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Energy efficiency procedures for agricultural machinery used in onion cultivation (*Allium fistulosum*) as an alternative to reduce carbon emissions under the clean development mechanism at Aquitania (Colombia).

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Abstract. Climate change has both causes and consequences over agriculture. This paper focuses on the first element and presents scenarios for ASOLAGO –an onion cropper's association in Colombia with 250 members– to reduce their carbon footprint. It evaluates a case study at "La Primavera" farm using a methodology approved by the United Nations Framework Convention on Climate Change. Land preparation and crop irrigation were analyzed as stages in order to propose energy efficiency alternatives for both the farm and the association. They include field efficiency, fuel economy and energy efficiency from biofuels for the first stage as well as solar and wind energy supply for the second. A cost-benefit analysis to generate additional income selling additional power produced by the system to the National Grid was done.

1. Introduction

This paper is the result of a research done for the most important onion (*Allium fistulosum*) farmers' association called –ASOLAGO–, located in Aquitania (Colombia). This municipality produces 75% of onion in Colombia representing 40% of the local income [1, 2].

In terms of environmental impact, Yoshikawa [3] analyzed carbon emissions related to this product through its lifecycle from extraction to final disposition. It was found a carbon footprint of 0,4 kg of CO_2 per kg of consumed onions.

The goals of this project were: i) to draw a baseline of carbon emissions at each crop stage, related to machinery use; and ii) to propose procedures using energy efficiency at selected stages.

The project was relevant to the guild, because of the lack of research on the product, and the increasing interest on two subjects: energy efficiency and clean development mechanism, at the agricultural level.

2. Methodology

The methodology used for this research was based on a deductive-descriptive analysis. It included the identification, registration and analysis of energy requirements for each step of the onion crop. As a reference, it was used the ninth version of the UNFCCC methodology "AMS II.F: Energy efficiency and fuel switching measures for agricultural facilities and activities" [1].

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2.1. Energy efficiency method selection

Two of the limitations that were considered to use this methodology were: i) geographical and physical location; and ii) total energy savings of the project are lower than 60 GWh per year. Three elements were considered to establish the baseline according to [1]: i) energy consumption should be reduced if adaptation actions are held; ii) if the energy is from fossil fuels, the baseline is equivalent to consumption for the activity; iii) it should be demonstrated the consumption of the agricultural activities, included the cultivated area and the crop performance.

This case study did not consider monitoring equipment transferred nor leaks that are present in them. Similarly, it was not applied to the same circumstances of a project activity under a program of activities specified in the methodology according to [1].

2.2. Methods used to calculate carbon emissions

In order to calculate carbon emission due to fossil fuels over the system, it was used the second version of the document provided by UNFCCC: "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion". To calculate carbon emission due to electricity consumption, it was used the first version of the document "Methodological tool to calculate project emissions from electricity consumption". It was used the emission factor for Colombia related to the National Interconnected System (SIN by its definition in Spanish) [2, 3, 4].

2.3. Methodology delimitation

Carbon emissions from soil preparation to onion yield were quantified. At "La Primavera", emissions related to energy use by agricultural machinery were calculated for soil preparation and irrigation, as shown on figure 1. Other cultural activities do not use machinery at the farm nor the association.

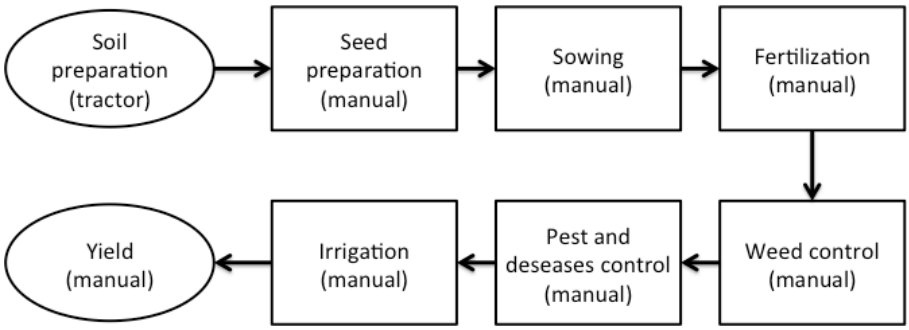

Figure 1. Onion production cycle

2.4. Other methodological considerations

One pilot survey was conducted to 25 farmers from the association to select the variables to be included on the final survey. The result was 25 variables classified into 5 categories: i) demographic information; ii) land characteristics; iii) soil preparation; iv) pests, weed and diseases control; and v) irrigation. Sampling unit for the survey was "the farmer". Sample universe correspond to 284 farmers. To determinate sample size, a 5% error continuous random variable was used, for a total of 58 farmers.

3. "La Primavera" baseline

Equation 1 was used to calculate carbon emissions at "La Primavera". Considering a cultivated area of 5.1 ha with an average of 3 harvests per year, 7.8 hours per ha for both plow and over-plow, and near 80 hours per harvest of soil preparation, carbon emissions correspond to 1.97 tCO_2/year. It was used fuel emission factor given by [5] as shown on table 1.

$$Em = FE \times H \times eff \quad (1)$$

Where,

Em	Are the total emissions in tCO_2 per year
FE	Is the energy of the fuel used in Gj
H	Is the number of harvests per year
eff	Is the emission factor of the fuel used in tons

A synthesis of the results is shown at table 1.

Table 1. Soil preparation associated emissions at La Primavera Farm

Variable		**Value**
Area (ha)		5.10
Harvests per year		3.00
Plow (h/ha)		7.80
Over plow (h/ha)		7.80
Soil preparation (h/harvest)		79.90
Diesel (gal/day)		20.00
Diesel consumption per harvest	(gal)	66.56
	(m^3)	0.25
	(kg)	209.73
Diesel energy (GJ)		8.85
Diesel emission factor (tons)		0.074
Carbon emissions per harvest (kg)		655.35
Total Carbon emissions (tCO_2/year)		1.97

Second stage –pump irrigation– used equation 2 to calculate carbon emissions. A total of 5.72 tCO_2/year are produced by this phase. Emission factor was provided by SIN. Results are shown on table 2.

$$Em = EC \times eff \quad (2)$$

Where,

Em	Are the total emissions in tCO_2 per year
EC	Electricity consumption per year in kWh
eff	Is the emission factor of the fuel used in tCO_2/kWh

The table 2 shows the results.

Table 2. Irrigation associated emissions

Variable	**Value**
Electricity consumption (kWh/month)	1,634.00
Emission factor (tCO_2/kWh)	0.29
Total carbon emissions (tCO_2/year)	5.72

Considering that just these two sources generate carbon emissions, total carbon emission was calculated by adding results from tables above. Table 3 presents the result and a 5 year and 10 year linear projection.

Table 3. Carbon emission scenarios

Term	Emissions (tCO_2)
1 year	7.69
5 years	38.45
10 years	76.90

4. ASOLAGO baseline

4.1. Characteristics of the association and its consumption patters

Results from "La Primavera" were used to forecast ASOLAGO's carbon emissions. Before showing results, it is important to highlight two characteristics of this organization: i) 8% of the owners are women and ii) 70% of the associates are over 50 years. Owners' lands have similar characteristics: 2.77 harvesting cycles per year, with 6 ha fields. 59% of the producers use tractors to do cultural activities with a 5.71 hours plow and 5.26 hours rake.

Tractors' cylinder capacity used by association members' determinate fuel consumption and therefore carbon emissions. 56% of farmers used low cylinder tractors (4,500cc or less), 44% medium machine cylinder capacity (4,500 to 9,000cc) and nobody large cylinder capacity engines (over 9,000cc).

Moreover, pest and diseases control is carried out by hand (cultural practices) and mechanized methods (motor sprayer). 29% of farmers use the second method, which is relevant to this study. Fuel consumption was estimated considering the average hours of the sprayer use; number of control activities per harvest cycle and average fuel consumption per sprayer. As a result, farmers consume 19.46 gallon of diesel per cycle.

For irrigation, farmers use water from Lake Tota and some water streams near their fields. 88% of farmers use electrical pumps, meanwhile 12% fuel pumps. For the first system, a theoretical demand of electricity was less than 3 MW, with an average use of 8.02 hours per day for irrigation during 1.5 days per week. For the second one, all fuel pumps use diesel. Three fourths of the farmers use electrical pumps with less and 47 hp. Figures 2 and 3 present a synthesis of the characteristics.

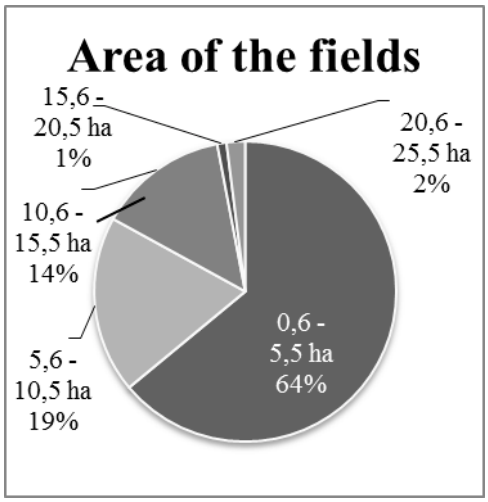

Figure 2. Field area at the association

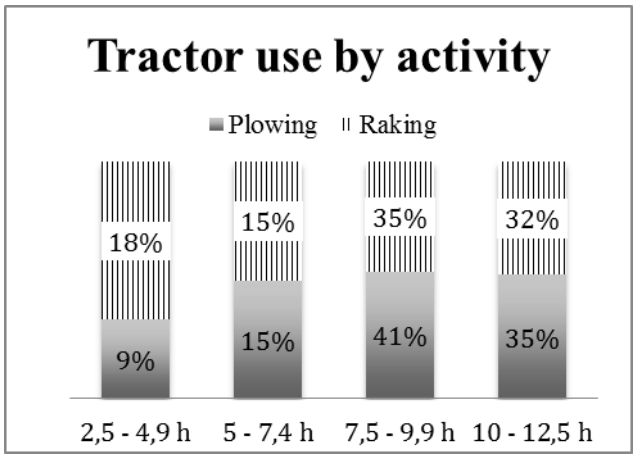

Figure 3. Tractor use by activity

4.2. ASOLAGO carbon emission

To calculate carbon emissions, information from a survey done to association was used. 88% of 250 farmers use electric pumps with an average consumption of 2,100 kWh per month. 56% of the farmers

use similar tractors as the case study ("La Primavera"), used as reference for the association consumption considering that plowing and raking activities are similar.

Fumigation stage involves mechanical sprayers. Data from the survey was used as reference. It was found that 29% of producers use this type of equipment. In consequence, to calculate carbon emissions generated 82 of 284 producers were considered. In addition 2.35 gallon per day of fuel were used for pest control. Total emissions considering three categories are 2,190 tCO_2 per year. Results are shown in table 4.

Table 4. ASOLAGO carbon emissions

Variable	**Irrigation**	**Ploughing**	**Pest control**
Fuel consumption (GJ)	0	8.85	2.36
Electricity consumption (kWh/month)	2,100	0	0
Emission factor	0.2917	74.01	69.25
Carbon emissions per harvest (tCO_2)	0.613	0.655	0.163
Carbon emissions per farmer (tCO_2)	7.35	1.97	0.49
Farmers using machinery	250	159	82
Carbon emissions per activity (tCO_2 per year)	1,837.12	312.51	40.38
Total emissions (tCO_2 per year)		2,190.01	

5. Energy efficiency procedures to improve energy efficiency

In order to present energy efficiency procedures, two elements are presented for "La Primavera" farm: soil preparation using tractor and irrigation using pumps. Using this information a forecast for the association is done.

5.1. Soil preparation procedures using tractor

Soil preparation procedures were analyzed within two scenarios: i) field efficiency and fuel saving using theoretical values in comparison with real data; and ii, biofuels as an alternative to diesel.

5.1.1 Field efficiency and fuel saving. To improve soil preparation efficiency, it was necessary to consider the field theoretical capacity (FTC) and the fuel efficiency (FE). The first one is a relation between width work tool and theoretical speed, expressed in ha/h [6]. The second element is a theoretical value that corresponds to the efficiency. For this case it was used 74-90%, according to [7]. For the second variable, it is necessary to evaluate real versus theoretical field capacity. It is expressed as a percentage. For the farm it was found an efficiency of 12,2% for plowing and 8% for raking. Table 5 presents a synthesis of the information.

Table 5. "La Primavera" field efficiency

Operation	**Plowing**	**Raking**
Speed (km/h)	6 - 8	6 - 10
Efficiency (%)	74 - 90	74 - 90
Theoretical field efficiency (ha/h)	0.13	0.13
Real field efficiency (ha7h)	1.05	1.62
Field Efficiency (%)	12.20	8.00

In order to improve efficiency from both plowing and raking, it is necessary to evaluate different alternatives. First, according to [8], consumption varies by engine speed and load. Efficiency can be increased having an optimal use of the pedal and gearbox. This can be understood as an increase of the transformation of fuel into energy and consequently will improve machine efficiency. Theoretical analysis establishes that the best scenario for a 100 hp engine is 300 – 400 rpm, which will save 1.5 – 2 liters per hour [9]. Two scenarios are derived from these values. A low consumption one with a 3.71

gallons per hour at 1,500-2,000 rpm and 67-87 hp and an optimal consumption one with 3.6 gallons per hour at 1,500 rpm and 75 hp.

Plowing activities use 6 hour of machinery, which has 22.2-gallon consumption. Raking, on the other hand, use 4 hours of machinery that represents a diesel consumption of 14.8 gallon. Total consumption is 37 gallon per cycle and 111 gallon per year, considering 3 harvests during this term. In contrast, current fuel consumption is 200 gallons per year. This represents diesel savings of 89 gallon per year, equivalent to 1.09 tCO_2. This is a reduction of 0.88 tCO_2 emissions per year considering a 1.97 tCO_2 baseline.

Other best practices that can be implemented are related to engine maintenance. It includes cleaning air filters in order to reduce fuel consumption from 10 to 15%. Another procedure is the correct use of lubricants so as to protect engine from friction, heating and wearing [10].

5.1.2 Energy efficiency using biofuels. The second scenario was to improve energy efficiency using biofuels, considering that it is not necessary to have drastic changes over the engine [11,12]. It was selected B20 biodiesel, as it is the one Colombia has established since 2007 [13]. This generates a 1.5-tCO2 carbon emissions per year due to this fuel consumption. A 0.42 tCO_2 reduction has been calculated. This represents a 21.46% of emissions. In terms of energy, and considering recommendations by [14], a recalculation of the efficiency reports a 20.3%.

5.2. Irrigation procedures using pumps

For this element two scenarios were analyzed, based on general data on solar and wind potential of Aquitania, Boyacá. No specific analyses were performed due to time limitation.

5.2.1. Solar energy supply. In Boyacá, average solar radiation is between 4.5 to 5.o kWh/m^2. Solar brightness is from 5 to 6 hours of sun per day [15]. Pick power of the photovoltaic panel is 250 W with an area of 1.69 m^2. Each panel has a cost of 550 USD. Energy consumption demand is 37.3 kWh (50 hp). Whereas the system requires 12 hours of irrigation per day, during 4 days per month, total consumption by the pump is 1,790.4 kWh/month.

The cost, considering the government subsidy of the 50% [16] is approximately 2,200 USD per year. Table 6 presents a synthesis of the main elements within 5 scenarios of solar panels to cover 25%, 50%, 75% and 100% of the energy demand for the farm.

Table 6. Solar energy supply for irrigation at the farm

	Scenarios				
Element	**100%**	**75%**	**50%**	**25%**	**0%**
Energy generation (kWh/month)	13,428	10,071	6,714	3,357	0
Number of panels	504	378	252	126	0
Area (m^2)	298.0	223.5	149.0	74.5	0.0
Cost of panels (USD)	161,416.7	121,062.5	80,708.3	40,354.2	0.0
Financial profit	15,277.8	11,458.3	7,638.9	3,819.4	0.0
Electrical consumption (kWh/month)	0.0	447.6	895.2	1342.8	1,790.4
Carbon emission reduction (tCO_2)	5.72	4.29	2.86	1.43	0.00
Carbon emissions (tCO_2 / year)	0.00	1.43	2.86	4.29	5.72

The best scenario –100% of energy supply using solar panels– generates a 16,000 USD profit per year with a 9.3 year return of the investment (ROI) with 160,000 USD initial investment. This value is very high for one farmer. Another element to consider was required area, which correspond to 298 m^2. This was the reason to determinate a scenario for the whole association, which will be presented in the numeral 5.3.

5.2.2. Wind energy supply. Second scenario analyzed was to supply energy demand with wind energy. Here was important to consider local characteristics in order to design a system. To begin, wind speed in Boyaca is 3.1 m/s. Horizontal wind generator of 3.3 kWh with a low cost per Watt and a 20 years

life cycle was used for calculations. Estimated cost was 6,555 USD per generator. Finally, potential generation is 117 kWh per generator in the farm [17, 18]. A synthesis of the results is shown in table 7.

The best scenario, 100% of energy supply using wind energy generators has a ROI of 47 years, and requires a 460 m^2 area for the project. 115 generators would be needed, creating problems such as landscape, noise and others, related to wind parks. This scenario is not attractive to the investors (local farmers) due to high costs.

Table 7. Wind energy supply for irrigation at the farm

	Installation scenarios				
Element	100%	75%	50%	25%	0%
Energy generation (kWh/month)	13,428	10,071	6,714	3,357	0
Number of generators	115	86	58	29	0.0
Area (m^2)	460.0	345.0	230.0	115.0	0.0
Cost of generators (USD)	752,376.1	564,282.1	376,188.0	188,094.0	0.0
Financial profit	15,254.6	11,440.9	7,627.3	3,813.6	0.0
Electrical consumption (kWh/month)	0.0	447.6	895.2	1,342.8	1,790.4
Carbon emission reduction (tCO_2)	5.72	4.29	2.86	1.43	0.00
Carbon emissions (tCO_2 / year)	0.00	1.43	2.86	4.29	5.72

5.3. Forecast for the association

A forecast was calculated for the association, taking into account variables of the local context. The first one was project design using 89% of the current associates, considering they use electrical pumps for irrigation. A synthesis is presented on tables 8 and 9.

Table 8. Solar energy supply for irrigation at the association

	Installation scenarios				
Element	**100%**	**75%**	**50%**	**25%**	**0%**
Energy generation (kWh/month)	3,021,300	2,265,975	1,132,988	283,247	-
Number of panels	67,140	50,355	25,178	6,294	-
Area (m^2)	113,467	85,100	42,550	10,638	-
Cost of Panels (USD)	36,367,500	27,275,625	13,637,813	3,409,453	-
Financial profit	3,430,957	2,573,218	1,286,609	321,652	-
Electrical consumption (kWh/month)	0.0	447.6	895.2	1,342.80	1,790.40
Carbon emission reduction (tCO_2)	1,837	1,378	919	459	-
Carbon emissions (tCO_2 / year)	0.00	459.28	918.56	1,377.84	1,837.12

Table 9. Wind energy supply for irrigation at the association

	Installation scenarios				
Element	**100%**	**75%**	**50%**	**25%**	**0%**
Energy generation (kWh/month)	3,021,300	2,265,975	1,510,650	755,325	-
Number of generators	25,823	19,367	12,912	6,456	-
Area (m^2)	103,292	77,469	51,646	25,823	-
Cost of generators (USD)	169,284,615	126,963,462	84,642,308	42,321,154	-
Financial profit	3,430,957	2,573,218	1,715,479	857,739	-
Electrical consumption (kWh/month)	0.00	447.60	895.20	1,342.80	1,790.40
Carbon emission reduction (tCO_2)	1,837	1,378	919	459	-
Carbon emissions (tCO_2 / year)	0.00	459.28	918.56	1,377.84	1,837.12

6. Conclusions

In conclusion, the AMS II.F methodology gave a first approach to calculate greenhouse gas (GHG) emissions to the project. However, if it is wanted to do a total balance of emissions in the cultivation of onions, this instrument does not allow carrying out this objective, which limits their use for future initiatives in the estimation of emissions.

The most relevant procedure for soil preparation at the farm is to change the fuel. This alternative does not imply additional investment and improves by 44.6% efficiency. For irrigation, solar energy is an environmental attractive alternative. However installation costs are very high for a single farmer. Initiatives like this must be accompanied of external investors (banks, multilateral funds, etc.). This could be reinforced with other alternatives such a clean development mechanism strategy. In order to improve this, it is important to prepare a project from the association.

Finally, project implementation related to alternative energies must evaluate financial dimension. This, because they require a very significant initial investment and such projects are very difficult to finance in contexts like small farmers at Colombia. On the other hand, to implement this kind of initiatives would benefit sectors like agriculture, which produce GHG at a local level. They could be part of the national inventories, which would give local governments the place at the agenda to attend cleaner production mechanisms and low carbon economies.

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