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Large-scale biofuel production and food security of smallholders: Evidence for Jatropha in Madagascar

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Abstract:

Large-scale agricultural investment in land was found to lead to positive employment and poverty reduction effects, however depending on the institutional context and the type of investment. This article aims to provide insights into the relationship between wage work for a large-scale Jatropha project and household food security, namely dietary diversity and food shortage. After the initial hype and the subsequent downfall of Jatropha, new projects are still being undertaken, yet little evidence in quantifying the long-term impacts of large-scale Jatropha production on smallholders' livelihoods exists. This article contributes to addressing this gap by using five rounds of panel data collected from 2008 to 2013 from 390 randomly selected households near a Jatropha project in Madagascar. Results show that labour demand declined substantially after the build-up phase and incomes from wage work were mostly used for food and other necessities. Impacts are estimated with the help of fixed effects models. Jatropha wage work contributed significantly to improved dietary diversity but not to a reduction of food shortage. Food production and consumption furthermore were highly influenced by seasonality, drought and locust plagues, which implies that complementing income creation with agricultural development strategies might have further positive effects on food security.

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1 Introduction

*Jatropha*¹ as biofuel feedstock has been used in the view of fossil fuel shortage and high prices already during the second world war (Foidl et al., 1996; Heller, 1996; Jones & Miller, 1992; Nielsen et al., 2013). Hopes were high in the early 2000s, when *Jatropha* was promoted as a means to utilize otherwise unused or degraded land and hence to reduce the competition between fuel and food production and environmental impacts (Francis et al., 2005; Renner, 2007). Drivers of investments into biofuels have been economic incentives in industrialized countries, which in turn increased attention and hence enhanced promotion and investments (Achten et al., 2014). Despite many failed projects, *Jatropha* production is still being promoted and new projects are still undertaken (Nielsen et al., 2013; Wahl et al., 2013). In 2016, *Jatropha* was still found to be the second most important agrofuel crop in large-scale land investments after oil palm and before sugar cane, however losing importance (Nolte et al., 2016).

Analysis based on cross-sectional data find mostly positive socio-economic benefits of *Jatropha* production on livelihoods, wellbeing, and food security (Peters, 2009; Schut & Florin, 2015; Thornhill et al., 2016). Yet, these studies do not control for selection bias and omitted variable bias. Some studies construct baselines through recall questions (Portale, 2012; Timko et al., 2014). Exceptions are also Negash and Swinnen (2013) who used a two-stage model to explain the food security impacts of castor production and Herrmann et al. (2017) who used propensity score matching and endogenous switching regressions to look at impacts of sugarcane outgrower schemes on food production. Moreover, the time of the impact assessment is likely to be relevant, as labour demand is significantly higher in the set-up phase and revenues from oil production occur only several years after the first plantation or are heavily subsidized in the first years (see e.g. Acheampong & Campion, 2014).

We therefore try to contribute to filling this knowledge gap by making use of an extensive panel data set collected from 2008 – 2013 from 390 households in three villages in the vicinity of a large-scale *Jatropha* project. By using panel data, different from the majority of socio-economic studies conducted on *Jatropha*, we controlled for selection and omitted variable bias, and test the sustainability of the formerly shown positive effects on income and living standard of the households. The main objective of this study is to provide insights into the relationship between employment for the *Jatropha* project and household food security, controlling for households socio-economic characteristics, seasonality and climatic shocks.

2 Material and methods

2.1 Conceptual framework

The socio-economic impacts of biofuel production have been widely studied. Mirzabaev et al. (2015) provide a conceptual framework for analysing synergies and trade-offs of bioenergy production, considering a food-energy-water nexus perspective. Other approaches have focused more on drivers of investment, policy processes and issues of land and social justice (e.g. Borras Jr et al., 2010; Venghaus & Selbmann, 2014). Jongschaap et al. (2007) have suggested the Sustainable Livelihoods Framework to assess the effects of biofuel production to smallholder

¹ The species *Jatropha curcas* L., a drought-tolerant shrub or small tree, produces oil-containing seeds (Jongschaap et al., 2007)

farmers. In this framework, food security considered as one of the outcomes of livelihood strategies, next to income, wellbeing, reduced vulnerability and a more sustainable resource base. Although not specifically intended in the project design phase, income earning on the Jatropha plantation and improved access to food is the main pathway by which the project affects livelihoods. Households reported to have spent majority of Jatropha incomes on food. This might lead to increased intake of nutritious food and therefore to an improved nutritional status (UNICEF, 1990).

2.2 Data

This study is based on primary data collected from households living in the vicinity of a Jatropha plantation project in Madagascar, operating since 2007. To assess the project's impact on surrounding communities, interviews with relevant stakeholders, like the project management, farmers, traders, and local government as well as semi-structured focus-group interviews were conducted in four villages in five survey rounds from 2008 to 2013.

The dataset contains 390 randomly selected households in three villages in 2008, representing the majority of households working for the Jatropha plantation (Jatropha households hereafter) and the majority of people living within 10 km radius from the original project site (Grass & Zeller, 2011). Table 1 shows the total number of households in the sample, the number of Jatropha households and households for whom dietary diversity variables and panel data were available for each survey year. In 2008 and 2009, dietary diversity was only captured for a random subsample, the sample of 2009 included newly migrated households to the area, but not all households from 2008 were covered. Due to the new and high employment demand on the Jatropha plantation, substantial immigration to the study area was observed until 2010. In 2010, the sample had been reduced by 25% due to logistical constraints. Moreover, death and migration, relocation of teachers and members of the gendarmerie, and unwillingness to respond led to attrition. This significant attrition can lead to an attrition bias, i.e. an unrepresentative sample. Therefore in table 7 variable means for cross-sectional data and panel data available up to 2013 are compared, showing only slight differences between them (see Glewwe & Kassouf, 2012).

Table 1: Number of households in the household survey from 2008 to 2013

Household survey year	Total number of households	Number (%) of Jatropha households	Number of households with dietary diversity variables	Household with panel data from 2008 to current year
2008	735	391 (53.2)	362	735
2009	613	303 (49.4)	287	569
2010	473	195 (41.2)	472	397
2012	418	140 (33.5)	418	352
2013	390	76 (19.5)	390	332

Source: Household surveys 2008 – 2013

Lack of food is measured for 30 days and 12 months prior to the interview, based on the question if there were days/months in the reference period, in which the household did not have enough food to meet the family's needs (Bilinsky & Swindale, 2010). Dostie et al. (2002) described a significant reduction in household food consumption

during the lean period in Madagascar. Therefore, to capture seasonal differences, the surveys have been carried out in two different seasons (2008 and 2012 in the rainy season, 2009, 2010 and 2013 in the dry season)

Next to food shortage in the lean season, the most prevailing problem in the region was low dietary diversity. We therefore include dietary diversity as indicator of a household's food security. We use dietary diversity for 7 days prior to the interview combined with the relative nutritional importance of the different food groups based on World Food Program methodology (Wiesmann et al., 2009). Data on consumption frequency is not available for all rounds of the survey; therefore, we use a dummy for consumption in the last 7 days instead of frequency. Equation 1 below shows the model specification

$$\text{Dietary diversity} = \alpha_{\text{staples}}d_{\text{staples}} + \alpha_{\text{pulses}}d_{\text{pulses}} + \alpha_{\text{vegetables}}d_{\text{vegetables}} + \alpha_{\text{fruits}}d_{\text{fruits}} + \alpha_{\text{meatfish}}d_{\text{meatfish}} + \alpha_{\text{sugar}}d_{\text{sugar}} + \alpha_{\text{dairy}}d_{\text{dairy}} + \alpha_{\text{oil}}d_{\text{oil}} \quad (1)$$

where α is the weight of each food group and d a dummy for consumption of the respective food group in the last 7 days, resulting in a minimum value of 1 and a maximum value of 16. Weights of the different food groups are shown in table 8. We also estimated a dietary diversity indicator with the same eight food groups without weights and a household dietary diversity score (HDDS) with 12 food groups (for staples distinguishing between cereals and roots / tubers, and for animal products between meat, fish / seafood, and including miscellaneous). Household dietary diversity was proved to be a valid proxy of household access to food, and a promising measurement of monitoring changes and impacts (Hoddinott & Yohannes, 2002). More specifically for Madagascar, dietary diversity has been shown to be a good predictor of children's micronutrient consumption (Moursi et al., 2008). Regarding cross-sectional and intertemporal validity and nutritional relevance, dietary diversity performed best compared to food expenditures, poverty and subjective indicators (Headey & Ecker, 2013). Although the inclusion of sugar, fats and oils weakens the correlation of dietary diversity scores with micronutrients, it has been validated as an indicator for household access to food (Leroy et al., 2015).

Additionally, we test the Food Consumption Score with frequencies (FCS) and the Household Food Insecurity Access Scale (HFIAS), which we are able to estimate for the year 2013. The HFIAS score is a continuous measure of the degree of food access in the household in the past 30 days. It has shown to be associated with determinants and consequences of food security (Leroy et al., 2015).

As indicator for Jatropha plantation work, we use the number of Jatropha household members working for the Jatropha project in the reference periods. Jatropha operations started in 2007; first wage work was demanded end of 2007. Additionally, we measure changes in living standards of households. In 2013, households were asked if their living standard has changed since the Jatropha plantation has been installed in 2007. Households were asked to point out the change on a scale from - 5 to 5; -5 meaning a drastic negative change in living standard, 5 representing a significant positive change, 0 standing for no change in living standard.

The first household survey captures the period from February 2008 to February 2009, i.e. no baseline data is available. Furthermore, all households were aware of the possibility to work as daily labourers at the plantation and were allowed to work they come to the site in the mornings. Therefore, this study has to deal with a selection bias consisting of the fact that households differ in socio-economic characteristics which influence their decision to work for the plantation or not. Households who decided to work might have had different outcomes than the control group even in the absence of the employment possibility.

Former studies have shown that Jatropha households have less land, agricultural equipment, cattle and off-farm income sources (Bosch & Zeller, 2013; Buenner, 2009; Grass & Zeller, 2011). Given the daily wage, which is equivalent to the wage for an unskilled agricultural worker, poorer households self-selected themselves into plantation work. In particular, those poorer households benefitted from wage work for the Jatropha project, by increasing their low income significantly. The two latter articles showed no significant or an ambiguous impact of employment on food security and dietary diversity, which could be due to methodological problems. Moreover, the impact on dietary diversity was mediated through a higher crop production diversity and through the market, and therefore might have materialized only over time. This study addresses these shortcomings with an extensive data set, allowing the application of a fixed effects model. Besides the comparison between households, households serve as their own controls. Further benefits of panel data are an improved efficiency of econometric estimates by increasing data points and degrees of freedom and therefore reducing the problem of multicollinearity and controlling for omitted variable bias (Hsiao, 2014). Equation 2 shows our panel data model.

$$FS_{it} = \beta X_{it} + \alpha_i + u_{it} \quad (2)$$

where FS it is the dependent variable observed for household i at time t , here different indicators for food security, X_{it} is a vector of explanatory variables for household i at time t , including the main variable of interest, the number of household members working for the Jatropha project, β is a vector of coefficients controlling for the propensity of Jatropha work, α_i denotes unobserved household specific effects, which in a fixed effects model are assumed to be invariant over time and vary across household i , and u_{it} is the error term. We use all observations for which at least two data points are available.

3 Results

Among the most mentioned benefits for households were the additional income source and the resulting higher living standard for workers, reforestation and overall rural development. Larger farmers, newly established businesses and sellers of agricultural products benefited from a higher purchasing power and improved security in the region. As the plantation was established on land that was very extensively used for cattle grazing, opportunity costs of land are assumed negligible. Discourses were mostly positive up to 2010; villagers were proud of the Jatropha project and considered it as a unique opportunity for development to be supported.

3.1 Employment

Table 2 shows the employment for the Jatropha project by village. During the labour-intensive planting phase from 2008 to 2010, workers were paid mostly on piecework and especially man could earn up to 10,000 *ariary*² a day. Supervisors, whose task was to train workers and control piecework, were responsible for a group of up to 50 workers were compensated with a monthly salary. For other tasks, e.g. applying cow dung and pruning, a daily wage of 3,000 *ariary* was paid. A political crisis in 2009 and a consequent economic recession led to an increase in poverty and inequality in the country, salaries for public employees were paid late or insufficient. Therefore, the Jatropha project also attracted workers from other communities. Until 2010, transport existed to the plantation site. In 2010, after having planted 1,000 ha, the management moved to a new site, around 12 km from village 1.8

² The official yearly exchange rate from Malagasy Ariary (MGA) to Euro (EUR) in 2013 was 1 EUR = 2,945 MGA.

km from Village 3 and 20 km from village 2. Transport and further plantation of Jatropha was stopped, and labour demand decreased considerably. In 2012, almost all of the newly migrated households had left again. For the Jatropha harvest not enough workers were found and daily wage was increased to 3.500 *ariary*.

Table 2 Employment for the Jatropha project (%), by village

	2008	2009	2010	2012	2013	Average years/HH
Village1	0.52	0.70	0.43	0.30	0.14	2.03
Village2	0.04	0.19	0.24	0.06	0	0.72
Village3	0.85	0.82	0.55	0.80	0.63	3.63
Total	0.45	0.60	0.41	0.34	0.20	2.00
Number of observations	735	709	474	418	390	390

Source: Household surveys (2008-2013)

Personal interviews with former supervisors showed that wage work in the region is seen as an inferior livelihood strategy. During focus group discussions, farmers reported that they prefer working on their own fields and sell part of their harvest, but that in drought years or when money for inputs is needed, the off-farm income source is appreciated. In 2013, 50% of the households reported to have taken up an off-farm employment during the last drought year and 70% said they would search an off-farm income source during future droughts. According to discussions with team leaders working on the Jatropha plantation, richer households who have not worked before for the plantation, decided to work to compensate for the harvest losses.

In 2014, Jatropha oil was still produced on a trial basis and wages were still pre-financed by the German investors. Due to agronomic and financial problems, only 1000 ha of the 3000 ha acquired had been planted and only 400 ha were intensively cultivated. Villagers were aware of the financial and production problems, but were also recruited for construction works, like a small hydroelectric power station and intercropping Jatropha with legumes. Cow dung applied by wageworkers on Jatropha fields is provided by cattle owners in exchange for cash or housing material. Employment is not monitored by the investor, therefore no figures on total employment and wage expenditures are available.

3.2 Living standards

Table 3 shows mean Jatropha incomes over time. Very few households rely on the plantation as a regular income source, which in the villages further apart might be explained with the time-consuming transport to the plantation site, the manual labour, and the wage that does not allow big investments or a significant change in living standard. Villagers decide to work if urgent money needs arise or if the weather does not allow for sufficient agricultural production.

Table 3 Mean Jatropha income, by village, per capita/month, 1.000 *ariary*

	2008	2009	2010	2012	2013
Village1	10.14 (14.0)	8.45 (12.3)	8.55 (9.4)	4.86 (10.7)	9.74 (18.7)

Village2	2.57 (3.1)	1.73 (1.4)	4.8 (2.7)	0.88 (0.6)	0
Village3	17.05 (16.0)	6.87 (6.5)	8.2 (6.9)	5.17 (6.2)	4.61 (6.2)
Total	11.83 (14.8)	7.77 (10.7)	7.95 (8.1)	4.83 (8.7)	6.63 (12.9)
Number of observations	391	303	195	140	76

Source: Household surveys (2008-2013)

Table 4 shows outcome and explaining variables, for agricultural production and other income sources. Only few household reported a reduction in their agricultural production due to the time spent on the Jatropha plantation up to 2010. Yet focus group discussions in 2010 show that agriculture was neglected in the first year of Jatropha work, resulting in a decline in a decline in production and mutual help in fieldwork, where workers were compensated with a meal or a small part of the harvest. Due to lack of agricultural workers in the villages, larger farmers started paying their workers a daily wage (2000 *ariary* for cassava peeling, 3000 *ariary* for field work, 10,000 *ariary* for preparing fields with cattle and machinery). According to farmers who hire agricultural workers, the high demand for daily wage labourers led to an improvement of workers' motivation and productivity. Farmers who were not able to afford paying workers and therefore relying on mutual help found it hard to maintain agricultural production. Agricultural production in 2010 was constrained by a severe drought, leading to major harvest losses (Bosch & Zeller, 2013). Weather data are only available from 2010 on and only for the Jatropha project site; therefore, effects from Jatropha work and weather cannot be disentangled. In 2012, production of almost all important crops has increased compared to 2008. In 2013, 87% of workers reported that they or their family members have been working more hours in total or only work for the Jatropha project when there was no work in the field, which was also encouraged by the project. The only crop with falling production was cassava, which is a staple crop mostly for poorer households and in the lean season when rice stocks are depleted. It is also the most important cash crop in the region, before rice, legumes and maize, in both volume and sales. Before selling, it is peeled manually, a labour-intensive job mostly done by women. Agricultural production in the season 2012/13 was constrained by a locust infestation and a drought period prior to the rice harvest, more than 90% of households reported losses in their rice production. Almost 80% of the households classified the season 2012/13 as the worst agricultural season in the past five years (see also FAO, 2013). Due to lack of other pest control measures, farmers try to fight locusts manually, keeping them away from the rice fields with fire. Therefore, agricultural wage work was particularly high and wages increased to 4,000 *ariary*.

Households also reported that the additional income allowed them to invest in agricultural equipment, seeds and other inputs and therefore cultivate more land and more intensively. During the focus group discussions, participants stated that before the Jatropha project, due to armed cattle rustlers, households only cultivated land near the villages and returned early from fieldwork. After the project has been in place, they were able to work longer in the field. Cattle thefts have decreased, mostly because the plantation site cut the usual route of cattle rustlers and the project employed gendarmerie for the protection of the site. Due to the increased security in the region, households reported to have started to cultivate more land further away from the villages and work more hours in the fields. As control households own significantly more land they were better able to expand food production.

Households who increased their agricultural production or diversified into other income sources could benefit from a higher demand for food and other products and services. Supply of food products, especially vegetables and meat

on the market increased in both quantity and quality. As a large number of households was working for the Jatropha project from Monday to Saturday until 2010, an additional market day was introduced on Sundays. Attracted by the high purchasing power and additional food demand of households, traders from outside of the villages started selling food. As mostly women are responsible for vegetable production and not able to earn the same as men in piece-work tasks on the Jatropha plantation, they invested in vegetable production and sales.

Asking other households for food or harvest thefts - common strategies for poor and food-insecure households during the lean season – decreased, which was reported by wealthier households. Poor households reported that the willingness to give food declined, whereas more households were forced to take consumption credits with high interest from wealthier households. The number of years working for the Jatropha project is significantly correlated with more credit for food. In 2012, harvest thefts were reported again.

Table 4 Outcome and explaining variables – Variable means

	2008	2009	2010	2012	2013
HH members working for Jatropha project (number)	0.91	0.82	1.1	0.54	0.29
Total land per capita (in ha)	0.55	0.42	0.41	0.52	0.43
Cultivated land per capita (in ha)	0.19	0.16	0.16	0.25	0.20
Crop diversity (Number of crops grown)	4.4	4.7	3.8	8.0	7.4
Storeroom for agricultural products (dummy)	0.26	0.29	0.34	0.37	0.38
Agricultural equipment (dummy)	0.47	0.45	0.53	0.63	0.64
Livestock per capita (number)	1.98	1.96	2.03	2.51	2.54
Livestock sales (dummy)	0.48	0.39	0.23	0.61	0.26
Public employment (dummy)	0.04	0.03	0.04	0.06	0.06
Own Business (dummy)	0.22	0.34	0.25	0.32	0.23
Employment as agricultural labour (dummy)	0.37	0.30	0.18	0.56	0.31
Dependents (number, <10 and >65)	2.0	2.1	2.1	2.0	2.3
Labour force (number, >=10 and <=65)	3.2	3.3	3.4	4.2	4.2
Total rice production (kg)	1,331	1,430	542	1,632	944
Total cassava production (kg)	2,267	767	642	1,666	1,991
Total maize production (kg)	316	135	45	380	158
Total pulses production (kg)	143	127	14	260	91
Agricultural workers (dummy)	0.24	0.42	0.34	0.31	0.38
Mutual help (dummy)	0.28	0.83	0.85	0.86	0.82
Number of observations	735	613	473	418	390

Source: Household surveys 2008 – 2013

Subjective wealth (elicited on a scale from 1-10, where 1 is the poorest and 10 the wealthiest household in the village) is significantly and positively correlated with an increase in living standard since the installation of the plantation. Households who assess themselves as wealthier in 2013 reported less credit for food in the last 5 years and invested more, among others into agricultural equipment.

The Jatropha project is the only important employer in the region and has support from government and a foreign company. Villagers stated that they feel voiceless and powerless when local team leaders were replaced with family members in 2012, when employment and piecework wages were reduced, when promised investment in village infrastructure was stopped and payment of property and income taxes to the local government refused until sustainable income from Jatropha oil sales would be achieved. Discourses about the benefits of the Jatropha project changed over time. In 2012/13, the project was seen by some as poverty reduction strategy and jokes were made about those who were “still in need to go working for the Jatropha project”. Unrealistic expectations in the implementation phase of the project and lacking transparency about the objectives and risks involved with Jatropha production and lacking participation of the population contribute to this. One village elder stated very angrily: “I myself was a big proponent of the Jatropha project at the beginning and helped them to convince the villagers, I thought we [the commune of Fenoarivo] were saved, but now I am very disappointed, they have not kept their promises”. Some farmers who set up rice fields at a riverbank on the plantation area with the approval of the project were told in 2012 to stop cultivating these fields and were prohibited to water their cattle at the river. The local government tries to mediate in these conflicts, but has a limited power towards an internationally acting company with official land titles. The mayor repeatedly stated the importance of the investment for the commune in times of political uncertainty and additionally is helped by the project in raising concerns with the national government. Close cooperation and communication with the mayor and village elders was considered very important, local government and informal laws were always adhered to. Team leaders which were recruited in the villages had a higher education level, opinion leaders or authorities speaking in favour of the Jatropha project. Most of them still spoke in favour of the project in 2013, still viewing the project as a unique opportunity for rural development.

3.3 Food security

Table 5 show the means of the food security over the years. Dietary diversity in 2008 and 2009 is only available for a random subsample; therefore, sample sizes are shown separately. The surveys in 2008, 2010 and 2013 were done at the beginning of the lean season, between August and October; the surveys in 2009 and 2012 were carried out between January and March. Rice harvest takes place between April and May.

Table 5 Mean food security variables, all survey years

	2008	2009	2010	2012	2013
Dietary diversity (8 groups, dummy past 7 days)	5.87	6.05	6.33	7.05	5.97
Dietary diversity (8 weighted groups, dummy past 7 days)	11.28	11.39	9.99	13.60	10.07
HDDS (12 food groups, past 7 days)	7.81	8.09	9.19	9.59	8.39
HFIAS	n.a.	n.a.	n.a.	n.a.	3.7
Number of observations	362	287	472	418	390
Number of rice meals (7 days)	14.4	15.7	14.4	16.4	14.1
Number of vegetable meals (7 days)	8.8	11	14.4	16.8	11.6
Number of meat meals (7 days)	0.7	0.8	0.8	1.1	1.2
Rice stock after harvest (in kg)	726	859	371	945	751
Rice stock left at time of interview (in kg)	53	233	107	142	253
Days not enough to eat (30 days)	7.7	5.1	3.4	3.5	2.4

Months not enough to eat (12 months)	1.46	0.27	0.25	0.17	0.18
Number of observations	735	610	472	418	390

Source: Household surveys 2008 – 2013

The three different dietary diversity indicators are all highly correlated with each other. Correlation between survey rounds is much weaker, pointing to seasonal and intra-year variation. The HFIAS score is negatively and significantly correlated with all dietary diversity measures from 2010 to 2013, but not before 2010. Jatropha households have a significantly higher HFIAS score as measured in 2013, reflecting self-selection of poorer households for Jatropha wage work

Table 6 shows the estimation results from the regression models. To account for detected heteroskedasticity, robust standard errors are reported (Wooldridge, 2010). Following a Wald test, year dummies are included. Results show that employment on the Jatropha project contributes to increased dietary diversity, but not to a reduction of the more subjective lack of food. Jatropha work is a significant and negative predictor of rice stocked after harvest (model four). The same is true for land area cultivated, rice and bean production and of establishing small enterprises (results not reported). Land owned by the households and access to mutual help led to significant improvements in rice stock in all models. Even though livestock ownership was positively associated with lack of food, the result was significant only at 10% level of alpha. Crop diversity increases dietary diversity and reduces the short-term lack of food. In the rainy season, dietary diversity is significantly higher, whereas both droughts in 2009/10 and 2012/13 led to a significant decline in rice stocks, dietary diversity and short-term lack of food. Agricultural employment, *ceteris paribus*, leads to a higher dietary diversity, but increased long-term food shortage and leads to lower rice stocks. Those who engage in businesses, which are mostly small shops or trading activities at the market, have a higher dietary diversity, higher rice stocks and report less lack of food. Year dummies for lack of food show an improvement in all years, indicating higher food availability in the market, especially during the lean season. Storage possibilities contribute to a reduction in the short-term lack of food, and agricultural equipment increases dietary diversity, rice stocks and reduces long-term lack of food. Despite its importance as subsistence crop, rice production is not significant in all models. Cassava contributed to a reduction of the short-term lack of food, similar to pulses, which also increased dietary diversity.

Table 6 Estimation results of the regression models

	(1) Dietary diversity (8 food groups with weight)¹	(2) Lack of food (30 days)	(3) Lack of food (12 months)	(4) Rice stock (kg, after last harvest)
Jatropha workers (number per household)	0.227** (0.107)	-0.013 (0.273)	0.002 (0.050)	-47.82** (23.08)
Total land owned (hectare, per capita)	0.372*** (0.133)	-0.683* (0.357)	-0.202** (0.080)	162.2** (79.64)
Livestock (number, per capita)	0.308 (0.275)	0.056 (0.079)	0.028* (0.014)	16.28 (10.21)
Crop diversity (number of all crops/vegetables/fruits grown)	0.090***	-0.243***	0.001	

	(0.028)	(0.070)	(0.013)	
Storeroom for agricultural products (dummy)	-0.025	-1.260*	0.043	85.10
	(0.035)	(0.668)	(0.090)	(58.80)
Agricultural equipment (dummy)	0.812***	-1.064	-0.237*	77.07*
	(0.250)	(0.811)	(0.141)	(43.96)
Own Business (dummy)	0.494**	-2.445***	-0.064	103.2**
	(0.227)	(0.526)	(0.085)	(44.56)
Agricultural employment (dummy)	0.325*	-0.562	0.123*	-77.97***
	(0.193)	(0.407)	(0.074)	(29.53)
Labour force (number, >=10 and <=65)	0.245***	0.017	-0.007	84.39***
	(0.085)	(0.180)	(0.031)	(24.50)
Mutual help (dummy)	1.148***	-1.421**	-0.303**	170.1***
	(0.219)	(0.623)	(0.125)	(36.86)
Cassava production (tons)	-0.012	-0.038*	-0.003	
	(0.012)	(0.022)	(0.002)	
Pulses production (ton)	0.638**	-0.273**	-0.003	
	(0.247)	(0.132)	(0.014)	
Rainy season (dummy, 2008 and 2012)	1.038***	-0.023		
	(0.262)	(0.614)		
Drought year (dummy, 2010 and 2013)	-1.313***	-2.757***		-208.7***
	(0.262)	(0.612)		(58.65)
Year dummies included	no	no	yes	yes
R ² within	0.24	0.08	0.09	0.17
R ² between	0.13	0.04	0.04	0.45
R ² overall	0.20	0.08	0.08	0.34
Number of observations	1,672	1,956	1,952	2,009

Robust standard errors in brackets. *, **, *** gives significance level at the 10, 5 and 1% significance level. ¹ Results for HDDS and household dietary diversity elicited by 8 food groups without weights are not reported, since coefficients do not vary considerably in direction and magnitude. Additionally, we control for rice production and public employment in all models, coefficients are not significant and therefore not reported, but can be obtained upon request from the authors.

4 Discussion of results

Results show that the Jatropha project became an important source of employment in the study region, especially for poorer households and during off-season and drought years. Nevertheless, as labour demand decreased significantly after the labour-intensive establishment phase, very few regular jobs have been created and households were mostly using wage work to cover basic needs, only a small part was invested in agriculture or business. Those who engage in Jatropha work, similar to agricultural workers, own less land and cattle, whereas better-educated households with more land mostly invested in other income possibilities like trade of agricultural products or small enterprises. This compares to other studies, where participation in biofuel feedstock plantation wage work (Herrmann, 2017; Mogaka et al., 2014; Schut & Florin, 2015), and in large-scale food production (Van den Broeck et al., 2017) has shown to be an income strategy for asset- or land-poor households. Given above-average wages and monthly contracts, Peters (2009) found an increase in income, expenditures, and working time,

but a decrease in food production and in other cash generating, one year after establishment of a plantation in Mozambique. Portale (2012) found that participation in *Jatropha* fuel supply chains improved subjective wellbeing of outgrower farmers in Tanzania. Minten and Barrett (2008) found that mean wages do not increase during the harvest season in Madagascar. Due to high dependency ratios and limited wage work possibilities, even fully employed wage workers are found significantly below the poverty line (ibid).

Our results show that *Jatropha* work increased dietary diversity but did not reduce the more subjective lack of food. One reason might be that over the years *Jatropha* households invested less in their own agriculture. Although the *Jatropha* project promotes flexible wage work, and recommends farmers to prioritize their own farm work, yet this might hint to labour constraints for working on the own farm versus *Jatropha* work. The results show that *Jatropha* households decreased their rice production significantly over time, while at the same time demand for labour declined. The participation in mutual help arrangements for farming activities increased dietary diversity and reduced lack of food, therefore it might be a risky strategy for households to drop out of those arrangements for the preference of plantation wage work. Negash (2013) found that participation in a castor bean outgrower scheme increased farmers' food consumption and narrowed their food gap. Schut and Florin (2015) find ambiguous effects on food security, depending on the *Jatropha* production scheme and the dimension of food security analysed. In the province of Antananarivo, Minten et al. (2009) estimated a reduced lean period of 1.7 months for a group of farmers participating in contract farming, compared to 3.7 before the contract and 4.3 compared to similar farmers without contract, based on farmers own estimation.

The low explanation power for lack of food might hint to measurement problems and the importance of unobserved factors like health and food utilization. Participants of focus group discussions reported that in the lean season when food shortage and high labour requirements coincide, people are more often sick and food utilization by the body might be reduced. Moreover, the region is affected by a high rate of water-borne diseases which might further constrain food utilization (in 2013, only 26% had regular access to a well, and only 33% reported to use latrines). *Jatropha* workers are especially vulnerable to water-borne diseases as the only water source available during work times is the river. The project donated a public well in one of the villages; *Jatropha* households are significantly more likely to have access to a well, and to use a latrine.

Crop diversity led to a significantly higher dietary diversity in our study. This compares to the results of Kabunga et al. (2014), who find that a higher crop diversity, especially vegetables and fruits, contributed to a more diversified diet with higher nutritional quality. According to a meta study, household production diversity affected household dietary patterns to a varying degree, but positively in most of the circumstances (Carletto et al., 2015). Sibhatu et al. (2015) argue that the effect of crop diversity on dietary diversity diminishes, probably because foregone benefits from specialization become more relevant for farms that are already highly diversified.

Although it coincides with the lean season, where food consumption has found to be significantly reduced in Madagascar (Dostie et al., 2002), dietary diversity in the rainy season is higher in our study. One explanation for this could be that due to lack of irrigation, crop diversity has increased especially in the rainy season. Another explanation is the increasing consumption of rice, which is traditionally complemented more with vegetables, meat or legumes than cassava, which is often prepared without complements (see also Hardenbergh 1993).

Numerous studies analyse positive impacts of off-farm income or income diversification on household food and nutrition security and argue that not only investment into agricultural growth, but also into households' access to off-farm employment should be considered as a development strategy (Babatunde & Qaim, 2010; Reardon, 1997; Ruben & Van den Berg, 2001). For rural Madagascar, a strong inverse relation between wage rates and the average length of the lean period has been found (Minten & Barrett, 2008). According to Sitienei et al. (2014), participation in low-income casual work on others' farms has been found to increase off-farm income but decrease own farm productivity, suggesting a possible poverty trap, due to the need for ever more off-farm income. The creation of permanent employment possibilities is not a feasible suggestion for *Jatropha* plantations and only possible if they also engage in other activities, e.g. intercropping with food or other cash crops.

During focus group discussions, the low bargaining power of workers for better working conditions was mentioned. Minten et al. (2009) suggest that even in situations where farmers are very poor, institutions and infrastructure barely exist and with monopsonistic companies, farmers can benefit substantially with the right incentives and management systems. An ethnographic study not far from the project under study shows that smallholders could oppose the additional acquisition of land by a biofuel company. Noteworthy in this case is that major actors were rich cattle owners and local elites, who had previous experience with international investors and the help of transnational activists (Gingembre 2015). Investments in new and emerging species can have negative social effects for involved communities, e.g. not improved planting material or lacking monitoring systems, or if the investments are stopped, e.g. income losses and negative attitudes towards new projects (Achten et al., 2014; Van Eijck et al., 2014). Strengthening farmer and worker associations could help in negotiating working conditions and mitigating negative social impacts like land disputes.

Although not intended by the *Jatropha* project, an important impact pathway is through higher security, less cattle thefts, more working hours in the field and an increase in agricultural land in the study area. This is remarkable as national data suggests an increase in cattle raids since 2009 (Jütersonke & Kartas, 2011), but could not be verified with the police station, as farmers do not report cattle thefts there. Insecurity, manifested in the fear of crop theft and encounters with cattle thieves was found to hinder the expansion of cultivated acreage, and more so in land-abundant, remote and insecure locations in Madagascar (Fafchamps & Minten, 2009). Harvest thefts were reported to first have declined and then increased again, which is consistent with the results of Fafchamps and Minten (2006) that crop thefts are used as risk-coping strategy and increased significantly with an increase in poverty in central Madagascar. Livestock ownership did not contribute to higher food security in our study. Cattle are an important status symbol in the region and usually not sold to smooth consumption. Livestock owners are richer households who might also report a higher subjective lack of food.

5 Conclusion and recommendations

As shown with the help of a fixed-effects model, wage work contributes to a higher dietary diversity, but not to a reduction of the more subjective lack of food and shortening of the lean season, and to a reduction of rice stocks. To increase spillovers to agriculture, the extension service could cooperate with the *Jatropha* project using its scale and central position for the promotion of crop diversification and the demonstration of improved inputs and technologies. Furthermore, the project could use its storage possibilities and access to markets to offer collective marketing of crops or livestock. *Jatropha* oil could be tested for local use, e.g. for generators and tractors could be rented out to prepare land for food production.

Health is an important component of food and nutrition security. In the initial negotiations, it was agreed upon donations to local infrastructure like wells and schools, which was stopped by the company due to financial problems. Providing access to safe drinking water to workers during work time and contributing to awareness of water quality might increase both worker wellbeing and productivity. Instead of unregularly donations, promoting public health services or supporting the local government in regard to health infrastructure could further increase collective action and access to health.

Several studies suggest that (international) development agencies could assist in the negotiating and managing of contracts and therefore overcome power asymmetries in agricultural investments and give farmers a better negotiating position (Burnod et al., 2013; Vermeulen & Cotula, 2010). The case of *Jatropha* showed that negotiations were based on largely overestimated yields, land and labour profitability, and non-existing value chains. An environmental impact assessment including socio-economic criteria is required by the Malagasy government after the contract is signed, but does not include a mechanism to monitor projects over time. Although stated during the implementation phase that jobs were temporary, communities might have overestimated labour demand and economic potential of *Jatropha*, and the promised investment in infrastructure. Putting in place a monitoring system, which covers work incidence and employment, could improve communication with workers and farmers. Land rights could be granted for a shorter period and prolongation only given against proof of compliance with the contract.

Large-scale production of *Jatropha* oil in Madagascar for the global market is not commercially viable with the currently used planting material, but improved cultivars are developed (see Senger et al., 2016) and local marketing options are available. Furthermore, since biofuel production has positive effects on poverty reduction and food security, (different) energy crops could be incorporated in rural energy projects, in agroforestry systems, in public works programs, e.g. as wind and erosion control or as fencing plant against cattle (see e.g. Mogaka et al., 2014), and afforestation or climate mitigation projects (Venghaus & Selbmann, 2014).

Providing energy for soil preparation, rice dehusking or cooking could lead to further and important spillovers to food security, since firewood collection is time intensive and firewood becoming scarce. The *Jatropha* project helped to question some of the taboos farmers are confronted with, e.g. not to use cow dung or plant several legume species and thereby allowing spillover effects to agriculture, which could lead to higher food security through the pathway of a higher crop productivity. Moreover, it helped to create awareness about bush fires and climate change, like droughts and soil erosion partly caused by deforestation. These and other spillovers could not be addressed in this study, but would merit further investigation.

Short-term impact assessments estimated higher positive income impacts than long-term assessments, whereas direct and indirect effects on food security have shown to occur with time delay. Therefore, we conclude that the time of the impact assessment is relevant and that it is important to show long-term viability as well as possible spillovers with the help of panel data. Dietary diversity variables are a good proxy for the socio-economic status and give important insights into the pathways of off-farm income on subsistence agriculture.

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Annex

Table 7: Selected variable means for cross-sectional and panel data, 2008-2013

	2008	2009		2010		2012		2013	
	Cross- section ¹	Cross- section	Panel ²	Cross- section	Panel	Cross- section	Panel	Cross- section	Panel
Dietary diversity (8 groups with weights)	9.83	9.50	9.49	8.51	8.60	13.60	13.62	10.07	10.12
JG (number of HH members)	0.91	0.82	0.82	1.10	1.09	0.54	0.56	0.29	0.31
Land (ha, p/c)	0.40	0.32	0.32	0.30	0.30	0.43	0.43	0.38	0.35
Labour force	3.18	3.27	3.34	3.45	3.44	4.19	4.13	4.13	4.07
HH head education	3.19	3.12	3.12	3.28	3.25	3.36	3.35	3.42	3.40
HH max. education	3.83	3.85	3.87	3.95	3.93	4.17	4.13	4.25	4.21
HH head age	41.37	41.91	42.30	43.42	43.85	45.59	45.95	46.03	46.21

Source: Household surveys 2008 – 2013, ¹Mean of all households surveyed in the respective year, ²Mean of all households with panel data from 2008 to respective year.

Table 8: Food groups and respective weights used for dietary diversity

Food group	Weight	Justification
Main staples	2	Energy dense, protein content lower and poorer quality (PER* less) than legumes, micronutrients (bound by phytates).
Pulses	3	Energy dense, high amounts of protein but of lower quality (PER* less) than meats, micronutrients (inhibited by phytates), low fat.
Vegetables	1	Low energy, low protein, no fat, micronutrients.
Fruit	1	Low energy, low protein, no fat, micronutrients.
Meat + fish	4	Highest quality protein, easily absorbable micronutrients (no phytates), energy dense, fat. Even when consumed in small quantities, improvements to diet quality are large.
Milk	4	Highest quality protein, micronutrients, vitamin A, energy. However, milk could be consumed only in very small amounts and should then be treated as condiment and therefore reclassification in such cases is needed.
Sugar	0.5	Empty calories. Usually consumed in small quantities.
Oil	0.5	Energy dense but usually no other micronutrients. Usually consumed in small quantities.

*PER: Protein Efficiency Ratio, a measure of protein quality of food proteins. Source: WFP (2008)