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Who benefits from energy policy incentives? The case of jatropha adoption by smallholders in Mexico

Iria Soto [a,b,*], Wouter M.J. Achten [c,1], Bart Muys [c], Erik Mathijs [a]

[a] University of Leuven, Department of Earth and Environmental Sciences, Division of Bioeconomics, Leuven, Belgium
[b] Forest Sciences Centre of Catalonia (CTFC), Solsona, Spain
[c] University of Leuven, Department of Earth and Environmental Sciences, Division of Forest, Nature and Landscape, Leuven, Belgium

HIGHLIGHTS

- We examine the allocation of subsidies for bio-energy crop cultivation.
- We used a multilevel and multi-approach technique to model adoption.
- Extension, community and households features influence subsidy distribution.
- Poor and marginalised farmers tend to be excluded from the subsidy.
- We provide tools to assess if subsidies reach targeted population.

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ABSTRACT

Understanding the distribution of policy incentives is important in evaluating the impact of promotion programmes. This study investigates the allocation of economic subsidies to jatropha cultivation by using adoption models at both the community and household levels in Chiapas. At the community level, we compared socioeconomic and environmental variables of the communities that adopted jatropha to non-adopters. At the household level, 420 farm households were surveyed to analyse both the determinants of adoption and the extent of adoption (i.e. hectares dedicated to jatropha). The variables determining adoption were analysed at both levels using generalised linear models. The extent of jatropha adoption was assessed using ordinary least squares multiple regression. Quantitative data was complemented with key stakeholder interviews and focus groups. Results show that subsidies tend to be allocated to larger, better-connected communities which have access to better services. Within adopter communities, the subsidy is distributed among households that have more resources, better risk-coping strategies, better access to information, more experience with similar technologies and whose attitude towards risk is positive. This study provides lessons that can be useful for the introduction of new energy crops to better reach the target group and ultimately achieve the aims of energy promotion strategies.

1. Introduction

The strong interest in biofuels lies in their capacity, as fossil fuel substitutes, to reduce greenhouse gas (GHG) emissions and energy dependency (Verrastro and Ladislaw, 2007), while enhancing rural development (Brittaine and Lutaladio, 2010). During the last few decades, many countries enacted policies and legislation to promote the production and utilisation of biofuels. Governments of both industrialised and developing countries have provided financial incentives (e.g. subsidies, tax breaks) for the establishment of biofuel crops and set up binding targets for their utilisation (Jull et al., 2007; Pradhan and Ruysenaar, 2014).

The sustainability of biofuel promotion programmes came into question when commodity prices spiked and concerns arose about the influence of biofuels on the instability of food prices, and associated negative socioeconomic impacts (Koning and Mol, 2009; Lei et al., 2013). Moreover, the environmental sustainability of biofuels production remains controversial (Creutzig et al., 2012) because energy crops can lead to land-use conversion from natural to agricultural land (IPCC, 2011) and can present a threat to

* Corresponding author at: Crta. de Sant Llorenç de Morunys, Km. 2, Solsona 25280, Spain.
E-mail address: iria.soto@ctfc.es (I. Soto).
[1] Present address: Université libre de Bruxelles, Institute for Environmental Management and Land Use Planning, Brussels, Belgium.

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biodiversity and water resources (Fargione et al., 2008; Laurance et al., 2014; Wu et al., 2014).

Jatropha curcas (henceforth jatropha) came about as a promising option for sustainable biodiesel production. It is a non-edible ligneous plant bearing seeds with a high oil content, and traditionally used in several developing countries on a small scale for soap production, medicinal purposes and as a living fence (Heller, 1996; Achten et al., 2007). As a biofuel crop it was claimed to enhance socioeconomic development (Brittaine and Lutaladio, 2010) by creating employment, increasing revenues for poor rural farmers and offering energy self-sufficiency for small communities (Fairless, 2007; van Eijck et al., 2014). Further, it was argued that it would reclaim marginal and degraded soils (Reubens et al., 2011; Valdes-Rodriguez et al., 2013) without competing with food production, depleting natural resources or reducing ecosystem services (Francis et al., 2005; Fairless, 2007). Others have argued that advantages of jatropha include its resistance to drought and pests (Openshaw, 2000; Francis et al., 2005; Garcia-Almodovar et al., 2014), unpalatability to cattle (Sharath et al., 2014), reduced gestation period (Altenburg et al., 2009) and a wide variety of possible by-products and their uses (Contran et al., 2013).

Since the 1990s, jatropha cultivation for energy production has been heavily promoted worldwide (Rajagopal, 2007; van Eijck et al., 2014) and supported by development donors, governments, companies and Non-Governmental Organisations (NGOs). Some projections estimated that jatropha cultivation would cover 12.8 million ha by 2015 (GEXSI, 2008) contributing to 10% of biodiesel production in developing countries by 2020 (OECD/FAO, 2011). However, in recent years, poor jatropha performance, limited yield levels and limited valorisation of by-products have resulted in negative socioeconomic and environmental impacts (Ariza-Montobbio and Lele, 2010; Schut et al., 2011; van Eijck et al., 2014) that have curbed the "jatropha hype". Kumar et al. (2012) and Axelsson et al. (2012) identified the lack of incentives, the lack of a sufficient number of demonstration projects and the limited technological development as the main causes of failure of the national government promotion programme in India.

Economic incentives are considered important elements to ensure viable pricing for selling jatropha biodiesel (Kumar et al., 2012). Subsidies can increase willingness to cultivate jatropha by reducing the high economic risk associated with agricultural innovations and motivating the least risk-takers, generally the poorest farmers, to implement the innovation. Different authors (Kumar et al., 2012; van Eijck et al., 2014) have recommended providing economic support to biofuel cultivators during the gestation period, as a strategy for the successful adoption of biodiesel crops in any biofuel policy. However, promotion programmes in which subsidies to jatropha cultivation were provided are scarce. We have found documented cases in only Southwest China (Weyerhaeuser et al., 2007), India (Axelsson et al., 2012) and Mexico (Skutsch et al., 2011). There is limited knowledge about the impact that the implementation of these policy measures have had on enhancing rural development. Likewise, there is an incomplete understanding of how those incentives are distributed among the rural population. A more detailed understanding of the effects of the policy incentives as well as its distribution among farmers would help policy makers assess the effects of the implementation of promotion strategies and thus support evidence-based and congruent policies.

The purpose of this paper is to analyse how promotion programmes, features of farmer communities and farmer characteristics affect the distribution of economic biofuel subsidies. With this aim, we focused our study on the State of Chiapas (Mexico), where the government has been providing economic support to jatropha production from 2007 to 2013. We performed the analysis in two steps. First, we analysed the regional governmental promotion strategy for jatropha cultivation (supported by a national governmental subsidy, the ProArbol programme). We compared the socioeconomic characteristics of the communities where there were farmers participating in the ProArbol programme with those communities where there were no participants. Second, within participating communities, we analysed the main factors that motivated and encouraged farmers whether or not to cultivate (adopt) jatropha. We gave special attention to risk and uncertainty indicators as key factors influencing adoption (Feder et al., 1985; Feder and Umali, 1993; Pattanayak et al., 2003) by using direct interview techniques to investigate the effect of farmers' risk attitudes. Risk and uncertainty have rarely been directly considered in empirical studies due to the difficulty in measuring them (Pattanayak et al., 2003; Marra et al., 2003) and their omission has often led to poor model specifications (Ghadim and Pannell, 2003).

Most farmers in Chiapas cultivating jatropha for commercial purposes were, to our knowledge, participating in the State's jatropha promotion programme and had previously been accepted to receive the subsidy. Therefore, in this study jatropha adoption is used as an indicator of subsidy distribution meaning that farmers that are cultivating jatropha were pre-selected to receive the subsidy. Using this approach, our assumption is that the socioeconomic characteristics of both communities and households have an effect on the pattern of jatropha promotion and adoption and hence on the distribution of jatropha subsidies. Our cross-cutting aim is to provide empirical data to help policy makers identify their future target farmers and assess the effects of the implementation of subsidised promotion strategies.

2. Study site and context setting: jatropha promotion in Chiapas

Although Mexico is a net exporter of primary energy (crude oil), 45% of the processed energy sources (i.e. gasoline, diesel) used in the country are imported (SENER, 2013). Moreover, Mexico has low energy diversification: 88.5% of the primary energy production corresponds to hydrocarbons of which 74% is crude oil (SENER, 2013), the proven reserves of which are decreasing (SENER, 2014).

The Mexican commitment to promoting biofuels as an alternative source of fuels is based on reducing fossil-fuel dependence by increasing energy diversification, reducing GHG emissions and promoting the development of the less-favoured rural communities (Law for the Promotion and Development of Biofuels, DOF 01-02-2008). This law, together with its regulation (approved in 2009), established the first legal framework for public policies aimed at biofuel development. However, some states, such as Chiapas, moved forward with their own promotion strategies of biodiesel production, as early as 2006.

The State of Chiapas is located in southern Mexico (Fig. 1). It is one of the least developed regions in Mexico, having the lowest Human Development Index of all Mexican states (UNDP, 2010) and ranking first in rural poverty (CONEVAL, 2012) and marginalisation (CONAPO, 2012). Its population is very dependent on the primary sector, the share of which corresponds to 9.7% of the gross domestic product (GDP), while at the national level it is 3.7% (INEGI, 2010). Animal husbandry, especially bovine, is a major activity in terms of land use (22% of Chiapas State) and income (SEMARNAT, 2009). Agriculture is also a major activity representing 18% of the Chiapas territory (SEMARNAT, 2009), mainly based on conventional crops such as maize, beans, pumpkin, peanuts and coffee (INEGI, 2010).

In 2006, the Chiapas Government initiated the promotion of biodiesel production (from jatropha and oil palm) with the

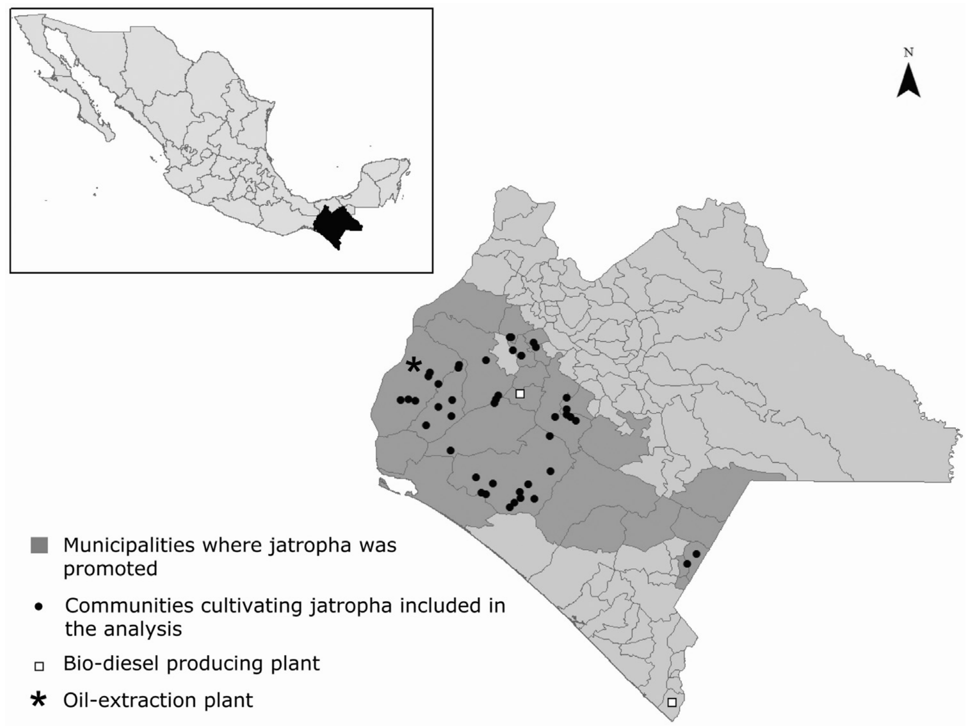

Fig. 1. Promotion of jatropha cultivation in Chiapas territory. Location of (i) the municipalities of Chiapas where jatropha was promoted during the period 2008–2011 (shadowed in grey), (ii) the communities of Chiapas cultivating jatropha included in the analysis (represented with black dots), (iii) the bio-diesel production plants (represented with white squares) and, (iv) the oil-extraction plant (represented with a black asterisk).

creation of the Biofuels Commission. The Government was at that time holding the "countryside mandate" (*sexenio del campo*) whose main political commitment was the development of rural areas, and was therefore very interested in supporting biofuels ventures. In 2007, the State of Chiapas created the Institute for Productive Reconversion and Biofuels [IRBIO, although the name and structure of the institute has changed over time (Valero-Padilla et al., 2011)], to promote biodiesel production and use in the region. The programme had three major axes: (i) promotion of jatropha cultivation and generation of reproductive material; (ii) oil processing and biodiesel production; and (iii) biodiesel utilisation.

The promotion of jatropha cultivation by the Chiapas Government consisted of providing all interested farmers with reproductive material (i.e. seeds and seedlings) and technical assistance for the establishment and maintenance of plantations. Although the government of the State did not provide direct subsidies to farmers, it supported farmers in applying for the subsidy provided by the Federal Government through the National Forestry Commission (CONAFOR) under the ProArbol Programme. The ProArbol Federal Programme provided financial and technical assistance to all types of landowners to protect, conserve, restore and sustainably manage their forest resources. Because jatropha was considered an afforestation species, from 2007 to 2013 jatropha was included in ProArbol as a sub-programme, offering a subsidy of US$486 (6310 Mexican pesos) per ha planted. This subsidy was assigned to cover the establishment and first years of maintenance of jatropha plantations for commercial purposes (CONAFOR, 2009). Hedge plantations were not eligible for the subsidy.

Biodiesel production through the processing of jatropha oil (biodiesel transesterification) was encouraged by the establishment of two processing plants in 2009 and 2010 (Fig. 1). An experimental plant in Tuxtla Gutierrez (in collaboration with the Colombian Government) had a production capacity of 2000 l/day, while a larger one in Puerto Chiapas could produce up to 28000 l/day. These plants began production using the available raw materials in the region (palm oil and in some cases recycled cooking oil) while jatropha oil has only been used in tests. In 2012 (2 and 3 years after opening) they had not yet reached their full capacity. Regarding oil extraction from jatropha seeds, it was not until 2012 that a extraction plant was installed in Cintalapa (335 km from Puerto Chiapas and 80 km from Tuxtla Gutierrez) (Fig. 1).

The promotion of biodiesel utilisation was centred on supplying the public transport sector (buses) in the major cities of the state (thus far Tuxtla Gutierrez and Tapachula) with a 5–20% blend of bio-diesel. To our knowledge, and in spite of the publicity by the State, biodiesel is made from palm oil. Jatropha oil has only been used on an experimental level.

3. Materials and methods

Our study focussed on the regions of Frailesca, Centro and Sierra within the Chiapas State. First, we gathered qualitative information in the Chiapas Region at both community and household levels. We conducted 25 semi-structured interviews with key stakeholders, including extension agents, government staff, social organisations, researchers and individual farmers during the period 2009–2011. Interviews were adapted to each key informant. Key stakeholders were selected using the snowball sampling technique (Goodman, 1961), by which we first selected initial informants (based on literature and local contacts) who led us to recruit further informants. Community focus groups were conducted in 6 adopter and 2 non-adopter communities. Adopter communities were selected using the census of the jatropha cultivators provided by IRBIO. This census included information of jatropha cultivation characteristics as well as their location. Based on the insights of extension agents we selected communities that, in their view, represented diverse situations in terms of adoption

Table 1
Community socioeconomic and environmental variables. Description of the variables used for the community adoption model in Chiapas.

Variables name	Variable description
ALTITUDE	Square root of the altitude (in m) of the community with respect to sea level
HHOLDS	Logarithm of the number of households in the community
YOUNG	Percentage of number of persons under 15 years with respect to total population
> 60YEARS	Square root of the number of persons over 60 years
INMIGR	Logarithm of the persons that lived in a different community in 2005
OTHER-LOC	Logarithm of the number of persons born in a different locality
NO-SPANISH	Percentage of persons that speak an indigenous language and do not speak Spanish
INDIGENOUS	Percentage of persons that live in a household were the household head or the consort speak any indigenous language
ILLITERATE	Percentage of persons older than 15 years that have not completed any school grades
SCHOOLING	Average school grade: result of dividing the completed school grades of all persons between 15 and 130 years among the number of persons
ECON-ACTIV	Economically active population as the number of people older than 12 years that had a job, were looking for a job or were unemployed during the reference week
NO-MEDIC	Percentage of persons that do not have the right to receive medical assistance in any public or private institution
NO-LIGHT	Square root of the number of households that do not have electricity
NO-WATER	Percentage of households that do not have channelised water
NO-DRAINING	Percentage of households that do not have a draining system
NO-GOODS	Square root of the number of households that do not have radio, TV, refrigerator, washing machine, car, PC, cell phone, phone or Internet
RADIO	Percentage of households that have a radio
TV	Percentage of households that have a TV
CAR	Percentage of households that have a car

rates and socioeconomic conditions. Non-adopter communities were randomly selected from the villages that had not received visits from extension agents. All the information was triangulated by at least two different sources of information. The information gathered through structured interviews and focus groups was used to set the context of more quantitative approaches explained below and facilitated the interpretation of the results.

3.1. Adoption at the community level

We collected 19 socio-economic and environmental variables (Table 1) for all communities within Chiapas from the State's population census (INEGI, 2010). Based on this information we generated a community database in which we distinguished between the communities where there were farmers cultivating jatropha (adopter communities) and those where there were none (non-adopter communities). We consider adopter communities as villages where farmers were visited by extension agents and decided to grow jatropha (Table 2 option 1.1) while non-adopter communities were considered as villages that were either not visited by the extension agents (Table 2 option 1.0) or where farmers were not interested in growing jatropha (Table 2 option 0.1). The database did not allow for the distinction between option 1.0 and 0.1. To our knowledge, there were no communities cultivating a substantial surface area of jatropha that had not received a visit from an extension agent.

In our dataset, communities were nested within municipalities. We restricted our analysis to those municipalities where there had been adoption of jatropha, in order to avoid the influence of large territories without jatropha adoption in our analyses. Municipalities for which the information was not complete were excluded from further analysis as well. The final database comprised 1317 communities of which 43 were cultivating jatropha.

Table 2
Typology of farmer participation in the ProArbol programme. Possible scenarios of community participation in jatropha promotion programme depending on farmers' willingness to participate and extension agents' interest or capacity in visiting the community.

		Farmers participating in the programme	
		YES (1)	NO (0)
Extension agent visiting	YES (1)	1.1 **(adopter community)**	1.0 **(non-adopter community)**
	NO (0)	–	0.1 **(non-adopter community)**

To analyse the differences between adopter and non-adopter communities we first used a multivariable approach to reduce the number of variables describing communities. We summarised the variation of the 19 selected socioeconomic and environmental variables (Table 1) by means of a principal component analysis (PCA). Following the scree plot criterion (McGarigal et al., 2000), we extracted two principal components, which accounted for 36.9% of the variance in the original dataset. PC1 was interpreted as a wealth gradient. At the negative end of the gradient we found communities with greater numbers of households having assets (i.e. TV, radio, cars) while villages with households having no such goods tended to be placed at the positive end. This gradient is also associated with age and ethnicity, with less indigenous communities with older people at the negative, wealthier extreme of the gradient. PC2 was interpreted as an access to services gradient because larger populations having access to services (i.e. education, health-care, drainage, lighting, water) were located towards its negative extreme (Fig. 2).

Second, to analyse the determinants of jatropha adoption at the community level we used PC1 (wealth) and PC2 (access to services) as predictor variables in a generalised linear model (GLM) with binomial error distribution (adoption vs. non-adoption) and probit link function.

3.2. Adoption at the farmer level

The data used for this adoption study were collected from June to December 2011. Seven enumerators and the first author attended a 2-day training and a discussion session on the content and objectives of the survey questionnaire. After the training, the questionnaire was pre-tested on 32 households in two different communities. These questionnaires were not included in the analysis. After each survey, time was spent to check and correct miscalculations and to convert local units to clarify the questionnaire. Survey data were gathered from 420 household questionnaires in 16 randomly selected communities where jatropha promotion activities were taking place. The households in the sampled villages were then stratified into two groups based on whether they grew or had grown jatropha after the promotion (adopter households) or not (non-adopter households). Jatropha

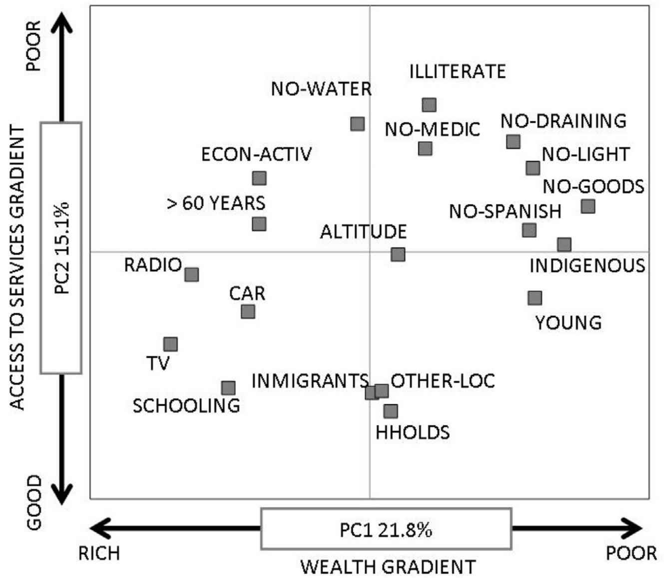

Fig. 2. Factor loadings of the principal component analysis. Graphic representation of the weight of the original variables used in the PCA for PC1 and PC2. Codes for variables are given in Table 1.

adopter households were chosen using systematic random selection from a jatropha growers register provided by IRBIO while the non-adopters were chosen using systematic random selection from a list of households provided by the mayor (*comisario ejidal*) of each village. A total of 14 households were selected in each stratum except for 2 communities where too few growers were reported. In these cases only 7 households from each stratum were sampled.

Data were gathered on the main categories of factors that explain technology adoption (Mercer and Pattanayak, 2003; Pattanayak et al., 2003) (Table 3): (i) household characteristics; (ii) resource endowments; (iii) market incentives; (iv) risk and uncertainly; and (v) biophysical factors.

Household characteristics represent the heterogeneity of households and their attitude towards a number of factors such as risk tolerance or attitude towards innovation. In this study, the level of education and the age of the household head were selected as proxies of household characteristics. Resource endowments indicate the resources available to the household for implementing the new technology. Proxies measured in this study are labour force, hiring of extra labour, income coming from off-farm activities, livestock and assets owned by the household. Market incentives represent factors related to the benefits and costs of the technology that has been adopted. Price, availability of markets, transportation and potential income gain are traditionally measured as market incentive proxies. However, since no jatropha market had been developed yet when we carried out the survey (i.e. information about prices or buyers was not available), we selected the distance of household plots to the nearest market as a proxy of market incentives. Risk and uncertainty reflect the unknowns in the market and institutional environment under which decisions are made (Pattanayak et al., 2003). We included in the analyses 4 risk and uncertainty proxies: (i) previous experience with the technology which evaluates how familiar farmers are with growing trees and is assumed to decrease the uncertainties associated with an investment; (ii) membership to cooperatives or other collaborative forums, which, together with (iii) quality of the household social network, evaluates participation and support from a community network. These three variables are expected to mitigate some of the uncertainties associated (with a new technology;) (iv) attitude towards risk which evaluates farmers′ willingness to take risks, rating themselves as risk-takers or risk-averse, in situations related to their agricultural production system (Dohmen et al., 2005). Biophysical factors, like soil quality or terrain slope may help to explain adoption incentives in relation to the expected results of this adoption: poorer biophysical production conditions often render a positive incentive to adopt innovations that will improve this situation (Pattanayak et al., 2003). Farmland surface variables (i.e. land dedicated to agricultural production) are usually treated as proxies of biophysical factors but due to their importance in determining adoption, they can also be a proxy for other categories of variables such as resource endowment (i.e. wealth and assets) or risk and uncertainty (i.e. risk tolerance) (Pattanayak et al., 2003). For that reason, we consider them as an independent category together with other variables representing amount of land dedicated to crop production and fallow. Two additional variables (participation in jatropha training activities and number of extension visits) were grouped as an extension characteristics category and included in the extent of jatropha adoption model. A total of 19 variables, grouped into 7 categories (Table 3) were initially selected to analyse the factors that determine the adoption of jatropha.

The factors related with the jatropha adoption process were analysed through a two-step approach. First, we used a Generalised Linear Mixed Model (GLMM) with a binomial error distribution and a probit link function to analyse the variables related to the farmers′ decisions to adopt jatropha. In these models the response variable was jatropha adoption by households (1 = adoption, 0 = no adoption) ($n=389$). Second, we used ordinary least squares (OLS) multiple regressions to analyse the extent of the adoption of jatropha i.e. the amount of land dedicated to jatropha cropping (in hectares, $\log_{10}(X)$-transformed). In this second step, the analyses was limited to jatropha adopters (1 s in the previous analyses) ($n=200$).

The variable "community" was included as a random factor in both models to control for the possible variation associated with intrinsic characteristics of particular communities that could influence the independent variable figures.

Complementary to multivariate models, univariate models were tested for each independent variable used in the GLMM and in the OLS multiple regressions to analyse the effects of individual factors on the adoption and extent of jatropha decisions.

To select the final appropriate adoption model we compared the Akaike second-order Information Criterion (AICc) of all possible models (all combinations of the categories of variables, a total of 64 models for adoption and 126 for the extent of adoption). AICc is similar to the Akaike Information Criterion (AIC) but corrected to remove small sample biases (Burnham and Anderson, 2002) increasing the relative penalty for model complexity with small data sets. For both the adoption and extent of adoption analyses, we selected the model that had the lowest AICc, as a trade-off between the goodness of fit of the model and the complexity of the model. A full list of the models and their AICc is contained in Appendix 1 in the Supplementary material.

All data were processed and analysed using the statistical programme Stata (Version 11, StataCorp, College Station, Texas).

4. Results and discussion

4.1. *Jatropha promotion strategy: process and characteristics*

Chiapas State, through the IRBIO, promoted jatropha in the territory by means of a network of extension agents that was supported with a media communications strategy (i.e. television, radio and newspapers). From 2007 to 2009, the only instruction

Table 3
Household summary statistics. Mean and range in brackets of the variables initially considered in the household adoption model (first six categories) and the household extent of adoption model (all categories).

Variable	Adopters ($n=200$)	Non-adopters ($n=189$)	Total ($n=389$)
Category 1: biophysical characteristics			
Soil quality: Average soil quality of all the fields that the household owned, rated from 1 to 5 (5 better quality)	2.46 (1.14–4)	2.53 (1–5)	2.50 (1–5)
Slope: Average slope of all the fields that the household owned, rated from 1 to 5 (5 steeper)	2.01 (1–4)	2.10 (1–4)	2.05 (1–4)
Category 2: household characteristics			
HH education: Education level of the household head, measured by the degree completed (from 0 to a maximum of 10, corresponding to university studies) (note: all education levels required similar study years)	3.28 (1–9)	3.10 (1–9)	3.19 (1–9)
HH age: Age (years) of the Household Head	51.35 (17–84)	49.86 (17–86)	50.62 (17–86)
Category 3: farmland surface			
Agricultural land: Surface (ha) dedicated to agricultural production by the household [$\log_{10}(X)$ transformed]	0.78*** (0–1.72)	0.58*** (0–1.20)	0.58 (0–1.72)
Cash crop land: Surface (ha) dedicated to cash-crops by the household [$\log_{10}(X+1)$ transformed]	0.12 (0–1.20)	0.12 (0–1.20)	0.12 (0–1.20)
Fallow land: Surface (ha) dedicated to fallow by the household [$\log_{10}(X+1)$ transformed]	0.28 (0–2.28)	0.24 (0–1.61)	0.26 (0–2.28)
Category 4: resource endowments			
Labour force: Number of household members as an indicator of potential labour force	3.82** (1–11.5)	3.37** (0–9)	3.60 (1–11.5)
Paid labour: Dummy variable (1=household paying for non-familial labour; 0=otherwise)	0.9*** (0–1)	0.79*** (0–1)	0.85 (0–1)
TLU: Number of tropical livestock units owned (1TLU=250 kg body weight) [$\log_{10}(X+1)$ transformed]	0.28** (0–1.93)	0.18** (0–1.59)	0.23 (0–1.93)
Off-farm: % of income from off-farm activities	49.40** (0–100)	42.22** (0–100)	45.91 (0–100)
Assets: Total value of the household assets (furniture, goods and vehicles) owned by the household [$\log_{10}(X)$ transformed]	4.24 (2.78–5.06)	4.20 (3.18–5.29)	4.22 (2.78–5.29)
Category 5: market incentives			
Market distance: Average distance (in time) of the plots to the nearest market	0.69 (0.04–1.60)	0.67 (0.04–1.79)	0.68 (0.04–1.79)
Category 6: risk and uncertainty			
Risk attitude: The mean of 7 binary behavioural questions representing the willingness to take risks under specific situations related to their agricultural production system (1=risk embracing attitude; 0=risk aversion attitude)	0.50** (0–1)	0.44** (0–0.85)	0.47 (0–1)
Previous experience: Dummy variable (1=household planting trees (e.g. coffee, lemon) on their fields; 0=otherwise)	0.26** (0–1)	0.16** (0–1)	0.21 (0–1)
Collective actions: Times the household head participates in collective actions (in the last year) [$\log_{10}(X+1)$ transformed]	0.77** (0–1.79)	0.67** (0–1.48)	0.72 (0–1.79)
Social network: Maximum value among the familiar links they have at the community level and the number of people they can ask for help [$\log_{10}(X+1)$ transformed]	0.92* (0–2)	0.85* (0–1.71)	0.89 (0–2)
Category 7: extension characteristics			
Training: Dummy variables: 1 if farmers participate during the last year in jatropha training activities; 0 otherwise	–	0.14 (0–1)	0.14 (0–1)
Extension visits: Number of times that jatropha extension agents visited the household during the last year [$\log_{10}(X+1)$ transformed]	–	0.71 (0.30–2.56)	0.71 (0.30–2.56)

*** $P<0.01$; ** $P<0.05$; * $P<0.1$.

given to extension agents was that "*jatropha shall be planted at altitudes below 1000 m*". Based on that criterion, technicians selected the municipalities and localities to be visited based on their own preferences. Extension agents had a salary incentive, which, according to IRBIO informants, "*was proportional to the hectares they introduced into the programme*" (personal communication, July 2010). Since 2010 the ProArbol programme began to include the municipalities that were eligible to apply to the programme.

The arguments given by the extension agents to motivate farmers to plant jatropha were diverse, as reported by the latter. Firstly, the ease of cultivation: "*We were told that jatropha was the wonder plant, that could grow in unproductive soils without fertilizers or water, that it was very easy to cultivate and that it would grow without difficulty since it is very resistant to pest and diseases and that the incomes that we might get would be enormous*" (focus group in Julian Grajales, 2010). The second argument used was the economic profit that farmers could earn from the commercialisation of the seeds in a hypothetical market: "*The extension agent told us that jatropha was a growing market and that thanks to the revenues of jatropha culture I would be able to buy a car by myself*" a farmer asserted (focus group in Tierra Santa, 2010). Although the buyer of seeds was still unknown, the agents verbally ensured producers that the government would purchase all jatropha seeds produced, making adoption more attractive. The third argument,

Table 4
Eligibility criteria of ProArbol. A selection of the eligibility and evaluation criteria of the programme ProArbol 2009 compared to the criteria of ProArbol 2008 (in brackets).
Source: http://www.conafor.gob.mx.

Criteria	Points
Forestry commercial plantations	
1. The surface to be supported in ha is	
Larger than 500 *(than 1000)*	**5**
From 100 to 500 *(501-1000)*	**3**
Smaller than 100 *(< 500)*	**1**
2. Type of technology to be applied for the establishment and management of the plantation	
Advanced	**3 *(5)***
Traditional	**1 *(3)***
3. Plant provision *(not evaluated in ProArbol 2008)*	
Production in own nursery	**3**
Acquisition from a third person	**1**
4. Precedence of the germplasm	
Origin Certified	**3**
Origin Unknown	**1**
5. Authorise via email notifications *(not evaluated in ProArbol 2008)*	
Yes	**1**
Specific criteria for *Jatropha curcas* plantations	
6. Type of persons that apply for the support *(not evaluated in ProArbol 2008)*	
Business entity	**5**
Ejidos and communities	**3**
Smallholders	**1**
7. Type of productive organisation	
Cooperatives and business associations	**5 *(3)***
Ejidos, communities and smallholders	**3 *(5)***
8. Does the applicant present an inversion project? *(not evaluated in ProArbol 2008)*	
Project for 10 years or more, specifying all project phases from planning to harvesting, including financial data	**5**
Project for less than 10 years, specifying partially project development phases, including financial data	**3**
The applicant does not present a financial project or budget	**1**
9. Exploitation and final destination of the production	
Own industry *(not evaluated in ProArbol 2008)*	**5**
Secure market	**3**
Undefined market	**1**

and the main reason why 98% of the farmers planted the crop, was the subsidy offered by the ProArbol programme (US$486/ha for the establishment of the plantation). Beneficiaries of the ProArbol call were selected on a competitive basis according to the scores obtained under a series of eligibility criteria (see Table 4 for some of the criteria of the 2008 and 2009 ProArbol call, more information at http://www.conafor.gob.mx).

Governmental programmes supporting rural livelihood are common in Chiapas. However, farmers had high expectations of this specific jatropha promotion programme due to the attractiveness of the arguments mentioned by the extension agents. Furthermore, the governmental media campaign, the visits of investors and researchers to farmer fields, and the construction of jatropha facilities (e.g. processing plant) further raised these expectations.

The promotion process within each community was initiated with the visit of extension agents who in a first step, presented the programme to the community leader (*comisario ejidal*). If the *comisario ejidal* was interested, the programme was presented to the community at the community assembly (*asamblea ejidal*). All interested farmers, independent of their productive capacity, were allowed to participate in the programme and to apply for the subsidy. The cultivation of jatropha represented an innovation for farmers: the plant had never been cultivated as a commercial plantation for energy purposes, thus requiring new plantation and management techniques. Furthermore, improved seeds (from India) had never been used before. However, the acceptance of jatropha was made easy in Chiapas because the plant species is native to the area, is widely known (locally called *piñón* or *piñoncillo*), and is often cultivated as a living fence by farmers (Ruíz-Valdiviezo et al., 2010).

Extension agents organised farmers to apply to the ProArbol call as a unit (*ejido*) and not as individual farmers. Therefore, the probabilities of being accepted into the programme were improved as this increased the rating under criteria 1, 6 and 7 (Table 4). Interested farmers were asked to decide how much area they wanted to dedicate to jatropha production with the aim of reaching a minimum of 100 ha among all participating farmers. Reproductive material (seeds and seedlings) and technical assistance (i.e. plantation density, planting techniques) were provided free of charge to interested farmers. However, during the planting process the techniques and the reproductive materials were found not to be appropriate (Valero-Padilla et al., 2011). Among other constraints, germination rates in 2008 plantations were estimated to be less than 40% (Valero-Padilla et al., 2011) and most farmers had to repeat the initial plantings (IRBIO, personal communication). Hence, farmers re-invested considerable time and resources due to the labour-intensive nature of jatropha plantation establishment.

Regarding the subsidy programme, extension agents were responsible for processing and submitting the applications to the CONAFOR (i.e. National Government) and informed farmers about their approval or rejection. Half of the subsidy was provided 3–6 months after planting, once the planting density, survival rate and health status fulfilled the standards set. The rest was paid 18 months later after a similar verification. However, the novelty of the programme led to misunderstandings of ProArbol rules between extension agents and farmers and, in many cases, farmers experienced delays in subsidy delivery.

4.2. Jatropha adoption at the community level

The "access to services" gradient defined by PC2 (Fig. 2) strongly discriminated villages where jatropha had been adopted from those in which adoption had not occurred (Table 5). Adopting villages were placed towards the negative extreme of the gradient

Table 5
Determinants of jatropha adoption at the community level. Results of the generalised linear model (GLM) with binomial error distribution and probit link function in which the response variable is whether or not there is jatropha adoption at the community level. The predictor variables are the principal components summarizing the 19 variables describing communities.

Probit model		
Variable	**β**	**S.E**
PC1 (wealth)	−0.088	0.092
PC2 (access to services)	−0.483***	0.071
Constant	−2.054***	0.090
$n = 1317$		
Log likelihood = −167.13		
LR chi² = 51.36		
Prob > chi² = 0.0000		
Pseudo $R^2 = 0.14$		

*** $P < 0.01$; ** $P < 0.05$; * $P < 0.1$

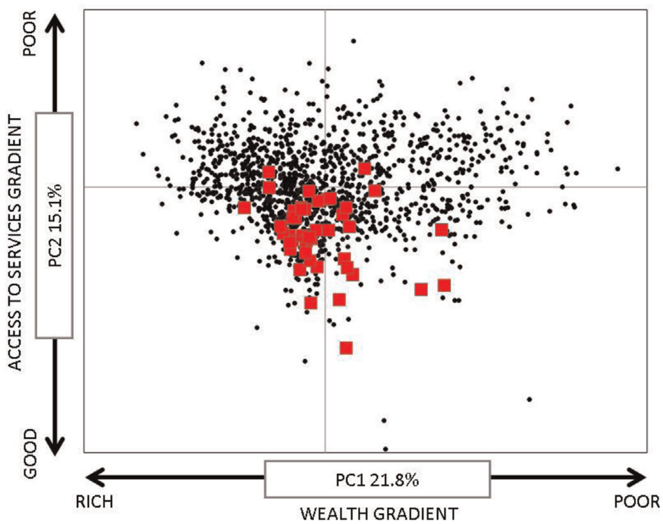

Fig. 3. Factor scores of the principal component analysis**.** Representation of the position of each community in the space defined by PC1 (wealth gradient) and PC2 (access to services gradient). The communities of Chiapas State included in the study are represented with grey dots. The communities with jatropha promotion are represented with black squares.

(Fig. 3), indicating that jatropha adoption tended to occur in larger and better-connected communities, with better services (i.e. education, health-care, drainage, lighting, water). Adoption never occurred in small, isolated villages with few services. In contrast, the "wealth" gradient (PC1) did not have any significant effect on the adopting or non-adopting character of villages (Table 5).

When visiting larger communities, extension agents had a greater chance of including more potential adopters and hence more hectares into the programme. Since the ProArbol eligibility criteria ranked larger surface areas higher (criterion 1, Table 4) and extension agents′ salaries were proportional to these figures, the system arguably created a strong incentive to sponsor jatropha cultivation in larger population centres. Visiting more accessible and better-connected communities minimised the transportation cost of the extension agents, a fact that could be important since, according to extension agents, travel allowances were irregularly paid and generally insufficient (see also Valero-Padilla et al., 2011). Furthermore, visiting larger and better-connected communities increased the possibilities of finding entrepreneurial applicants (criteria 3, 4 and 7), with access to advanced technology (criterion 5) and the Internet (criterion 9), features that improved scores on the ProArbol call and increased the chances of success. Due to these probable preferences of extension agents and the characteristics of the ProArbol call itself, small, poorly developed communities remote from services tended to be neglected, preventing them from obtaining the subsidy offered by the jatropha programme. This finding is in agreement with Minten and Barrett (2008) who showed that more remote communities have a lower likelihood of adopting technologies. The more remote the communities are, the poorer the information flow and the poorer is their integration into the commercial trading system, thus facing higher transaction costs (Minten et al., 2013).

Moreover, both political leaders and farmers from well-connected communities are better linked and have better information on governmental promotion programs, which had been endorsed by the media (TV and radio). Better access to information has an effect on the overall attractiveness of the innovation (Feder and Umali, 1993; Marra et al., 2003). Better access to information increases the knowledge of innovation implementation reducing the uncertainty of the potential benefits (Marra et al., 2003). Therefore, communities with better services were more aware of the jatropha promotion programme, more receptive to the extension agents and thus more prone to collecting the subsidies.

4.3. *Jatropha adoption at the household level*

The final model for the adoption of jatropha included five categories of variables (biophysical factors, household characteristics, farm characteristics, resource endowments and risk and uncertainty) and excluded one (market incentives) (Table 6).

Table 6
Determinants of jatropha adoption and extent of adoption at the household level. Coefficient estimates for the factors influencing farmer decisions to adopt jatropha (GLMM with a binomial error distribution and a probit link function) and the extent (OLS) of adoption of jatropha at the household level. The village variable was included as a random factor to control for the possible variation associated with intrinsic characteristics of particular communities.

Variables		**Probability of jatropha adoption**		**Extent of adoption (ha)**	
		B[a]	**Bu**[b]	**B**[a]	**Bu**[b]
Household characteristics	HH education	**0.0926**	0.0827*		
	HH age	**−0.0007**	0.0051		
Biophysical factors	Soil quality	**−0.3008****	-0.1975		
	Terrain slope	**−0.1637**	−0.2672**		
Farmland surface	Agricultural land	**2.2383*****	2.0201***	**0.2767*****	0.31***
	Cash crop land	**−1.0283*****	0.0518	**−0.0578**	0.08
	Fallow land	**−0.1795**	0.016	**0.0655****	0.03
Resource endowments	Labour force	**0.1661*****	0.1215***		
	Paid labour	**0.4727****	0.7353***		
	TLU	**0.1256**	0.4896***		
	Off-farm	**0.0149*****	0.0055**		
	Assets	**−0.9368*****	0.4045*		
Market incentives	Market distance			**−0.0844**	−0.0652
Risk and uncertainty	Previous experience	**1.4624*****	0.9360***		
	Collective Actions	**0.3185**	0.5315***		
	Social Network	**0.6284*****	0.4182**		
	Risk Attitude	**1.1270*****	0.7392**		

For the adoption model: R^2 (adjusted)=0.26. n=389.
For the extension model: R^2 (adjusted)=0.39; n=200.
*** $P<0.01$; ** $P<0.05$; * $P<0.1$.

[a] Coefficient of each variable for the complete GLMM.
[b] Coefficient for each univariate model.

Regarding the extent of jatropha adoption, the final model selected included only two categories (farm characteristics and market incentives).

Our results show that smallholders with more agricultural land, labour availability and hired labour capacity were more likely to adopt jatropha than smallholders with less access to these resources (Table 6). Therefore, the jatropha subsidy tended to be allocated to households that have greater resource control and production potential. These components can be translated into perceived wealth, contributing to the sense of security of the producers, which has been shown to reduce aversion to adopting risky technology (Rogers, 1983; Caveness and Kurtz, 1993). This subsidy allocation is in fact promoted by the ProArbol programme criteria (Table 4), since it gives priority to large plantations, favouring both farmers with more land to get into the programme and extension agents to seek out larger landholders. The labour-intensive nature of jatropha cultivation (especially for the establishment of the plants and the collection of the seeds and cuttings) encourages the adoption of jatropha in households with a larger labour force, either within the household or hired. This may have been boosted by the fact that the initial planting techniques were not appropriate and farmers had to repeat the plantings investing a lot of labour. Labour-constrained farmers could as a result have been excluded from the process, and thus from the subsidy.

Household assets, as a resource endowment indicator, were expected to be positively correlated with the adoption (Pattanayak et al., 2003). This expected positive relationship was in fact observed in the univariate model. But in the multivariate probit model, the slope of this relationship changed (Table 6). The negative relationship between the value of assets and adoption might be explained by the high % of migrants in the region (Pickard, 2006), who send remittances that can generate a mismatch between wealth and our measured assets proxy. Additionally, during the survey it was observed that farmers were reluctant to talk about the remittances from family members who emigrated which may therefore not have been accurately included in the off-farm income proxy. On the other hand, better-off farmers may be less likely to adopt jatropha, everything else being equal. This may be related to the fact that among the wealthy farmers that are able to pay for labour and that have more land, the extremely better-off farmers are not interested in the jatropha subsidy. For those landlords who are involved in more productivity activities, the opportunity cost of their land, labour and capital is higher than the jatropha culture (and its subsidy) and they do not want to risk investing in a new crop from which the profit might be lower than the actual one. This hypothesis is reinforced by the fact that farmers with greater amounts of productive cash-crop land and of better quality, which are expected to be wealthier, were less likely to adopt jatropha (Table 6). Additionally, only 2.3% of jatropha adopters cultivated jatropha in plots that were previously occupied by cash crops while 83.0% of jatropha producers cultivated in land occupied by subsistence crops (mostly maize and beans).

Access to information plays a major role in the adoption decision by reducing the risk of adopting an innovation (Feather and Amacher, 1994; Liu and Huang, 2013). Information availability and information gain may determine the willingness of the household to adopt the innovation. Better-informed households may have a more reliable perception of the innovation profitability and potential uses (Marra et al., 2003). Our results show that the number of social connections had a positive influence on the decision to adopt jatropha and obtain the subsidy (Table 6). Better-linked households, with larger numbers of social network ties are better situated socially. Therefore, since jatropha promotion was initiated by opinion leaders, they have a higher probability of being repeatedly exposed to the information regarding the innovation, leading to adoption. Additionally, they are better situated for coping with the uncertainties associated with the new technology. Non-adopter farmers often stated that they did not adopt because they were informed too late and the groups for applying for the subsidy were already closed. Greater proportions of off-farm income may also indicate a diversification of information access, especially since in our study case off-farm activities involved constant contact with people (i.e. farm wage-labour, shopkeeper, merchant, and teacher). Hence, off-farm activities may increase the probabilities of being aware of the programme development and its implications.

Previous experience with the technology, although rarely considered, tends to be significant in adoption studies (Mercer, 2004; Jera and Ajayi, 2008). Previous involvement in tree-planting (e.g. lemon, coffee), as an experience proxy, positively influenced the decision to grow jatropha (Table 6). Households that are habituated to growing trees may reduce the uncertainty associated with a new investment with unpredicted returns. They are able to better identify the non-immediate potential benefits of tree-based plantations, also knowing how to plant and manage trees more efficiently, thus increasing the likelihood of receiving the subsidy.

Additional to the above-mentioned elements, attitudes towards risk (whether in the form of risk aversion or ambiguity aversion) has major effects on adoption of a new technology (Marra et al., 2003; Foster and Rosenzweig, 2010; Barham et al., 2014). Households with a positive attitude towards risk were found to be more likely to adopt jatropha (Table 6), and hence to benefit from the subsidy. This subsidy allocation on risk-embracing households is reinforced by the ProArbol programme criteria (Table 4) because it favours farmers with an entrepreneurial spirit (Cramer et al., 2002; Caliendo et al., 2009). In addition to attitude towards risk, farmers with important off-farm incomes were also more likely to adopt jatropha (Table 6). Farmers with diversified income sources would be most likely to assume adoption risks, because they would be in a better position to cope with risk (Ito and Kurosaki, 2009) and more willing to assume risk-seeking behaviour to improve their returns. Our results show that producers with a better risk-coping strategy and positive attitude towards risk are more likely to assume the risk of adopting jatropha (Table 6). Households that have more capital availability to deal with risk, in terms of resource endowments (i.e. land, labour, tenure) and in terms of information (experience, membership), can afford the investment in uncertain and unproven technologies, thus tending to adopt jatropha.

The availability of land area was the only factor that influenced the amount of land dedicated to jatropha cultivation (Table 6), and thus the quantity of the subsidy given to adopters. As well as for the subsidy allocation, larger quantities of the subsidy tended to be provided to households that have large land resources, either used for agricultural production or unproductive. This might indicate the absolute importance of the available productive land on the extent of adoption decisions. Contrary to our expectations (Mercer, 2004; Baumgart-Getz et al., 2012), the extension services and training did not influence the amount of jatropha planted. This may be related to the fact that the amount of land dedicated to the programme (extent proxy) was decided at the beginning of the promotion, before submitting the application, when the extension agents were active and dedicated to the extension services.

4.4. *Policy implications*

The Mexican Promotion and Development of Biofuels Law specifically targets rural development to "*contribute to the reactivation of the rural sector, the generation of employment and to a better quality of life of the population, in particular from the high and very high marginalized*" and "*promote the development of the least favoured rural communities*". However, contrary to the energy policy objectives, the subsidy, as an instrument implementing the law and encouraging cultivation, was, thus far, not provided to the target population.

The ProArbol programme also took a rural development approach, its first objective being "*to reduce poverty and marginalisation index in forestry areas*". However, our results neatly show that subsidies have benefited both the least marginalised communities (Fig. 3) and the most favoured households (in terms of resources control and production potential) within those communities (Table 6). The priorities of the promotion programme, the extension agents′ strategy for engaging farmers and the intrinsic household characteristics all played an important role in the distribution of the subsidies, and hence in jatropha adoption. At the community level, the two first factors affect the distribution of incentives, since the ProArbol programme structure motivated extension agents to visit well-connected communities. At the household level, the ProArbol programme criteria encourage the adoption of jatropha by the resource-rich households in each community. The subsidy incentive did not reach poor households from marginalised communities nor motivated them to cultivate jatropha. Therefore, the subsidy tended to be concentrated among communities and households that were better informed about the innovation.

The risk coping strategy and the positive attitude towards risks, which is related to wealthy and resource-rich households, also played a major role on the subsidy allocation having a positive effect on the distribution of economic biofuel subsidies, and hence on the success of the policy promotion strategy. Those households have a better capacity to maintain their plantations in a healthy state and to cope with the delays of the subsidy payment.

Although economic subsidies have been traditionally considered as instruments to minimise the risk associated with new technologies and to boost early adoption, at our study site, they did not incentivize risk-averse farmers. Therefore, promotion strategies should be carefully planned. These strategies should take actions to allow the poorest farmers, which cannot afford risk, to access incentives. Valdés-Rodríguez et al. (2014) proposed the establishment of intercrop systems to increase income during the first plantation years, which may reduce the uncertainties related to the production system. These strategies must consider a detailed extension plan as well as an exhaustive and appropriate communication strategy to target isolated communities to ensure the spread of the innovation.

Additionally, the access and requirements to obtain this subsidy should be assessed to allow poorer, risk-averse farmers from marginal communities to benefit. Policy makers should also ensure the continuity of the activity promoted as a strategy to prevent farmers, who risked participating in the programmes, from being reluctant to participate in subsequent programmes, thus increasing mistrust in public institutions.

Other types of incentives may be provided to the processing and commercial sectors, as a mutual agreement between energy suppliers and buyers proposed by Mola-Yudego et al. (2014). This contract could contribute to the reduction of the uncertainties related to the crop motivating adoption among the poorest, risk-averse farmers. In this agreement (Mola-Yudego and Pelkonen, 2011), the buyers would have the obligation to buy the produce at the market price and the farmer would be expected to sell all produce to them.

However, the strongest determinant in encouraging the adoption of jatropha in the long term is the profitability of the crop. In Mexico, reliable cost–benefit analyses do not exist, yield is still limited, the valorisation of by-products is missing and, according to Valdés-Rodríguez et al. (2014) a national biofuel market is still lacking.

5. Conclusions

This study analyses the promotion and adoption process of jatropha cultivation through different approaches and scales using a combination of quantitative and qualitative methodologies. It also provides tools for energy researchers and governments to assess whether future subsidies for other biofuels or other emerging species reach the targeted population and demonstrates the possible contradictions in policy applications.

Jatropha subsidy allocation in Mexico is influenced by both extension agent preferences and community and households socioeconomic characteristics. Although the Mexican Biofuel promotion policy has a pro-poor approach, aiming at reducing poverty and marginalisation, it does not achieve its goals. The manner in which ProArbol criteria are defined, as well as the way that the extension strategy is implemented has an effect on farmer adoption excluding poor and marginalised farmers from the subsidy. However, those poor farmers that were excluded from the subsidy, and from jatropha cultivation, may have been prevented from engaging an innovation of uncertain returns. Further research on the economic profitability of jatropha cultivation under Chiapas conditions needs to be assessed to identify whether policy incentives should be encouraged or removed.

If the economic assessment is positive, increasing the repercussions of energy policy programmes and their economic incentive, efforts can be made in the development of well-adapted promotion strategies. These strategies should also take action to allow the poorest farmers, who cannot afford risk, to access the subsidy. They should also avoid raising farmer expectations when the profitability of the crop is unproven.

The quantitative tools used to analyse the allocation of policy incentives can provide a deeper understanding of the accomplishment of energy promotion programme goals, thus helping policy makers monitor and evaluate their results.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2014.12.028.

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