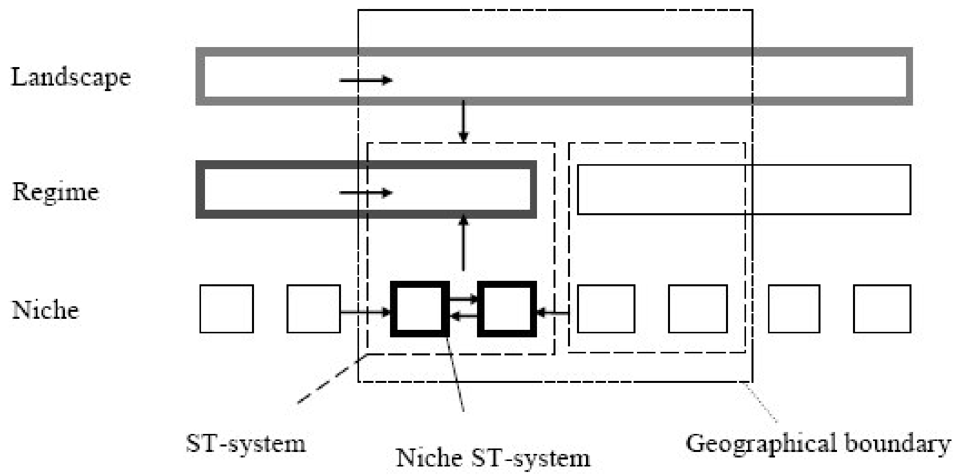

Figure 1. The three level perspective of socio-technological system. Adopted from Geels (2002).

tions about the new technology over time, under the influence of further development of the new technology and their exposure to it (Caniëls and Romijn, 2006).

The potentials benefits and the limitations of the new technology for people become clearer as the experiment evolves. People's expectations about it become more specific and consistent ("robust") as initial vague beliefs give way to accumulating facts, figures and experiences (Raven, 2005).

To sum up, Kemp et al. (1998) said that "experiments are a way to stimulate articulation processes that are necessary for the new technology to become socially embedded".

Thus, a good learning process is (a) a broad – focusing not only on techno-economic optimization, but also on alignment between the technical (e.g. technical design, infrastructure) and the social (e.g. user preferences, regulation and cultural meaning) and (b) is reflexive – there is attention for questioning underlying assumptions such as social values, and the willingness to change course if the technology does not match these assumptions (Van Der Laak et al., 2007).

The third process is the building of social networks. According to Hoogma (2000), it will be conducive to success when actors' motivations to participate are not centered on short-term financial gains. In particular in early phases of an innovation's life cycle, the social network is still very fragile. Experimentation in niche markets can bring new actors together and make new social networks to emerge. Building social networks is considered good when (a) the network is broad (including firms, users, policy makers, scientists, and other relevant actors), and (b) when alignment within the network is facilitated through regular interactions between the stakeholders (Van Der Laak et al., 2007).

Finally, the participating actors in the network should share a common core view about where they are going with each other and with the technology. Actors' strategies, expectations, beliefs, practices, and visions must go in the same direction, run parallel (Hoogma, 2000, p.85).

Sometimes, an already existing social network that evolved for some unrelated purpose can serve as a useful basis for designing a new experiment. However, this may not always work well, especially when it means that the stakeholders that are important to the development of the new technology are left out (Raven, 2005; Hoogma, 2000). The interaction between these three processes forms the basis within SNM for understanding success and failure of sustainable technology introduction.

However, more recent SNM work concludes that the internal niche processes are important but not sufficient pre-condition. Raven (2005, 2006) explicitly includes the dynamics in established socio-technological regimes as explanatory variable for understanding success and failure. Thus, in the case of biofuels the regime focuses on CO_2 emission reduction and because SNM is concerned with understanding failure and success of sustainable innovations, it was used as an analytical framework for the purpose of this paper, that is, to contribute for introduction of export-oriented Jatropha biodiesel production in developing countries.

This was done on the basis of the three internal niche creation processes and their characteristics described above. The explanatory variable, that is, the influence of the established socio-technological regime is only dealt with in an indirect way. Due to different regimes like the energy, the agricultural and the transport regime, full regime analysis for all these domains is beyond this study.

Therefore, this research concentrated mainly on Niche ST-system because new technologies usually appear at niche level, and as it was emphasized by Eijck and

Romijn (2006) creation of niches can serve as protected spaces in which new technologies are given opportunities to incubate and mature through gradual experimentation and learning by all the stakeholders involved in Jatropha value chain. More specifically, we used SNM to analyze Jatropha biodiesel production projects in India and translate that judgment into insights on how bio-based energy transition could be studied in developing countries, and guidelines relevant for designing supply chain and biofuel policies.

ANALYSIS OF JATROPHA BIODIESEL PROJECTS BY STRATEGIC NICHE MANAGEMENT

This is an exploratory study aiming at developing an understanding of introduction of new sustainable technologies. A theoretical framework "Strategic Niche Management-SNM" was applied to analyze Jatropha biodiesel projects from India. The projects were selected from internet and research reports used here as secondary sources of information. A total of eight projects have been analyzed but we limited ourselves to four. The choice for these four projects was based on wide coverage and technological advance in relation to Jatropha biodiesel production. However, for the purpose of this study the focus was mainly on one stage of Jatropha production chain, "cultivation' where case studies of agronomic practices regarding environmental criteria were analyzed for four Jatropha biodiesel plantation projects. The projects were chosen in an attempt to represent a variety of plantation schemes, business models, project sizes and different geographic locations, such that three of the projects chosen were national development programs where the first project is managed by the National Oilseeds Vegetable Oils Development (NOVOD) board; the second project managed by the state forest department of government of Tamil Nadu and the third project is under Chhattisgarh Biofuel Development Authority (CBDA). Apart from these, the last one is a rural development project in Rajasthan.

In India, the majority of the population lives in rural areas and is dependent on land for its livelihood, where agriculture contributes with 33% of the country's GDP. The trend of increasing population and declining available agricultural land is leading to reclaim degraded lands for productive use. According to India's strategy on biofuels and land recovery, producing biofuel from eroded soils promises to achieve both wasteland reclamation and fuel security goals and is therefore in line with the Government of India's policy of national development.

The suitability of promoting large-scale Jatropha cultivation on land that currently are not used for food crop cultivation, as well as wasteland lands, is questioned though less controversial when compared to Jatropha cultivation on fertile land replacing other food and cash crops in the tropics. According to India's government definition of "wasteland" includes the common lands and forests that many farmers, pastoralists and indigenous people depend on for their food and fuel needs. A majority of such wastelands are classified as common property resources (CPR). This implies that a group such as a village collectively owns such resources and membership in the group confers an individual the right to access the resource. There are some researches on CPRs which revealed that such resources play a vital role in the lives of its users by supplying a wide variety of commodities like food, fuel wood, fodder, timber, and thatching material for home roofing (Gundimeda, 2005; Ravindranath and Hall, 1995).

Jatropha has several drawbacks in this context. First, the leaves of Jatropha are not suitable for livestock, that is, not suitable as fodder. Second, Jatropha yields insignificant amount of wood per tree. Thus, policies which promote energy crops that provide diverse benefits should have much less adverse impact on the rural poor (Rajagopal, 2007).

Based on Francis et al. (2005) indicative economic analysis of *Jatropha curcas* plantations on wastelands for large-scale biodiesel production, such land is without opportunity cost as it can not be used for other agricultural purposes. The challenges for research and technology development for improving the profitability and the acceptability of the Jatropha system should not be underestimated at this stage because according to the authors the net price of US$40 per litre for Jatropha diesel was calculated excluding taxes. So, for market introduction of Jatropha biodiesel, tax exemption would be necessary and would result in loss of revenue for the government of India if the product is marketed on a large scale.

As mentioned earlier that the major obstacle to produce biodiesel is higher cost than petroleum diesel. Currently significant positive impact on both yield and quality of horticultural crops have shown that irrigation regime has Jatropha biodiesel production is economically unviable particularly if by-products are not included in the calculation profits. According to Openshaw (2000) estimates, the selling price of Jatropha and other plant oils might be 2.5 times more than diesel price. However, for Subramanian et al. (2005) the actual cost will depend also on economies of scale in manufacturing and the political decision to promote biodiesel in India. The cost factor may also be considered taking in view of increased rural employment opportunities, indigenous energy sufficiency and savings of foreign exchange. The glycerin and cake would be valuable products, which further reduces the cost of biodiesel. Oil cake can be used as a raw material for production of biogas which would be a leverage to start many type of industries.

Furthermore, the possibilities offered by the clean development mechanism (CDM) of the Kyoto Protocol could be utilized to elicit international funding and further enhance the project's cost-effectiveness.

On the other hand, according to Rajagopal (2007), economic estimates of Jatropha plantations are incorrect in assuming zero opportunity cost for wastelands because most of these studies do not even include environmental benefits in the accounting models and still find a positive return on investment. That is, to say, there are several competing crops and uses for these wastelands. The essential point is that while the wastelands represent a vast untapped land resource there is little reason to believe that more than 10% of the total wasteland resource could be commercial viable as Jatropha plantations. In addition due to the poor soil condition, marginal lands cannot support high plantation density without adversely affecting output per plant.

The cultivation of bioenergy crops can only be sustainable if water requirements are managed well and if the available water supply for other agricultural purposes and human consumption is not negatively affected (UN, 2007). Thus, according to Berndes (2002), there was no study which included large-scale energy crops production as a new source of water demand in the future. The author argues that the projected irrigation water withdrawals are related to demand in the food sector that is determined by population size and other factors such as diet and mix of food crops under irrigation whilst the energy withdrawals are dominated by thermoelectric generation.

One of the major reasons for selecting of Jatropha is its low water requirement and therefore its suitability to dry and arid lands. According to Rajagopal (2007), the fact that Jatropha plants can survive droughts does not mean they will not be more productive if they get more water. It may be true that perennial crops are better adapted to withstand long spells of dry weather compared to short duration crops, however even trees require well spaced irrigation especially during the initial few years of development barring which their growth and productivity is permanently affected. Numerous scientific studies on a fruits. As in recognition of this fact, agronomic experiments and field trials on Jatropha at institutions like the Tamil Nadu Agricultural University are being conducted under irrigated conditions. Also according to CSMCRI's test plots, the optimum amount of water for Jatropha is still unknown (Nature, 2007). It is quite likely that fruit and seed production of Jatropha in dry rainfed conditions would be below and hence economically unviable. As the majority of small farmers rely on rain-fed conditions they might not reap the benefits of Jatropha biodiesel production because they do not have access to water, and in order to make large-scale Jatropha cultivation economically viable it may require irrigation systems.

In relation to value chain configuration there is a concern about a possible conflict of increasing orientation of bioenergy crop cultivation in developing countries towards product export. Because power structures in biofuels markets might lead to unfair distribution of benefits along the value chain, where most of the biofuels supply chains which are or would be targeting export markets have the risk that the value added process takes place in importing countries. This may occur with Jatropha biodiesel production chain in India since the world's leading developer of Jatropha biodiesel (D1 Oils) has its biodiesel refinery in England which currently relies on soybean oil from Brazil, but it will soon switch to Jatropha oil sourced from its own plantations. In the mean time, the company has already planted 81.000 hectares of Jatropha in Chhattisgarh and in the southern state Tamil Nadu, with plans for an additional 350.000 hectares over the next few years (Nature, 2007).

According to Mr. Elliot Mannis, Chief Executive of D1 Oils, "as our plantations of primary feedstocks, *J. curcas*, begin to produce oil in volume over the next few years, we will increase significantly the import and refining of low-cost feedstock sustainably produced overseas" (Grain, 2007).

This contradicts the idea, increasingly recommended by UN and NGOs, of an agricultural economy emphasizing the development of internal markets. The distribution of revenue between local/regional and national/international players, and between sub-national groups and nations can vary, depending on the potential source of bioenergy and the degree of centralization of the pre-manufacturing process.

According to report of the committee on development of biofuel (India, 2003) of India's planning commission, it envisages the setting up of large processing units with a capacity of 7.500 tons of seeds per year and centralized refineries with a capacity of about 100.000 tons of Jatropha oil per year. Notwithstanding the differences between different production systems, feedstock or historical patterns of agricultural production and poverty levels, the economies of scale are important in cultivation of many energy crops and in the transformation of these feedstocks to biofuels.

Regarding Jatropha biodiesel production, a decentralized model would be more beneficial in the long run than large scale production capacity though it may offer/favor economies of scale. For Francis et al. (2005) decentralization would include other benefits, such as creating local employment opportunities, making fuel supply widely available throughout the region, and facilitating easier local redistribution of by-products particularly the seed cake. In the same line of thinking, of, accrue from the pro-poor/small farmer nature of production system. Thus, the closer the locations of cultivation and biofuel conversion are, the greater the contributions to rural job creation and cutting greenhouse gas emissions are likely to be.

Although efforts have been in research of Jatropha cultivation practices, growers are still unable to achieve the optimum economic benefits from the plant. The entire cost economics is dependent on the quality and performance of the raw material. Yield and oil content are the two primary factors responsible and special emphasis is being laid on improved production and productivity of the planting material.

Therefore, quality of planting material is most important for establishment of successful plantations. According to Swamy and Singh (Rashtrapati et al., 2006), with the growing demand to increase area under Jatropha plantation, the quality is sometimes compromised. Besides, the lack of knowledge among the growers (including private and govt. nurseries) on the importance of using quality planting stock which hampers the exploitation of total yield potential of Jatropha, facilities and cost of production are other reasons for not keeping quality in commercial nurseries.

On the other hand, D1 Oils is working on development of high-yielding Jatropha varieties, which much of its breeding work is focusing on India. So the challenge lies in identifying and developing the most promising wild varieties of Jatropha and producing hybrids with enhanced yield, higher oil content, and drought resistance characteristics. Once such desired varieties are found, corporations like D1 will surely apply for patents, as they commonly do for other agrofuel crops (Grain, 2007).

With this improved Jatropha variety through technology, it will become more expensive and it is questionable whether most developing countries will afford to obtain such technology. Thus, the interaction of strong technology especially in developing countries may be A prerequisite for sustainable large-scale production and trade of biomass (biotrade) is that production and trade must be beneficial with respect to the social well being of the people (people), the ecosystem (planet) and the economy (profit) (Smeets et al., 2005). International trade in biofuels and related feedstock may provide win-win opportunities to all countries: for several importing countries it is a necessary precondition for meeting their self-imposed blending targets while for exporting countries, especially small and medium developing countries, export markets are necessary to initiate their industries.

With considerable increase in feedstock and biofuels expected, sustainable production is becoming a key concern and is currently being considered as a possible requirement standards for market access, for example the first draft of EU biofuels directive (Zarrilli, 2006; EC, 2006). Setting standards and establishing certification schemes are possible strategies that can help to ensure that biofuels are produced in a sustainable manner. Recently, policy makers, scientists and others have recognized these aspects.

The existence of diverging technical, environmental and social standards and regulations for biofuels in different countries can pose serious restrictions on biofuel trade. To enter certain markets, especially developed markets where consumers may be particularly sensitive to environmental and/or social issues, biofuels certification systems that attest compliance with the established criteria should be developed. Precedents in the field of sustainability certification exist for a wide range of products. Criteria, basic principles and processes of existing international certification schemes and indicators systems for agriculture and forest addressing sound resource management are available (e.g. Forestry Stewardship Council - FSC certification; EUREPGAP; SAN), and partly are being used in the development of biomass certification system.

Based on the analysis from Lewandowski and Faaij (2006) of existing certification systems, sets of sustainability criteria and guidelines on environmental or social sound management of resources, we attempted to identify some environmental criteria that appropriately describe the requirements for sustainable Jatropha cultivation towards biofuel export production (Table 1).

So, this analysis has provided a birds-eye view on the implications of large-scale Jatropha cultivatiofiguren in developing countries for biodiesel export. The Strategic Niche Management framework proved to be a useful instrument for this study. For this purpose we explore the developments in India which can serve as an example for other developing countries.

It should be concluded that the transition towards Jatropha biofuels in India is going well since progress has been made towards jatropha biodiesel production and usage. Despite the importance of contextual 'landscape' factors and 'socio-technological' regime of SNM approach as explanatory variable for understanding success and failure of introduction of export oriented jatropha biodiesel production, they were dealt with in is beyond this study).

The niche analysis showed that the processes in the cultivation stage of Jatropha production chain have proceeded quite well. It revealed a wide and interconnected actor network which is expanding quite rapidly as more and more stakeholders including farmers are starting to plant Jatropha. According to the Ministry of Rural Development estimation, there are already between 500.000 and 600.000 hectares of Jatropha growing across the country. The actor network is also quite diverse, since there is participation from NGOs, private farmers, farmers groups, individual larger farmers, private companies as well as research organizations.

All this clearly indicates that India is on the right track towards energy transition towards Jatropha based biofuel owing to the fact that the niche analysis on cultivation stage of Jatropha experiments has shown to be successful have created much awareness and interest in the *J. curcas* L., which future developments can capitalize on. Therefore, our analysis with SNM yielded insights on how bio-based energy transition could also be studied in

Table 1. Relation of biomass sustainability criteria and Jatropha cultivation.

Environmental sustainability criteria	Jatropha production practices
Conservation of biodiversity	Agrisilvicultural trials through intercropping were undertaken Superior planting material were selected and used
Conservation and improvement of soil fertility	Multi-location trials under different agronomic climatic conditions Development of tissue culture for mass multiplication of superior planting material Hybridization programs – propagation techniques trough tissue culture, cuttings and seeds
Preservation of existing sensitive ecosystems	Packages of production practices implemented according to specific location, method of multiplication, nutrient management, plant protection and harvest management Progeny trials of Jatropha seedlings established
Protection of the atmosphere	Use of *Jatropha curcas* plant
Conservation of ground and surface water	Use of Jatropha plant which requires less water Application of nutrient management regarding different locations
Combating desertification and drought	Planting Jatropha only in degraded or marginal lands which were economically unviable for agriculture
Combating deforestation	Use of wasteland for Jatropha biodiesel plantation No expansion of agricultural food crop area
Landscape view	Establishement of Tree Borne Oilseeds (TBOs) gardens programme has been initiated to create the awareness about TBOs, its potential and uses in the urban, sub-urban and metropolitan cities

Source: Authors own adaptation

other developing countries and to set guidelines relevant for designing supply chain and biofuel policies.

ACKNOWLEDGEMENT

This work was supported by Fapergs/Finep-MCT-Brazil, Projeto Estruturante em Agroenergia.

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