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Life Cycle Analysis of Carbon for Palm Oil in Colombia

Celso-Antonio Vargas-Gómez

Universidad Pedagógica y Tecnológica de Colombia,
Duitama Branch .
COLOMBIA.

Correo electrónico: celso.vargas@uptc.edu.co
cavargasgo@gmail.com

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1. Abstract

The present paper aims at contributing to the study of the oil palm, from the point of view of CO_2 produced and captured from the harvesting to the production of the Crude Palm Oil, CPO having in mind that it will be the raw material for the production of biodiesel in Colombia. To carry out this study, the "LIFECYCLE ASSESSMENT (ALC)" (Life Cycle Analysis), methodology was used, NTC - ISO 14040, 14041 and 14042 standards and one ton of the CPO was taken as bases for it. The information had a secondary.

Character because it was originated on data from the countries that, Currently are the largest producers of palm oil in the world such as Malaysia, Indonesia, Thailand and of course Colombia. The results show that from the harvesting to the production of the Oil there is a positive balance of 5.43 t of CO_2 per each ton of CPO, and the aspects that most impact the balance are: soil respiration, with a 65.72%; the CO_2 produced by vegetal waste, 15.6%; the CO_2 emitted in the plants of effluents treatment, 7.8%; the CO_2 produced in the boilers of steam production, 7.1%; the production of fertilisers, 1.5%; and the CO_2 equivalent of the methane produced in the plants of effluents treatment, 1,36%.

Key words: oil, palm oil, CO_2, life cycle, energy, palm, oil palm.

2. Resumen

Con el presente trabajo se pretende hacer un aporte al estudio de la palma de aceite, desde el punto de vista del CO_2 producido y capturado desde el cultivo hasta la producción del aceite crudo de palma (ACP), teniendo en cuenta que en Colombia será la materia prima para la producción del biodiesel. Para realizar el estudio se utilizó la metodología del ANÁLISIS DEL CICLO DE VIDA (ACV), Normas NTC -ISO 14040, 14041 y 14042 tomando como base una tonelada de ACP. La información fue de carácter secundario proveniente de países que actualmente son los mayores productores de aceite de palma en el mundo como es el caso de Malasia, Indonesia, Tailandia y por supuesto Colombia.

Los resultados muestran que desde el cultivo hasta la producción del aceite, se tiene un balance positivo de 5,43 *t* de CO_2 por cada tonelada de ACP y que los aspectos que mas impactan al balance son: la respiración de los suelos con un 65,72%, el CO_2 producido por los residuos vegetales 15,6%, el CO_2 emitido en las plantas de tratamiento de efluentes 7,8%, el CO_2 producido en las calderas de producción de vapor 7,1%, lo mismo que la producción de los fertilizantes 1,5% y el CO_2 equivalente del metano producido en las plantas de tratamiento de los efluentes 1,36%.

Palabras clave: aceite, aceite de palmal, CO_2, ciclo de vida, energía, palma.

3. Introduction

The industrial revolution that began two centuries ago is primarily an energy revolution that first incorporates to the system the fossil energy and afterward the nuclear energy. The fossil energy is not other one than the solar energy accumulated by plants and buried at the bottom of the earth millions of years ago where has slowly become coal and petroleum (Angel 1995). This paper addresses the issue of the crisis in fossil fuels at international level, emphasizing on the depletion of reserves due to high consumptions in recent times. The necessity of exploring new alternatives to replace the derivates of petroleum now used in internal combustion engines is increasing, being the biofuels the closest alternative.

To start this section, quotations were taken from a teleconference given by Dr. Roberto Bermejo from The University of the Basque Country, in November 2005. Where an analysis about the world energy aspects was addressed "phenomena begin to occur in the world which are forcing

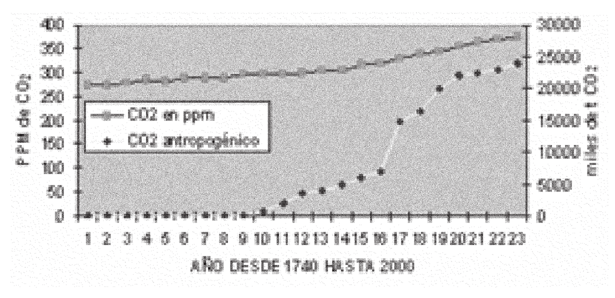

Fig. 1. Increment of CO_2 in the atmosphere since the Industrial*.

rapid changes maybe in not quiet circumstances and among chaos, conflicts, tensions and wars. Climate change, for example, will be increasingly acute; But there is another more dramatic phenomenon which is the end of the cheap oil era , which causes a change in the energy model of the world", it is also stated that " energy determines the society development and its collapse as well" such a statement, corroborated by numbers, is of general concern. "The largest oil fields in the world were found between 1940 and 1970 and today one of each six barrels consumed is new, the rest are reserves; besides, during the 50s 30.000 million barrels were discovered and 4000 million consumed. Today 4000 million barrels are discovered and 32.000 million consumed" In this scenario it can be said that although oil is still there for many years, it will be available at very high prices, which will wide the gap between rich and poor countries, with consequent social unrest.

Furthermore, due to the uncontrolled consumption of fossil fuels in the whole world, and especially since the industrial revolution, the so-called greenhouse gases have increased, the CO_2 among them, which will cause a rise in the global temperature over 4 °C and up to 15 °C in some parts of the earth during the period 2000-2100 (*Atlas Le monde,* 2003). Therefore, it is necessary to implement policies and technologies aimed at reducing the consumption of fossil fuels. If bearing in mind that the per capita consumption of energy is proportional to the technological development, in the future, the average world consumption will be expected to exceed the 1671 kg of oil equivalent per capita; this added to the growing of the world population will consume near 50% more than the current in 50 years. It is also important to emphasize the fact that the petroleum and natural gas reserves are concentrated in few countries focusing the attention of the the major world powers as a result, the map of reserves coincides with the map of the main armed worldwide conflicts. This supports Dr. Bermejo's thesis in the sense that energy will cause wars and destruction in a no far future.

Moreover, the increment of CO_2 concentration in the atmosphere, since the industrial revolution until today is worrying due to the consequences that this aspect implies. Figure 1 shows evidence to support this argument.

It is necessary then to have a close study in terms of CO_2 balance when a biofuel program is attempted to be implemented in most countries of the world.

4. Methodology

The methodology to be followed in this work is related to ISO 14040, 14041, 14042 standards and those dealing with the lifecycle of products or services.

4.1. Life Cycle Anaysis (LCA)

In 1997, the ISO 14040 standard included the definition of LCA as, "a technique for assessing the environmental aspects and the impact potentials associated with a product through:

- An inventory of relevant inputs and outputs of a system.
- The assessment of potential environmental impacts associated with those inputs and outputs.
- The interpretation of results of the phases of analysis and assessment of impact in agreement with the objectives of the study "(NTC-ISO 14040).

This definition suggests that the LCA is a tool that can be used to evaluate the environmental burdens associated with a product, process or activity across its life cycle, (N Anneliese, 2006). Therefore, for a certain activity, the problem is not just confined to the manufacturing plant, but it is also necessary to establish the contribution in pollution from all the pre and post activities originated by the product.

The proposed methodology has its origins in the concept of sustainability, which first appeared in the document our common future or Brundtland report (WCED, 1987) which addresses the three dimensions of development, which are defined as follows:

- Environmental sustainability must ensure that development is compatible with the maintenance of essential ecological processes and biological diversity of natural resources.
- The social and cultural sustainability must ensure that sustainable development increase the control of individuals

*Source: Own design based on: M Trachtenberg, removing CO_2 from the source, Department of Energy. USA, 2006.

over their lives, be compatible with the culture and values of individuals and maintain and reinforce the identity of communities.

- Economic sustainability must ensure that development is economically efficient benefiting all agents from the affected region and that the resources are managed so as to preserve for future generations.

The way towards sustainable development requires changing our patterns of activity, pursuing the reduction of levels of materials and energy consumption and a decrease in the associated environmental impact.

In these terms, several environmental management tools have been developed through different procedures, looking for a reduction in the environmental impacts associated with the products, processes or services. Thus, if the objective is to identify the environmental burdens related with a factory whose technology is located in a given area and the implementation of a environmental policy in the company, the required tool for such analysis are the Environmental Management Systems (EMS): standard ISO 14001 (Clements 1997) and EMAS regulation. But if the goal is to define the best location for a technology, the best route for a highway for example, the Environmental Impact Studies (EIS) are more suitable (Costa, GF2007). On the contrary, if for the reduction of wastes, the best available technologies are implemented, the principles of clean production will be applied this under the perspective of prevention and control of pollution (IPPC) (Costa, GF2007). The concept of Industrial Ecology (IE) represents an integrated view of the environmental impact of industrial systems, where an industrial plant is not analyzed in isolation but as part of a set, as part of a system, similar to a species studied by ecologists as part of an ecosystem (Costa, GF2007). This tool has a special interest in the study of industrial centers, in such a way that synergies between different companies are established; for example, when designing a plant of treatment wastes, which uses a minimum of energy consumption in the reduction of the emissions o the industrial center.

However, it is sometimes necessary to consider the full lifecycle, in its temporal dimension, of a product or service, compared with a more focused perspective on the control of emission sources. This lifecycle philosophy, also known as the "from cradle to grave" approach, states that all phases involved in the lifecycle of a product or service, have a responsibility for the environmental consequences of it itself and, therefore a role to play (Costa, GF2007).

The methodology of Life Cycle Analysis (LCA) is the tool for wider use when considering the environmental impacts in a systematic way across the lifecycle of a product or service. The LCA estimates in a general way the potential impact of all emissions from the system under study regardless of whether these emissions are below the allowable threshold or above it; this can be understood as a preventive measure. Furthermore, the study is carried out from different perspectives :(Rodriguez, M. 2005). The complete life cycle of the product, analyzing both the previous and post stages to the manufacture.

- Consumption of non-renewable energy resources.
- Emissions, considering environmental rates according to their ecological scope.

According to the above guidelines, the LCA is divided into four phases, which will be addressed taking as a guide the Standard NTC-ISO 14040 Section 4.2.

1. Objectives and Scope.
2. Inventory Analysis.
3. Impact assessment.
4. Interpretation of results.

4.2. Methodology description

4.2.1 Objectives and scope

It will be developed based on NTC-ISO 14040, Section 5.1 and ISO-14041 NTC Section 5.

In the LCA objectives and scope definition, an exact definition of the issue to be addressed, the scope and depth of the study are included; to determine the purposes of the results. This phase includes a definition of the system or systems to be studied along with its limits. It also includes the information needs, the starting hypothesis and the level of detail to be addressed. Everything has to be compatible with the objective and aspects such as geographical environment, temporal aspect and variability estimation of data that can be accepted for the accurate achievement of the study, should be considered.

4.2.2. Inventory Analysis

This analysis will be developed based on the NTC-ISO 14040, Section 5.2 and ISO-14041 NTC Section 6 being a technical process based on data to quantify the energy and the materials consumed, the emissions to air and water, as well as the solid waste and other residues left to the environment during the whole life cycle of a product, process, material or activity.

4.2.3. Impact assessment

The impact assessment phase interprets the findings obtained in the inventory component and it is regulated in NTC-ISO 14040, Section 5.3 and NTC-ISO 14042 Sections 4, 5, 6. The LCA impact assessment phase aims at assessing the significance of the potential environmental impacts using the results of the inventory lifecycle. In general, this process involves associating inventory data with specific environmental impacts and the attempt to know these impacts. The level of detail, the selection of assessed impacts and methodologies used will depend on the objectives and scope of the study.

4.2.4. Interpretation of results

At this point, the interpretation of the results is very important because it will provide the conclusions and recommendations as one of the relevant components of the work. This process will be based on NTC-ISO 14040 Section 5.4 and NTC-ISO 14042, Section 7.

4.3. Information

The information will be used to reach the proposed goal, it will be of secondary type, obtained at nationally and internationally levels, due to information about oil palm and oil extraction is applicable to any country located in the equatorial line. The collected data will be analyzed and logically and critically discussed to obtain accurate information from reality, so it can be applicable and suitable used to achieve the stated objective.

5. Method implementation

The methodology implemented in this chapter will be the same as proposed by the standard NTC-ISO series 14040 which deals with the life cycle analysis (LCA), so the objective could be reached in a reliable way.

5.1. Objectives

As a starting point for the present study the following objective is considered: "To make an analysis of the carbon life cycle during the production of palm oil in order to implement the biodiesel as a substitute of the ACPM".

The reason for this study is the fact that the biodiesel will have to replace the ACPM in the future, especially in equatorial countries, due to the energy and environmental crisis that has been worsening since the industrial revolution in the XIX century, so it is necessary to clearly and accurately know what will occur to the carbon cycle, in order to establish policies that mitigate the global warming. This paper will develop just one part of the life cycle of carbon and the information obtained here can be used with that achieved in later studies and will have to do with the life cycle of the carbon in the production and consumption of biodiesel from palm oil.

Inherent to the main objective, the following ones trace the path for the study:

- To calculate the CO_2 captured by the oil palm.
- To calculate the CO_2 emitted in the production of palm oil.
- To calculate the IS palm oil = CO_2 impact on global warming for the oil palm in t of CO_2 equivalent per t of palm oil.

5.2. Information

5.2.1. Functional unit

For the purpose of work a functional unit is a ton of Crude Palm Oil clarified. (CPO)

5.2.2. System Limits

The limits of the system are given based on flow charts for an oil palm plantation, which takes into account the stages of pre-nursery, nursery and plantation; in the same way for an oil extraction plant, all processes to obtain the crude and clarified palm oil will be considered. Figure 2 shows the limits to be used during the analysis.

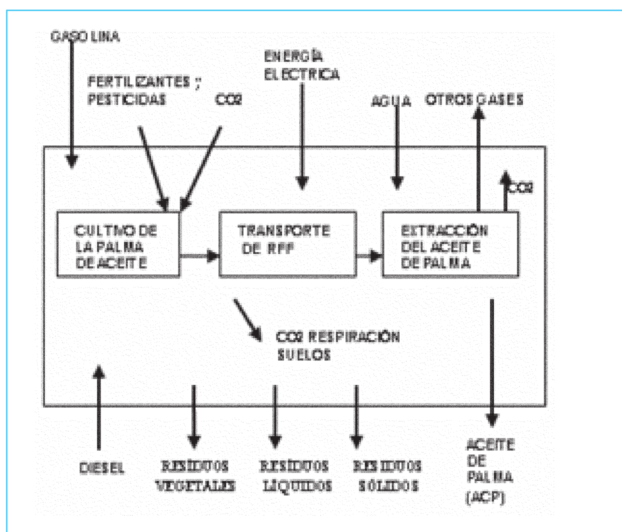

Fig. 2. System boundaries for the carbon life cycle in the extraction of palm oil.

Table 1. Data necessary for the system.

INPUTS and UNITS	OUTPUTS and UNITS
DIESEL GJ. t^{-1} ACP	CRUDE PALM OIL CLARIFIED t
ELECTRICAL ENERGY kWh. t^{-1} ACP	VEGETABLE WASTES t. t^{-1} ACP
GASOLINE GJ. t^{-1} ACP	LIQUID WASTES m^3. t^{-1} ACP
FERTILIZERS AND PESTICIDES GJ. t^{-1} ACP	SOLID WASTE t. t^{-1} ACP
CO_2 t^{-1} ACP	OTHER GASES t. t^{-1} ACP
WATER m^3. t^{-1} ACP	

5.2.3 Data Categories

The data to be used will be gathered from sources at national and international levels namely from secondary type. Data is divided into two groups: inputs and outputs (Table 1).

Regarding to quality, data should be ruled by the following parameters:

- Geographical Coverage: Data should come from countries located between 15N latitude and 15S latitude for any length
- Data will be calculated from secondary information from national and international level.

Finally, averages are obtained as necessary.

The data to capture CO2 from the oil palm provided by other countries are valid for Colombia, taking into account ecophysiology studies of the palm, especially those by Cayon 1990, in such a way that information from Malaysia and the countries near the Equator Line is applicable to some areas of Colombia and in turn the gather information in our country is applicable to Malaysia.

6. Life Cycle Inventory Analysis (LCIA)

When using this procedure data collection and calculation procedures to quantify the inputs and outputs of the defined system, tables will be done including different data related to inputs and outputs of each one of the unitary process that comprise the system (to which multiple data from different references exist), to be analyzed and to select the most appropriated datum.

7. Assesment of life cycle impact

Initially the CO_2 equivalent for each one of the inputs and outputs of the process is calculated to finally obtain the effective carbon dioxide consumed in the plantation of oil palm and the produced one in the extraction of oil which allows the calculation of:

ISpalm oil = CO_2impact on global warming for the palm oil in t of CO_2equivalent per t of palm oil.

- Diesel: to calculate the CO_2diesel equivalent, the emission factor for the Colombian CPOM will be used, this has been reported by UPME and it is equal to 74,869 kg of CO_2. TJ-1 (UPME 2006 FECOC).
- Gasoline: Emission factor: 74,570 kg of CO_2. TJ-1
- Fertilizers: assuming that for their production the consumption is from fossil energy, the ACPM emission factor will be used.
- Energy in nursery and pre-nursery: this energy is represented primarily in transportation and fertilizers, for that reason, the ACPM emission factor.
- Steam: steam in the oil extraction plants, generally occurs from the combustion of palm fiber, This is why the emission factor of fiber palm will be used: 94,114 kg CO_2. TJ-1 knowing that 1 t of palm fiber produces 5.49 tons of steam at 10 bar (R Pardo, 2006) 0.5 tons of fiber will be required to produce the necessary steam; the heating of the palm fiber is 22.02 MJ.kg-1 (UPME 2006 FECOC).
- Electric energy: From the expansion plan of UPME 2005:149, the emission factor for electric energy is equal to 200 kg of CO_2.MWh-1
- Effluent: The effluent released from the extractor plant, go through a treatment system that emits a series of gases, among which the CO_2 is in a 35% and methane in a 65% (L Reijnders, 2006:3), therefore, the CO_2 produced by the effluents will be of 0.0044 t.
- Methane through effluents: the CO_2 equivalent is calculated based on the information published in Reijnders L, 2006, as follows: CH4wastes x GWPCH4, where CH4wastes = t of methane. t-1 of CPO; GWPCH4 = global warming potential of the CH4, (= 24.5 CO2 equi.).
- Vegetable Waste: these residues are formed by fibers, cuesco and empty clusters, which contain an average 18.8% of weight of fixed carbon (Z Husain, 2002), which when it is brought back to plantations to be either biodegrade or burned releases carbon as CO_2, so that 3.32 t of waste contain 0.62 t of carbon which in turn generates 2.29 t of CO_2.

With the information from Table 2 it is calculated:

ISpalmoil $CO_2cap = -(CO_2di + CO_2ga + CO_2fer + CO_2vive + CO_2res + CO_2vap + CO_2ele + CO_2resi + CO_2emi + CO_2eflu + CO_2CH4) = 5.43$ tons of CO_2. t –1 CPO

8. Discussion of results

With regards to the data analysis for the life cycle inventory (LCIA), displayed in Table 2, it should be concluded that:

- The captured CO_2 has a large standard deviation which is reasonable if it is considered that the data corresponding to plantations of different ages, and the plantation age determines the photosynthetic rate (Cayon 1990).
- Regarding the fertilizer applied in plantations, there is a considerable difference among findings due to some plantations use organic matter, previously treated in biodigesters, while others apply agrocheimals which are reported as such increasing considerably the costs for the plantations.
- The soil respiration shows very different values which is also reasonable, if considering the fact that this factor depends basically on the content of organic matter which increases if the plantation uses its wastes to fertilize the soil, from this point of view this practice would be counterproductive, because the emission of greenhouse gases will considerably increase. Notice that percentage of the impact for this item is the highest (65.72%).
- There is limited information about the amount of methane produced in a sewage plant, therefore new research studies should aim at measuring this volume of production due to its impact as gas of green house effect is 24 times greater than the CO_2 one. Again the doubt on the suitability of the use of biodegradable organic matter to fertilize the soil appears.
- A research study may focus on establishing if there are advantages of using vegetable wastes as fuel to reduce electric energy consumption of the network, or if they must be taken to a biodigester to produce fertilizers. In both cases the emission of gases of greenhouse effect is very different.
- What can be said is that the vegetable wastes should not be left on the soil of the plantations because Soil respiration increases and consequently the emission of CO_2 and methane.
- The impact of CO_2 on global warming for palm oil (ISpalm oil) is positive with a value of 5.43 t CO_2 . t 1-CPO, indicating that the CO_2 captured by the plantation is higher than that produced across the whole process, but this surplus is not very large, 27% of the total captured, suggesting that if there is a production of biodiesel from palm oil, the total balance could

Table 2. Assessment of lifecycle impact per ton of CPO .

INPUTS and UNITS	AVERAGE (Standard deviation)	CO_2 equivalent t of CO_2	IMPACT %
NECESSARY RFF (t)	4,35(0,375)		
DIESEL (GJ)	0,64(0,13)	CO_{2di} 0,05	0,34
GASOLINE(GJ)	0,19	CO_{2ga} 0,014	0,09
WATER (m3)	19,25	0	0
FERTILIZER (GJ)	3(0,83)	CO_{fer} 0,22	1,5
NURSERY AND PRE-NURSERY ENERGY (GJ)	0,61 (0,29)	CO_{2vive} 0,46	0,31
CO_2 CAPTURED t	20,1(6,87)	CO_{cap} 20,1	0
CO_2 SOILS RESPIRATION	9,64 (4,9)	CO_{res} 9,64	65,72
STEAM (t)	2,74(0,76)	CO_{2vap} 1,04	7,1
ELECTRIC ENERGY (kWh)	107,8(48,3)	CO_{2elec} 0,022	0,15
WATER (m3)	10		0
VEGETABLE WASTES (t)	3,32(0,32)	CO_{2resi} 2,29	15,06
CO_2 EMITTED (t)	1,15(0,08)	CO_{2emi} 1,15	7,8
EFFLUENTS (m3)	4,17	$CO_{2efleen}$ 0,0044	0,03
METHANE BY EFFLUENTS (t)	0,00816	CO_{2CH4} 0,2	1,36

Table 3. Energy consumption.

STEAM MJ	6153	9846	7272	7272	5944	12214
ELECTRIC ENERGY MJ	252	670	396	324	306	590
TOTAL GJ	6,405	10,516	7,668	7,596	6,250	12,804
COUNTRY	Malaysia	Colombia	Malaysia	Thailand	Malaysia	Malaysia
REFEREN.	Wambeck 2005	Brown, R 2006	Arrieta, 2007	Arrieta, F. 2007	Mahlia T. 2001	Husain Z. 2003

Table 4. Total energy in the process.

COUNTRY	Colombia	Malaysia	Malaysia	Malaysia	Malaysia
REFERENCE	Brown, R 2006	Gurmit 1999	Wambeck 2005	L.Reijnders 2006	Henson. 1999
TOTAL ENERGY PLANTATION (GJ)	4,28	5,22	3,06	9,7	2,46

become negative, because the production of biodiesel generates CO_2, the same as the consumption in the Diesel engine. This study should continue to determine whether the production Biodiesel from palm oil, from the point of view of the CO_2 is suitable or not.

- The standard deviation of electric energy consumption in the production oil industries is very large. Colombia has the highest value, which indicates that in the studied plant a lot of energy is being wasted that is why energy should be bought out of Colombia. Other possible reason to this energy waste could be the technology used and its modernization.
- Colombia is the country where more RFF is required to produce a ton of CPO, it might be due to the old or new technology implemented in the oil production, or maybe due to the varieties planted are not the most appropriated to our soils. A worthy research in this aspect would be the production of varieties of plants more suitable for our case. About the consumption of energy in the process of oil extraction, it is worthy to analyze the information, to what units should be unified, so that knowing the steam consumption in t, its pressure and assuming saturated vapour the MJ consumed can be obtained. Similarly the equivalence of the electrical energy in MJ is found, to obtain Table 3, From which it can be concluded that Colombia ranks the second position in the consumption of energy during the process of oil extraction. Colombia needs to implement programs to save energy and to make it efficient within the Colombian industry, or programs about technologic modernization so the costs for oil production could be worldwide competitive.
- When totalizing the amount of energy, table 4, given to the plantation as power subsidy, it is observed that Colombia is not over to what happen in other countries, even in Malaysia there is a very superior number, which indicates that in this aspect we are well, but we must find ways to improve, to reach the lower levels of energy consumption.

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