Analysis of national Jatropha biodiesel programme in Senegal

Dafrallah, Touria ; Ackom, Emmanuel

Published in:
A I M S Energy

Link to article, DOI:
10.3934/energy.2016.4.589

Publication date:
2016

AIMS Energy

AIMS Energy, 4(4): 589-605.
DOI: 10.3934/energy.2016.4.589
Received: 29 December 2015
Accepted: 07 June 2016
Published: 15 June 2016

http://www.aimspress.com/journal/energy

Review

Analysis of national Jatropha biodiesel programme in Senegal

Touria Dafrallah[1] and Emmanuel Kofi Ackom[2,]*

[1] ENDA—Energy, Environment, Development (GNESD Member Centre), 54, Rue Carnot, P.O. Box 3370, Dakar, Senegal (the author worked with ENDA at the time this study was undertaken).
[2] Global Network on Energy for Sustainable Development (GNESD), UNEP DTU Partnership, UN City Campus, Denmark Technical University, DTU Management Engineering, Marmorvej 51, 2100 Copenhagen, Denmark

* **Correspondence:** Email: emac@dtu.dk; Tel: +45-4533-5289.

Abstract: Growing Jatropha curcas for energy applications has been established through several initiatives in Senegal. The government of Senegal launched the National Jatropha Programme (NJP) in 2006 with the goal of planting 321,000 ha of Jatropha curcas, with an average of 1000 hectares (ha) in each rural locality. This paper reviews existing policies with relevance to *Jatropha curcas L* production in Senegal. It assesses the NJP implementation, identifies potential gaps and provides recommendations with regards to planning, institutional management, regulation, and implementation. The potential of Jatropha and other biodiesel crop options, based on findings from an agro-environmental mapping exercise have been shown. Findings show that prior policies in agricultural and energy sectors had been instrumental in developing the NJP. It highlights significant challenges in the value chain, the implementation of NJP and on the importance of using empirical assessment of evidence to inform on the biodiesel crop type compared to a focus on only one crop, Jatropha. Agro-environmental mapping was identified as useful technique prior to biodiesel cultivation. The work reported here indicates Jatropha having the largest suitability of land areas equating to almost thirty times (30) the original estimations in the NJP followed by Pongamia and sunflower with 6,796,000 ha and 5,298,900 ha respectively. Recommendations are provided suggesting, scientifically sound analysis from agro-environmental mapping to inform on the suitability of areas for Jatropha cultivation and on environmentally, socially and culturally sensitive areas. Policy options have been suggested for environmentally benigned sustained biodiesel activities in Senegal.

Keywords: National Jatropha Programme; Biodiesel; Agro-environmental mapping; Senegal

1. Introduction

The seeming potential of *Jatropha curcas L* to help in energy security, agricultural product diversification and overall development of rural communities in Senegal, has been of interest to government and donor organizations. Additionally, interest has been shown by industrial investors who are primarily concerned with profits rather than development assistance. Research on the Jatropha plant, its potential benefits, risks as well as the hype linked with it is ongoing. The plant could be found in different parts of the world, including several locations in West Africa, where its utilizations had been limited to medicinal purposes, land and road fencing. A number of small-scale initiatives in West Africa are on-going particularly those in rural areas that have been motivated by issues of local development and women's empowerment, with the utilization of the plant for oil and soap production [1]. Jatropha is a tough, drought resistant plant, possessing toxic chemicals that are unpalatable to livestock [2-4]. It has a rather short gestation period and produce seeds of relatively high oil content ranging between 27–40% (w/w) [5-12]. Detailed physico-chemical properties of Jatropha has been studied and reported [8,13-14]. Jatropha similar to other vegetative biodiesel has been heralded as a suitable alternative to petroleum diesel but without sulphur and potential environmental damaging effect from the sulphuric acid that occurs during combustion of petroleum diesel [15-18]. Similar to most plants, Jatropha requires good moisture, temperature and soil nutrients in order to produce high fruit yields. However, the plant was heralded as an excellent high yielding oil crop even under marginal conditions and possessing considerable carbon dioxide mitigation potential, hence its hype in the early 2000s. During the hype, for example, India and China introduced mandatory biodiesel (primarily Jatropha) blending targets of 30% and 15% respectively by the year 2020 using marginal lands. Similarly, other countries in Asia, Africa and Latin America follow suit and did cultivate Jatropha on large tracts of marginal land only to be disappointed with very low yields. In India, it is reported that 85% of Jatropha farmers have abandoned their operations as a result of the meagre yields [19]. Epigenetic characteristics, however, of Jatropha enables the plant to survive and bear fruits even in drought conditions but this has a consequent lowered seed production that is not desired by investors [20]. Most affected in the global hype were poor farmers who had shifted from food cultivation to the apparently lucrative Jatropha as well as those that were displaced from their farmlands by large Jatropha investment companies. It is important therefore that due diligence, informed by empirical scientific findings be exercised prior to any large scale Jatropha cultivation [20]. Additionally, extensive stakeholders' consultations with all relevant parties and sectors need to be done before any commercial scale Jatropha activities.

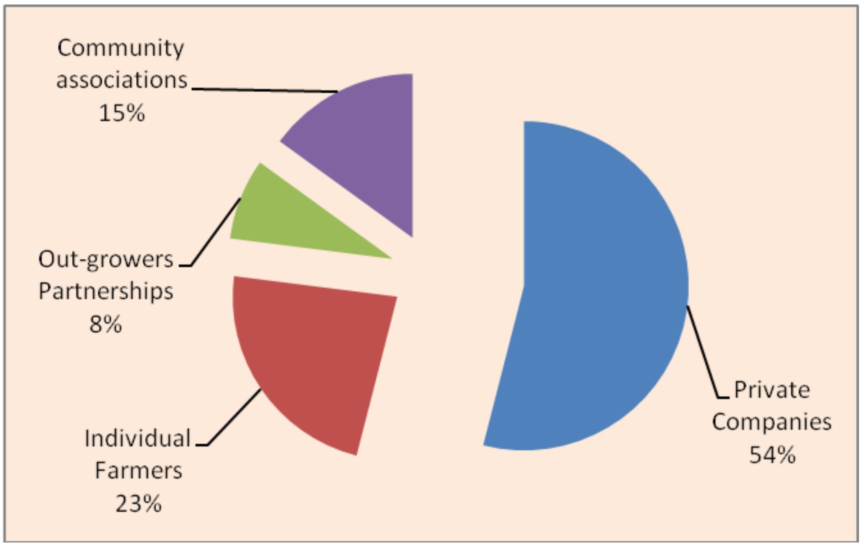
Senegal is a country in West Africa with a total land mass of 19.7 million ha, of which 3.8 million are arable (19% of the total area of the country), 9.6 million are not arable (49%), and 6.3 million (32%) are protected areas. Despite the availability of sufficient arable land, Senegal imports food crops including staple cereals therefore it is important that land for biodiesel production be carefully selected so as not to compete with food production. It is imperative, that large scale Jatropha activities be carefully considered on a holistic perspective (as will be explained later in this study) otherwise it could present significant socio-economic challenges (including food security) and environment threats.

Due primarily to high import bills on petroleum diesel by Senegal, there has been urgent need by the government to identify alternative options to offset petroleum diesel demand from year 2012. Biodiesel from Jatropha is considered by the government as the suitable alternative to offset import bills from petroleum diesel without due consideration to other potential biodiesel crop options (which will be explained later). The government thereby established the National Jatropha Programme (NJP) to offset Senegal's reliance of crude petroleum. The decision on the choice of selected biofuel crop could have benefitted from empirical scientific analysis, examining a number of competing alternatives; however, this was not the case for the NJP. Senegal therefore launched the NJP in 2006 with the ultimate goal of achieving biodiesel production from Jatropha to provide 100% of the country's diesel needs starting in 2012. The NJP sought to convert 321,000 ha for Jatropha cultivation, with an average of 1000 ha planted in every rural locality in Senegal. Overall, it is expected that the 321,000 ha would be available and utilized resulting in estimated production of approximately 1 billion litres of Jatropha biodiesel to completely offset petroleum diesel starting in year 2012. This development regarding the NJP has led to significant increase in Jatropha activities with several plantations primarily by private companies being established in the country over a short period of time (Figures 1&2) without much due diligence to potential risks. Majority of these Jatropha activities (approximately 88% of all Jatropha cultivations) are large scale plantations typically 50ha or more (Figure 2). However, as earlier indicated, it is needful to carefully investigate the realistic potential benefits as well as associated threats prior to any large scale Jatropha activity, hence the rationale for this study.

The objectives of this paper were to address the following research questions:

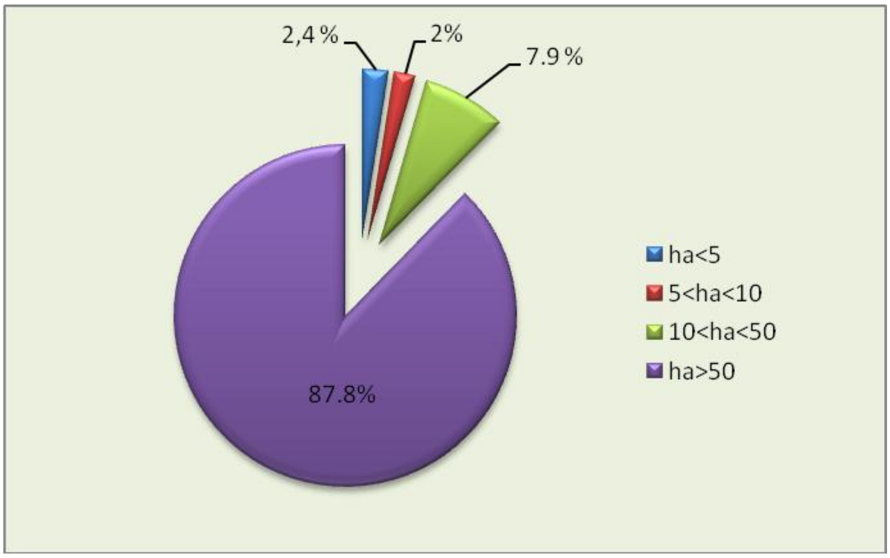
- how the National Jatropha Programme evolved?
- what are gaps in the National Jatropha Programme?
- how much of the biodiesel production should rely on Jatropha and other crops using agro-environmental mapping?

The paper then proffers policy options for sustained, environmentally benign biodiesel production.



Source: [21].

Figure 1. Distribution of key players in Jatropha cultivation in Senegal.



Source: [21].

Figure 2. Distribution of Jatropha curcas cultivated areas.

2. Methodology and structure

In terms of method, this paper utilized a combination of desktop study and geographical information system (GIS). The geographical information system Arc-GIS 9.3 was used for information and data processing regarding the agro-environmental mapping. This software provided maps based on satellite images and topographical background.

The rest of the paper is structured in the following sequence along the lines of the study's objectives. It first explores the evolution of the NJP by reviewing previous policies in relation to relevant sectors mainly the agricultural and energy sectors. It subsequently investigates gaps in the NJP and provides recommendations on how to redress loopholes in the NJP. This is followed by estimations on the biodiesel potential from *Jatropha curcas* and other energy crops (such as Pongamia, sunflower, cotton) that could be sustainably produced based on information from agro-environmental mapping. Findings from the agro-environmental mapping were then compared with the government's estimates (which were primarily based on national petroleum diesel demand) for policy options recommendation and finally, conclusions.

3. Evolution of the National Jatropha Programme: review of relevant related policies (past and existing)

Several economic sectors such as agriculture, energy, land, water are linked to Jatropha as well as rural development issues including healthcare, education, food security and environment. This section focuses on policy issues of two key sectors that is agricultural and energy and how they have contributed to the establishment of the National Jatropha Programme. (Institutional arrangements on the NJP and the potential for effective streamlining such institutional issues can be found in the supplementary material).

3.1. Agricultural policy

Agriculture has an important place in the economic and social life of Senegal. This sector contributes significantly to the country's gross domestic product GDP amounting to approximately

15.2% in 2012 and involves a large proportion (>60%) of the workforce. In addition, agriculture is the primary basis for agro-industrial and craft development. Population growth and increasing urbanisation is a concern for agricultural production and food security in the country. Achieving food securing and reducing poverty are key to the Government's agricultural policies.

Policy in Senegal's agricultural sector is based on the Guidance Law on Agriculture[i] adopted by the National Assembly on May 25, 2004. This law defines the nation's agricultural and rural developmental policies for the next 20 years. Excerpts of specific goals in this law with relevance to biodiesel include:

- the formal recognition of professions and professional organisations in agriculture;
- the social protection and the definition of legal statuses for farm and land use;
- the assessment of food security and water control;
- the diversification of production, including energy crops, market regulation, and the development of infrastructure and public services in rural areas;
- the promotion of social equity in rural areas and protection against the natural calamities and hazards related to agricultural, forestry, and livestock activities;
- the development of agricultural information and education, training, and capacity-building for rural organisations; and
- the development and provision of sustainable financing for agricultural services.

To implement this national policy, the government initiated development programmes such as "Return to Agriculture" (REVA 2006; please refer to Box 1, in the supplementary material), which helped established the country's Biofuels Programme, and the Great Agricultural Offensive for Food and Abundance Programme (GOANA; see Box 2 in the supplementary material).

Relevant to Jatropha, the existing agricultural policies (i.e., REVA and GOANA—supplementary materials) seem on the one hand to have provisions to protect farmers and their lands, prioritizing food production and avoiding other competing activities with food production while on the other hand encouraging agricultural products diversification with specific mention of energy crops. Implementation and enforcement however, of the provisions in the policies seem weak but there exist good opportunities for strengthening the NJP.

3.2. Energy policy

The Government of Senegal allocates almost half of the country's export-derived revenue to import petroleum products. Energy imports increased from 184 billion CFA Franc[ii] in 2000 to 600 billion CFA Franc in 2008 [2].

3.2.1. Policy paper for energy sector development

To increase energy independence, reduce reliance on thermal energy sources, and address the shortfall in energy services, the government has adopted a new energy policy that includes increased development and use of renewable energies including biodiesel. The target of the energy policy is to increase the share of renewable energy and biofuel (including biodiesel) by up to 15% by 2020. This was established in the Policy Paper for Energy Sector Development (LPDSE), the most recent version

[ii] Loi d'Orientation Agro-sylvo-pastorale

[ii] 1 Euro = 655.9 CFA Franc, which is the currency of eight states in West Africa, the Financial Community of Africa (Communauté Financière d'Afrique)

was submitted in September 2012. Objectives of the LPDSE that pertains to biodiesel includes: i) to develop and mobilise local energy resources such as renewable energy and biofuels; ii) to diversify the energy mix through the use of mineral coal and renewable energy, especially hydropower; iii) to increase access to modern energy services; iii) to improve energy efficiency and demand-side management; and iv) to promote good governance through the participation of the private sector and the restructuring of the power sector. The LPDSE provides modalities for operationalization of the Renewable Energy Agency and the development of incentives for renewable energy.

3.2.2. Renewable energy and biofuel laws

Rudimentary analysis suggests a strong political support for biodiesel in Senegal. For example, the Renewable Energy Directorate, established the Renewable Energy Guidance Law (Law 2010-21) that was enacted in December 2010. Subsequently, two implementing decrees i.e., by-laws 2011-13 and 2011-14, were passed in December 2011. Furthermore, the government enacted the Law for Biofuels (2010) and initiated its implementation by decree (2011). This guidance law is designed to create the conditions required for biodiesel and other biofuel production for the local market. The law include incentives to promote biofuels (including biodiesel) via the following support systems that: i) all tools, seeds, and seedlings used for biofuel production are exempt from the value added tax and customs duties; ii) revenues from biofuel farming are tax exempt for up to 5 years; iii) entrepreneurs interested in biofuel crop production benefit from the state's support in accessing seeds, seedlings, fertilisers, equipment aimed at improving biofuel productivity; and iv) specific by-laws are set to provide attractive biofuels prices. The next sub-section provides more information on the biofuel programme that embodies the NJP.

3.2.3. Overview of the National Jatropha Programme: its design

The Biofuels Programme includes the NJP biodiesel and ethanol production using the molasses generated from the sugarcane industry) [5]. However, the focus of this paper was on biodiesel components and the NJP. Senegal's NJP has several objectives involving agriculture, energy, rural development as well as aspects of economy and trade, such as:

- the reduction of household energy expenditures;
- energy source diversification;
- the reduction of the country's oil expenditures for energy provision;
- the promotion of energy independence and diesel self-sufficiency beginning in 2012;
- the production of ethanol from crops such as sugarcane;
- the production of electricity from power plants that operate using Jatropha crude oil;
- the creation of (approximately 100,000) jobs in the agricultural sector;
- crop diversification;
- agriculture modernisation;
- the creation of an attractive rural environment;
- improving the trade balance; and
- the reduction of poverty and the minimisation of the disparity between rural and urban areas.

Biodiesel aspect of Senegal's Biofuel Programme was designed to be implemented in three phases as follows:

- Phase 1. Production of Jatropha seeds (2007–2012);
- Phase 2. Processing Jatropha seeds into oil; and
- Phase 3. Biodiesel distribution.

In the NJP seeds, seedlings, and technical support would be provided to local communities. Additionally, it provides support for investors regarding administrative, informative, and counselling functions on industrial scale biodiesel production. The NJP recommends the use of oil presses or light expeller units for processing on-farm or community biodiesel production. Biodiesel production from the NJP is planned to be sold either to the state or to private market organisations at a price fixed by state-partners agreement.

According to the NJP, the Ministry of Agriculture is responsible for implementing seed production at a national level. This ministry also leads a national technical committee that consists of representatives from the ministry, farmers' organisations, rural organisations, professional agricultural organisations, elected officials, deputy governors for development, non-governmental organizations (NGOs), representatives of youth and women's village associations. Regarding the NJP implementation, Senegal's Institute for Agricultural Research (ISRA) is in charge of the technical coordination. Additionally, a national programme supervisor represented by the president of the National Rural Councillors Association in Senegal (ANCS) is responsible for awareness-raising activities, liaising with rural authorities and rural producers, and returning with the rural communities' requirements to the programme's national coordinators.

In addition to the NJP's objectives, important conditions and safeguards have been set as the basis for implementation, including

- at least 51% of the capital for any biodiesel industry establishment should be Senegalese;
- guaranteed prices for farmer production to ensure massive refunds and secure farmer interest;
- state-partner sales agreements that include secured prices for biodiesel sales to the state or appropriate institutions;
- assistance to farmers through the provision of agricultural inputs and technical expertise by promoters of the programme;
- land tenure based on the protection of national patrimony (i.e., the land remains the property of the state or local community owners and is not subject for sale or lease); and
- oil production and processing to be conducted in the country.

The following sections summarises the potential for Jatropha plantations in terms of land and water resources; moreover, it considers the critical issue of Jatropha competition with food security, which affects biodiversity and conservation.

4. Gaps in the National Jatropha programme

Senegal launched the National Jatropha Programme (NJP) in 2006 with the ultimate goal of achieving diesel production from Jatropha that would serve 100% of the country's diesel needs starting in 2012. The NJP sought to convert 321,000 ha for Jatropha cultivation, with an average of 1000 ha planted in each rural locality. The estimated 321,000 ha area according to Senegalese government would correspond to the production of approximately 1 billion litres of biodiesel thereby ensuring independence from diesel imports. This was to be utilized as an alternative to petroleum diesel starting from year 2012. It is worth noting that the implementation of the National Jatropha Project (NJP) only commenced in 2007–2008 and the achievement within the first years were very limited. The reasons for the limited achievements on the ground (against the planned targets in NJP) predominantly include institutional and regulatory challenges, gaps in the strategy and the absence of clearer action plans.

Under the NJP, 5293 ha of Jatropha were planted during 2007–2008; with the total cultivated area reaching only 10,000 ha by end of 2011. This represents significant delays in the progress of meeting the NJP targets and the reasons being primarily due to apparent lack of ownership by rural communities but also the other factors already mentioned including institutional, strategy and the absence of clearer action plans. In spite of the delayed progress, the NJP did not completely stop in 2011 but it is ongoing.

The government enacted the Biofuels Law in 2010, but the process of endorsing the related by-laws has not yet been finalised. The Biofuel Law provides appropriate guidelines for the promotion and development of biofuels in Senegal. However, the implementation of the Biofuels Law (which includes Jatropha biodiesel) has lagged behind the demands of private investors for land upon which to grow Jatropha. There was no commencement of liquid biofuel bioconversion from Jatropha seeds in contrast to what was stipulated in the NJP.

Additionally (as earlier noted), the Directorate of Biofuels has been under the supervision of several ministries since the launch of the Biofuel Programme in 2007. From June 2010 to April 2012, the Ministry of Renewable Energy conducted and supervised activities pertaining to regulatory aspects of Jatropha biodiesel. The institutional framework in Senegal for coordinating biofuel activities has been rather unstable with several ministries having taken on the responsibility of policy development and regulating the biodiesel activity, which has caused delays in the implementation of the NJP. Detailed analysis on market and value chain analysis are yet to be undertaken. Notably absent from the NJP are allocations of the produced Jatropha biofuel to the various sectors of the domestic economy as well as the portion for export.

Notwithstanding these institutional, regulatory and implementation challenges, several Jatropha cultivation by private initiatives have been launched including small- to large-scale Jatropha plantations. However, further Jatropha development in Senegal under the NJP would require additional scientific information and experience with its cultivation as well as knowledge of redressing practical barriers and helping to shape existing policies and regulations. These aspects are prerequisites for the successful large-scale deployment of Jatropha biodiesel production in Senegal.

5. Land suitability regarding which biodiesel crop type to cultivate?

The Environnement et Développement du Tiers Monde (ENDA-TM) with the support of United National Environment Programme (UNEP) conducted an agro-environmental mapping of the potential for biofuel (including biodiesel) production in Senegal. This mapping exercise was done in collaboration with the Senegalese Institute for Agricultural Research (ISRA) and the National Institute of Pedology (INP) [22]. A key objective of the mapping was to provide a comprehensive zoning of potential lands and assess the areas suitable for which type of biodiesel crop. This mapping took into account major selection criteria including the appropriateness of the crop vis-à-vis eco-geographical conditions in the country; the biochemical quality of extracted oils; socioeconomic advantages including intercropping with suitable food crops, the avoidance of competition with food production, water, biodiversity conservation, increased contributions to local economies based on generated by-products, and social acceptability; and political interests.

This mapping process considered the following major crops: Jatropha, Pongamia, sunflower, and cotton. These crops were selected for their capacity to adapt to the ecological and geographical conditions in Senegal, for being socially acceptable to the communities, and for not generating competition for land and water with staple crops. Other crops (e.g., castor, palm, soy, maize, and cashews) were excluded for various reasons including the lack of significant commercial exploration of their potential for large-scale plantations or verified experimentations. Peanut, which is a cash crop in Senegal, was excluded from the mapping process because its use for biodiesel source is likely to conflict with current utilization for food.

The four broad criteria utilized for biodiesel crop selection include:

i) The crop should have agronomic features that match the eco-geographic conditions of the country's land (e.g., required temperature, rain, and soil quality).
ii) The characteristics and quality of the extracted oil should be of good standards for local use without additional treatment.
iii) Crop selection should help provide socioeconomic advantages including intercropping with suitable food crops, the avoidance of competition with food production, water, biodiversity conservation, increased contributions to local economies based on generated by-products, and social acceptability.
iv) Prioritization of crop development should not be in conflict with government priorities. (As indicated earlier it is important to realise that the government highly prioritizes Jatropha).

The primary agro-environmental data considered in the mapping process based on some of the above listed key criteria are presented in Table 1.

Table 1. Jatropha's agro-environmental data.

Parameters	Jatropha
Ecological requirements	
Water/rain required	300 to 1200 mm
Temperature	20 °C to 42 °C
Altitude	0 to 1500 m
Type of land	Sandy, degraded, saline soils (NB. compacted lands hinder the plant growth).
Land pH	5 to 8
Density of plantation	1500 to 2500 plants/ha (in monoculture)
Fertiliser	Manure or plantation compost
Toxicity	Average
Crop yield	1.75 to 9.75 tonnes/ha/year (Can reach 12 tonnes/ha/year with irrigation)
Biodiesel Characteristics	27% to 40%
Oil content	600 to 1800 litres/ha
Oil yield	Low viscosity
Oil quality	
By-products	Jatropha cake
Other uses of the by-products	Soap, fertiliser, pesticides
Competition with food crops	Monoculture/intercropping
Intercropping with food crops	Associated with grain or vegetable crops (large planting distance)
Type of plant	Shrub with long life expectancy

Source: [22] based on information provided by ISRA.

The mapping process has preliminarily zoned the potential land to be used for cultivating the selected biodiesel crops based on the exclusion of certain areas (e.g., natural parks, classified forests, fauna reserves, shooting sites, grazing land, biodiversity zones, and marine protected areas (refer to Map 2 and 3 in the supplementary material).

With regard to land tenure, clarification is required to assess the extent to which the NJP could be implemented across all rural communities of Senegal as the NJP suggests that every rural locality should be able to dedicate 1000 ha to Jatropha plantation.

Findings from the agro-environmental mapping revealed that land suitability for Jatropha plantations is not found in all rural localities but only in some areas. Therefore, the implementation of the NJP according to its planned objectives of total 321,000 ha (distributed throughout 1000 rural communities in the country) is experiencing challenges in terms of availability of 1000 ha of suitable land in each rural locality in Senegal. Furthermore, the NJP is focused on the production/agriculture aspects; however, a gap remains in terms of the processing, distribution, and end use of biofuels. The mapping process also revealed that Jatropha initiatives in the NJP have been planned to spread out across a wide variety of zones in Senegal even in pristine and protected ecosystems (which should not be if agro-environmental mapping had been undertaken in the NJP).

The agro-environmental mapping process undertaken in this study did reveal interesting findings with regards to land tenure, food security and water requirements. Findings show that the proposed distribution of 1000 ha of Jatropha in each of the 321 rural administrative zones leads to some land-tenure problems. For example, the mapping revealed that several rural localities in the north, northeast, and central-east are not suitable and cannot host the 1000 ha needed for an additional energy crop without land expropriation or conversion from food crops, especially in cases of large-scale production systems. Conversely, food security might be compromised by attractive biodiesel prices, thereby driving farmers to switch from traditional food crops to Jatropha. Therefore, it could be a recommended option that the NJP approach and its position concerning land tenure possibly be carefully re-examined. With regard to water requirements, young Jatropha shrubs must be watered during the initial years after planting if they are to survive in areas where the rainfall is less than 700 mm per year. Therefore, water difficulties might occur among rural communities located within these isohyets. In these agricultural and grazing areas, conflicts over water distribution should be expected if Jatropha is planted at large commercial scale as stipulated in NJP where irrigation is inevitable.

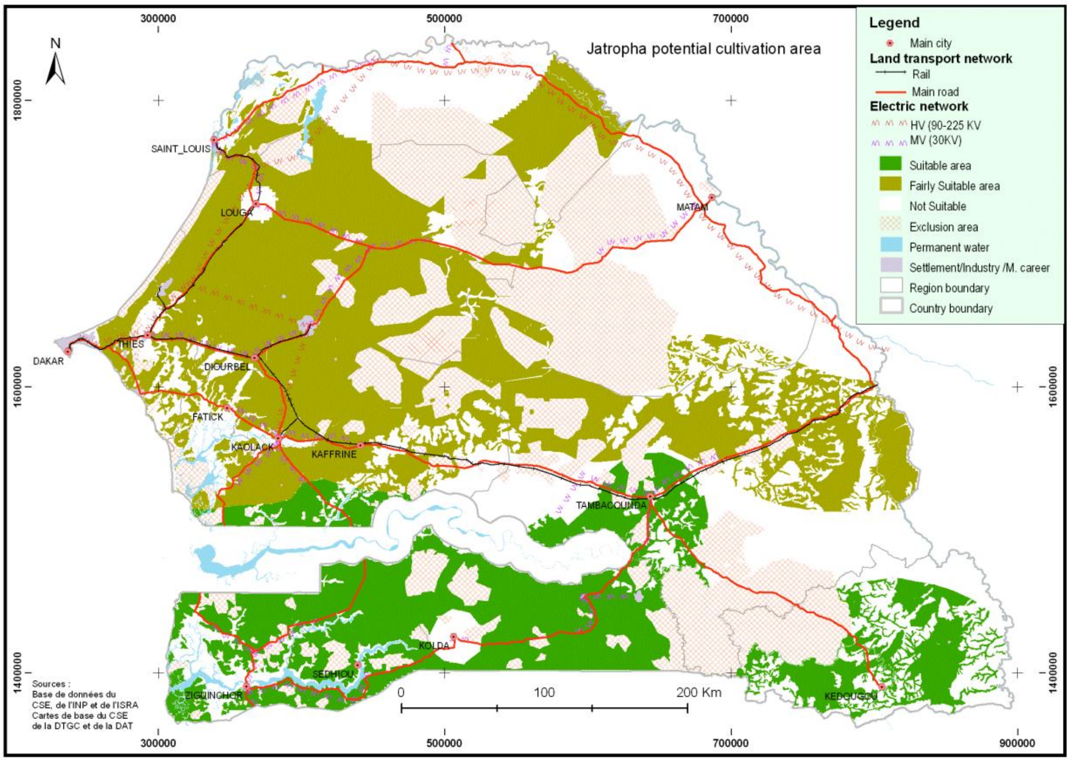
The strategic decision to deploy Jatropha on a large scale for energy proposes (as contained in the NJP) was made without assessing the potential for Jatropha production in terms of farming and climate suitability or socioeconomic sustainability. The issues that could have been appraised prior to rolling out the NJP could have included the use of appropriate scientific tools and criteria that analyzes for example, the availability and capacity of land to produce Jatropha, the social acceptability of land use for Jatropha, crop specifications in terms of water and land requirements, temperature, yield, the quality of the crop for generating fuel, competition with food crops, and knowledge of planting practices.

The agro-environmental mapping process undertaken in this study determined the areas suitable for Jatropha cultivation and categorizes the land into the following:

- *Highly Suitable*. This category refers to areas with biophysical features (i.e., land types), environmental (e.g., temperature and rainfall), and socioeconomic variables (such as avoidance of competition with food, biodiversity conservation, water requirement etc) that allow for sustainable crop production. Highly suitable land is located in the south and southeast regions of Senegal and (to a limited extent) in the west and central regions (Map 1).

Highly suitable zones coincidentally are located in the regions of the country that have the most significant rainfall (700 to 1200 mm).

- *Fairly Suitable*. This category refers to areas that partially meet the biophysical features and socioeconomic elements (such as possible competition with food, biodiversity conservation, water requirement) that allow for sustainable crop production. Fairly suitable land is located in the central, west, and northwest regions, with scattered locations in the northwest region of the country (Map 1). Fairly suitable land (400 to 600 mm of rainfall) is more extensive than highly suitable land.
- *Not Suitable*. This category refers to areas that are not recommended for biofuel plantations because they do not comply with the identified criteria related to the land type, environment, or socioeconomic variables (such as competition with food, biodiversity conservation, water requirement. Not suitable areas are located in the north and east regions, with scattered locations along the southeast and central regions as well as along the coast. Not suitable land generally has high salinity (Map 1).



Source: [22].

Map 1. Land suitability for Jatropha plantations in Senegal (year 2010).

In addition to Jatropha, the suitability of other bioenergy crops namely, sunflower, Pongamia and cotton were also assessed. The potential benefits of ensuring that all biodiesel crops meet environmental and socio-economic criteria and are cultivated in zones that have been demarcated via agro-environmental mapping are humongous. It provides basic minimum requirements of properly undertaking biodiesel activities that are socially acceptable and environmentally benign. Even though the government's NJP plan to cultivate 1000 ha in each of the 320 communities was not possible due simply to the right eco-geographical conditions or the lack of it in each community, agro-environmental mapping findings show Jatropha has the largest suitability of land areas. The suitability of land identified via agro-environmental mapping is twenty-seven (27) times more in comparison to original estimations in the government's NJP (Table 2). Findings from Pongamia and sunflower show a total of 6,796,000 ha and 5,298,900 ha respectively, regarding land suitability areas for biodiesel cultivation (Table 2). Total land availability for cotton seems to be the least and amounted to 29,512 ha. Rather than focusing all national biodiesel interest and policy solely on Jatropha, complimentary biodiesel crop options such as Pongamia and sunflower, could also be explored and utilized.

The *highly suitable* land area for Jatropha planted as single major crop is estimated to be 2,535,700 ha, although an additional intercropping of 614,500 ha with other food crops is available (Table 2).

The area of *fairly suitable* land is estimated to be approximately 2,860,200 ha, of which 2,751,600 ha can be added by intercropping Jatropha with suitable food crops (Table 2). Analysis revealed that several private initiatives have been implemented without a deep knowledge of the suitability of the land for Jatropha plantations. The agro-environmental mapping shows that the projects implemented in the south and southeast areas are located in *highly suitable* land areas for Jatropha, whereas the projects undertaken in the central areas are situated in *fairly suitable* land areas which potentially compete with land dedicated for food crop plantations (Map 1).

6. Policy considerations

A timely, comprehensive implementation strategy with clear principles and indicators along the Jatropha biodiesel value chain should be set in place. Even though, Senegal developed a Law for Biofuels that help promote NJP, however, such comprehensive strategy is yet to be established. The strategy should include blending mandate, estimated in-country utilization amount as well as exportation. Guiding strategies should include principles for implementing local partnerships as well as farmer involvement, rights, and land tenure after considering social, economic, and environmental sustainability to ensure mutually rewarding investments and generate employment [23-25]. The guidelines regarding the best practices for harvesting, processing, and marketing biodiesel products need to be developed. Such strategy could complement already determined safeguards stipulated in the NJP including guaranteed prices for farmers, secured prices for biodiesel sales, the provision of agricultural inputs and technical expertise to farmers, the prohibition of land transfers or leases, and in-country processing.

The strategic harmonisation of sectoral policies is required to ensure the successful implementation of Jatropha plans. This is because several ministries and institutions operating in different sectors are involved in the development of Jatropha biodiesel. Additionally, since the announcement of a governmental programme to develop Jatropha at a large scale, several ministries have taken on the responsibility of hosting the office/department in charge of the biodiesel policy and regulation. This situation has delayed the implementation of the programme; therefore, the implementation of a stable institutional framework is recommended to ensure the sustained supervision of the biodiesel sector and the revitalisation of the NJP. This implementation should be performed in consultation with all relevant government departments [25]. One possible option is the establishment of a separate and semi-autonomous regulatory authority to coordinate, monitor and regulate the sub-sector.

Table 2. Findings on suitability of land area for different biodiesel crop options (monocropping and intercropping) based on agro-environmental mapping.

Crop	*Jatropha* (monocropping) (ha)	*Jatropha* (intercropping) (ha)	*Jatropha* (total) (ha)	Sunflower (monocropping) (ha)	*Sunflower* (inter-cropping) (ha)	*Sunflower* (total) (ha)	Pongamia (monocropping) (ha)	Pongamia (intercropping) (ha	Pongamia (total) (ha)	Cotton seed (monocropping) (ha)	Cotton seed (intercropping) (ha)	Cotton (total) (ha)
Highly suitable	2535700	614500	3150200	419600	1705700	2125300	1050500	2204200	3254700	6885	12377	19262
Fairly suitable	2860200	2751600	5611800	2094300	1079300	3173600	2034200	1507100	3541300	4514	5736	10250
Total	5395900	3366100	8762000	2513900	2785000	5298900	3084700	3711300	6796000	11399	18113	29512

Source: Authors modifications based on [22].

*The amount of hectares indicated for jatropha, sunflower, pongamia and cotton are exclusive and not inclusive

.

Coordination of activities at the local level between the NJP agencies and private initiatives is highly recommended. This is due to the fact that the investors and farmers involved in private initiatives do not have sufficient knowledge of the agro-environmental potential of the land they selected for Jatropha plantations. This reveals a possible need of decision-making protocols and regulations for the land allocated for energy crop plantations. Overcoming the coordination challenge, would help improve the local management and marketing of Jatropha. Additionally, strategic cooperation among biofuel experts, farmers, agronomists, environmentalists, energy specialists, relevant government agencies and investors is required [25]. It is noteworthy that significant co-benefits (in addition to biofuels) such as biofertilizers from seed cake also provide revenue and employment for communities [26-27].

Incentives to encourage the participation of local entrepreneurs and farmer associations as business partners should be developed. Investment in processing facilities (refineries) should be promoted, possibly through public private partnerships and frequent involvements with foreign investments. Proper assessment of the true viability and competitiveness of Jatropha must be undertaken along with an assessment of the need for incentives such as tax holidays and levy rebates on machinery and parts or actual subsidies.

Land selection for biofuel cultivation requires rigorous scientific investigation that should have considered all possible crop options and not only Jatropha. No convincing scientific evidence seem to exist suggesting only Jatropha to be the most appropriate crop, especially considering its requirements for water and production yields. It therefore appears that the decision for Jatropha was actually made without adequate scientific consideration and it did not explore other alternative options. Several alternative energy crops options for example, could have been considered to fulfil the government's objectives for energy diversification including (but not limited to) sunflower, Pongamia and the use of residues. Crop choice should as much as possible be based on scientific criteria that recognises the entire value of biofuels.

Spatial distribution of land as set in NPJ for the large-scale Jatropha plantations should have been assessed in close cooperation with agronomists, energy and climate specialists, and decision makers. This is because findings from the agro-environmental mapping process suggests that achieving equal distribution across all localities as stipulated in the NJP does not seem possible (with the exception of only the south, southeast, east, and central regions of the country are suitable). Therefore, findings from the agro-environmental mapping if considered, could lead to successful execution of the NJP.

The mapping process based on the agro-environmental assessment indicated that enough land is available for Jatropha production to meet the NJP target; in fact, 614,000 ha were deemed highly suitable. The NJP assessment indicated that 3–5 million ha overall were suitable for Jatropha. This figure exceeds the planned NJP target area of 321,000 ha by 191%.

Findings from the agro-environmental mapping from this study appears to hold good promise in undertaking Jatropha activities and could be recommended for possible consideration by decision makers and relevant stakeholders. Undertaking a detailed mapping of land-tenure status (e.g., family property, local authority property and state land) to guide future use of land is highly recommended. This mapping would help to properly allocate land for Jatropha plantations and assess the financial and organisational needs to implement projects.

Land-use practices should be defined, and land-tenure options should be established to ensure food security and protect farmer interests. The practices and acceptability of intercropping should be carefully assessed.

Mappings of suitable areas for biofuel production must be made available to interested parties, both local and domestic investors, in order to avoid the use of pristine ecosystems such as forest land for biofuel plantations. Incentives should be provided to encourage biofuel production in designated areas and dissuade the use of pristine and 'sensitive' lands.

7. Conclusion

Three key conclusions could be drawn from the NJP case study in Senegal regarding its evolution, gaps and the realistic potential of biodiesel including the use of other bioenergy crop options.

Policies in the agricultural and energy sectors have been instrumental in framing the NJP. Specifically, the Guidance Law on Agriculture from the agricultural sector and from the energy sector; the Policy Paper for Energy Sector Development (LPDSE), the Renewable Energy Guidance Law and the Law for Biofuels, have contributed significantly to the preparation and formation of the NJP

Considerable gaps exist in the implementation of NJP such as institutional challenges that has resulted in duplicity of efforts and therefore the need to coordinate and streamline activities with clear roles being assigned to all relevant participating institutes. The current NJP tend to focus more on the upstream activities of Jatropha and weak on the downstream side of the value chain such as biodiesel distribution (for domestic utilization or export) and sectorial utilization. Potential market chain analysis would be useful in providing information towards possible refinements in this area. A range of biodiesel crop options informed by scientific assessments should be considered for petroleum diesel substitution in Senegal and not just Jatropha.

The benefits of ensuring that biodiesel crops meet environmental and socio-economic criteria and are cultivated in zones that have been demarcated via agro-environmental mapping are humongous. Agro-environmental mapping provides basic minimum requirements of properly undertaking biodiesel activities that are socially acceptable and environmentally benign. Even though the government's NJP plan to cultivate 1000 ha in each of the 320 communities was not possible due simply to the right eco-geographical conditions or the lack of it in each community. Agro-environmental mapping findings show Jatropha having the largest suitability of land areas which is twenty-seven (27) times more in comparison to original estimations in the NJP but only in designated areas. Pongamia and sunflower with a total of 6,796,000 ha and 5,298,900 ha respectively, also show great potential next to Jatropha regarding total land suitability areas for biodiesel cultivation. Rather than focusing national biodiesel interest and policy solely on Jatropha, complimentary biodiesel crop options could be considered such as Pongamia and sunflower.

Further, Jatropha development in Senegal under the NJP would require additional scientific information and experience with its cultivation as well as shaping existing policies and regulations that would resolve the present barriers. Other factors including good harvest and markets are also crucial to the success of biodiesel which needs to be further investigated. These aspects are prerequisites for the successful large-scale deployment of Jatropha biodiesel production in Senegal.

Acknowledgments

The authors wish to acknowledge the support of the Global Network on Energy for Sustainable Development (GNESD) for the financial support to accomplish this research paper, and the United Nations Environment Programme (UNEP) for its assistance in conducting the Agro-Environmental Mapping of Biofuels Production in Senegal. Finally, but not the least the, Interdisciplinary Centre for

Comparative Research in the Social Sciences (ICCR) for the technical support to carry out the mapping of *Jatropha curcas* initiatives in Senegal. Both mappings provided relevant inputs to this article. This paper is one of five GNESD studies that cover various aspects of biofuel sustainability in Africa, Asia and Latin America, which was coordinated and co-authored by Emmanuel Ackom from the GNESD Secretariat. Authors will like to thank several people for reviewing earlier versions of the work including GNESD members and Cosmas Ocheng (formerly of UNEP DTU Partnership, UDP) as well as external reviewers namely Sergio Ugarte, Edward Smeet and Barry Kantor. The paper also benefitted from discussions with John Christensen (GNESD/UNEP/UDP) and Martina Otto (UNEP). The opinions and recommendations expressed in this report are from the authors and do not necessarily reflect those of UNEP, UDP, DTU or GNESD. The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of UNEP, UDP, DTU or GNESD concerning the legal status of any country, territory, city, or area or of its authorities.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Ackom EK, Ertel J (2015) An alternative energy approach to combating desertification and promotion of sustainable development in drought regions. *Forum der Forschung* 18: 74-78.
2. Pandey VC, Singh K, Singh JS, et al. (2012) Jatropha curcas: A potential biofuel plant for sustainable environmental development. *Renew Sustain Energy Rev* 16: 2870-2883.
3. Zahawi RA (2005) Establishment and growth of living fence species: an overlooked tool for the restoration of degraded areas in the tropics. *Restor Ecol* 13: 92-102.
4. Gubitz GM, Mittelbach M, Trabi M (1999) Exploitation of the tropical oil seed plant Jatropha curcas L. *Bioresour Technol* 67: 73-82.
5. Openshaw K (2000) A review of Jatropha curcas: an oil plant of unfulfilled promise. *Biomass Bioenergy* 19: 1-15.
6. Achten WMJ, Verchot L, Franken YJ, et al. (2008) Jatropha biodiesel production and use. *Biomass Bioenergy* 32: 1063-84.
7. Sujatha M, Reddy TP, Mahasi MJ (2008) Role of biotechnological interventions in the improvement of castor (Ricinus communis L.) and Jatropha curcas L. *Biotechnol Adv*. 26: 424-35.
8. Akintayo ET (2004) Characteristics and composition of *Parkia biglobbossa and Jatropha curcas* oils and cakes. *Bioresour Technol* 92: 307-310.
9. Francis G, Edinger R, Becker K (2005) A concept for simultaneous wasteland reclamation, fuel production, and socio economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations. *Nat Resour Forum* 29: 12-24.
10. Jones N, Miller JH (1992) *Jatropha curcas*: a multipurpose species for problematic sites. ASTAG technical paper. Land resources, vol. 1. World Bank Washington (DC, USA). 12.
11. Kumar A, Sharma S (2008) An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): a review. *Ind Crops Prod* 28: 1-10.
12. Jain S, Sharma MP (2010) Prospects of biodiesel from Jatropha in India: a review. *Renew Sustain Energy Rev* 14: 763-771.

13. Kandpal JB, Madan M (1995) Jatropha curcas: a renewable source of energy for meeting future energy needs. *Renew Energy* 6: 159-160.
14. Augustus GDPS, Jayabalan M, Seiler GJ (2002) Evaluation and bioinduction of energy components of *Jatropha curcas*. *Biomass Bioenergy* 23: 161-164.
15. Fukuda H, Kondo A, Noda H (2001) Biodiesel fuel production by transesterification of oils. *J Bioscin Bioeng* 92: 405-416.
16. Srivastava A, Prasad R (2000) Triglycerides-based diesel fuels. Renewable Sust Energy Rev 4: 111-133.
17. Soumanou MM, Bornscheuer UT (2003) Improvement in lipase catalyzed synthesis of fatty acid methyl esters from sunflower oil. *Enzyme Microbiol Technol* 33: 97-103.
18. Vicente G, Coteron A, Martinez M, et al. (1998) Application of the factorial design of experiments and response surface methodology to optimize biodiesel production. *Ind Crops Prod* 8: 29-35.
19. Axelsson L, Franzen M (2010) Performance of Jatropha biodiesel production and its environmental and socio-economic impacts. Dissertation. FRT 2010:06, Chalmers University of Technology: Sweden.
20. Kant P, Wu S (2011) The Extraordinary collapse of Jatropha as a global biofuel. *Environ Sci Technol* 45: 7114-7115.
21. ENDA Energy and ICCR (2010) Approvisionnement durable en Energie: Production et Importation de la biomasse et des carburants biogènes.
22. ENDA Energy and UNEP (2010) Cartographie Agro-Environnementale du Potentiel de Production de Biocarburants au Senegal (Agro-environmental Mapping of the Potential for Biofuels Production in Senegal).
23. Ackom EK, Mabee WE, Saddler JN (2010) *Backgrounder: Major environmental criteria of biofuel sustainability*; International Energy Agency (IEA) Bioenergy Task 39 Report Vancouver, Canada. Available from: http://www.task39.org/LinkClick.aspx?fileticket=wKf0TFLjXu0%3d&tabid=4426&language=en-US.
24. Ackom EK (2012) Industrial Sustainability of Integrated Forest Biorefinery. In *Integrated Forest Biorefineries: Challenges and Opportunities*; Christopher, L., Ed.; Royal Society of Chemistry: London, UK.
25. Ackom EK, Brix MP, Christensen J (2011) Bioenergy: The potential for rural development and poverty alleviation. Global Network on Energy for Sustainable Development (GNESD), (GNESD-SPM-BET-11/2011). Available from: http://www.gnesd.org/PUBLICATIONS/Bioenergy-Theme (Accessed on 30 January 2016).
26. Poonia MP, Jethoo AS (2012) *Jatropha* plantation for biodiesel production in Rajasthan: climate, economics and employment. *Univ J Environ Res Technol* 2: 14-20.
27. Jiang H, Wu P, Zhang S, et al. (2012) Global analysis of gene expression profi les in developing physic nut (*Jatropha curcas* L) seeds. *PLos One* 7: 1-12.