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Alternative biodiesel feedstock systems in the Semi-arid region of Brazil: Implications for ecosystem services

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ABSTRACT

The Northeast region of Brazil has low levels of human development and a marginal environment subject to chronic water scarcity. This paper assesses the potential impacts of bioenergy production from local varieties of castor oil plant and jatropha that could reduce the import of energy in the region, while developing its economy. Biodiesel systems based on these crops can be suitable for the Northeast region as they have low water needs, and are either indigenous or have shown excellent adaptation to the local climate. Apart from biodiesel production, the residue from their processing can be a valuable resource usable for biogas production and bio-fertilizers. Using the ecosystem services approach, five land management alternatives are compared: (i) Caatinga woodland (a type of dry savannah native to the region), (ii) a scheme of local jatropha varieties and vegetation for Caatinga forest restoration, (iii) a crop rotation scheme of castor oil plant and cowpeas, (iv) cowpea mono-cropping, and (v) pasture. Based on the analysis of secondary data, some provisioning and regulating services were assessed quantitatively, while others qualitatively. The results suggest that the conversion of (i) cowpea mono-cropping to a rotation of cowpeas and castor and (ii) degraded pastures to a jatropha-Caatinga forest restoration scheme can provide a bundle of provisioning, regulating and supporting ecosystem services. Feedstock for bioenergy is the most important ecosystem service derived from these multi-functional landscapes. In particular converting pasture to a jatropha-Caatinga forest restoration scheme could provide per hectare 0.7 t of oilseeds for biodiesel production and 1.8 GJ of usable energy, in the form of biogas from the residual seedcake. The castor-cowpea rotation scheme could provide per hectare 1.5 t of oilseeds for biodiesel production together with 2.2 GJ of usable biogas energy, per hectare.

1. Introduction

Brazil contains a variety of different biomes and climatic conditions. Caatinga is one of these biomes and is exclusively native to Brazil. It occupies 982,563 km^2 or around 11% of the landmass of the country (Fig. 1), and is characterized by xerophile vegetation such as cacti, succulents, crassulaceous and shrubby trees well adapted to recurrent droughts, poor/marginal soils and brackish groundwater [1].

Situated within the Northeast region of Brazil, which is the homeland of 22 million people, Caatinga is one of Brazil's most endangered ecosystems. While the coastal strip that borders the Caatinga is more humid and fit for agriculture, Agricultural activities in the arid interior are limited to the pasture of goats and cattle and small-scale farming. Extractive activities undertaken by the local population has led to rapid environmental degradation. For example, most of the native shrub forest has been cut down for firewood or to clean land for pasture. Currently, only 0.28% of the Caatinga area is protected as a natural reserve.

At the same time the Northeast region registers some of lowest human development levels and economic opportunities in Brazil. It has to import most of the gas, fuel and electric power needed from the rest of the country. In this context, renewable energy resources are assets that could promote the sustainable development of the region. For example, the region has an enormous solar energy and wind power potential that could make it a net-electricity exporter in upcoming years [2,3]. Furthermore, while the cultivation of biofuel crops is not as extensive as in the Centre-West or Southeast regions, the Northeast can play a major role in the cultivation of biodiesel feedstock.

The Brazilian Program for the Production and Use of Biodiesel (PNPB) was launched in 2004. Among its goals was to involve small

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Fig. 1. The Caatinga biome.

farmers of the Semi-arid region in biodiesel feedstock production [4]. Since then, the mandatory blending of biodiesel in the country has risen to 7% (B7) in 2016, and is on track to reach 10% (B10) by 2020. However, despite this impressive uptake of biodiesel, the current feedstock production patterns are quite different than what was expected at the early stages of the PNPB. According to the Brazilian National Agency of Petroleum, Natural Gas and Biofuels, biodiesel feedstock production is dominated by soy (around 70%) and bovine tallow (around 20%), while castor oil plant and jatropha have currently no participation in the biodiesel production [5]. Castor oil has remained a raw material for the pharmaceutical and cosmetics industry, while jatropha, following initial optimism, failed to arouse any commercial interest partly due to its widespread collapse in Africa, India and Southeast Asia [e.g. 6,7]. When scrutinising the results of the PNPB over the past decade [8], it can be inferred that a program designed to empower family-owned farms through their integration in the biodiesel production chain ended up benefitting soy producers, mainly corporate farms from outside the Semi-arid region.

However due to the prevailing climatic condition some neglected biodiesel feedstocks could still play a role in the Northeast. The castor oil plant (*Ricinus communis*, referred to as castor for the remainder of the paper) and different jatropha varieties are already present in the region and have showed good adaptation to the local climate and soils, as well as the ability to coexist with either locally grown food crops (for castor) or the native shrub forest (for jatropha). Regarding the latter, there are several endemic varieties of jatropha in the Caatinga biome such as *J. mollissima* (34% oil content), *J. mutabilis* (39% oil content) and *J. ribifolia* (33% oil content) [9,10].

When it comes to castor, there is a well-established cultivation and commercialization chain based on family farm cooperatives that make Northeast Brazil the second highest producing region of the world, behind only India. Furthermore, castor shows complementarities with cowpea, maize and other crops in terms of sow/harvest cycles and soil nutrients, which point to interesting intercropping (crop rotation) possibilities (Section 3.1.2).

On the other hand, the agro-industry for jatropha has not yet been developed. However the endemic varieties of jatropha could act as nurse plants for Caatinga vegetation by facilitating the development of native plant species beneath their canopy as they can offer benign microhabitats that are more favorable for seed germination and seedling recruitment than the degraded pasture or farmlands found in the region [11–13].

The aim of this study is to identify the potential trade-offs of biodiesel production from oilseeds adapted to the semi-arid climate of the Caatinga biome. In particular, this study assesses the potential impacts of two alternative ways to cultivate such oilseed species: (a) castor intercropped with cowpea and (b) local jatropha varieties combined with Caatinga native vegetation to restore forest in degraded pasture lands. The former has gained some prominence in the Northeast [14], while the latter is a novel proposal that could have some benefits.

In order to identify the main trade-offs expected to emerge following the conversion of common agricultural/livestock land uses in the Northeast with the two feedstock production systems, this study adopts the ecosystem services (ES) approach (Section 2). Given the lack of significant feedstock production in the area using the studied modes of production, it provides an analysis based on secondary data collated during an extensive literature review (Section 3). Section 4 summarises the main expected trade-offs for different types of ecosystem services and outlines some of the key research gasps and challenges promoting further these production models.

2. Methodology and ES mechanisms

To identify the main trade-offs of biodiesel production through the two studied schemes, the ecosystem services approach is adopted [15,16]. The ES is a powerful framework both for the synthesis and meta-analysis of biofuel impacts [17,18] as well as for the assessment of the impacts arising from landscape transformation for biofuel production [19,20].

Initially, an extensive literature review is performed to identify the ecosystem services and disservices provided by these biodiesel landscapes, as well as the mechanisms through which these services/disservices emerge (Sections 3.1.3 and 3.2.3). Subsequently the ecosystem services/dis-services provided by feedstock systems are compared to those of the reference land uses prevalent in the Northeast, i.e. pasture and single-crop farmlands (Section 4.1).