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Environmental Assessment of a Crude Palm Oil Production Process under North-Colombian conditions Using WAR Algorithm

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Abstract: The environmental assessment of a process allows detection of improvement areas from this point of view, serving as a tool for making decision and quantification of environmental benefits for a raw material transformation into a final product. In this work, a real crude palm oil extraction process found in North Colombian region was analyzed using WAR algorithm to evaluate 8 impact categories. Results show that in general terms, the process is environmentally beneficial. The total generated PEI is negative and 10^{-4} order, in addition, although output impacts occur, these are low compared to the PEI output of an oil extraction process with chemical solvents. Moreover, high emissions of greenhouse gases do not occur, however, if energy improvements in the process are carried out by changing the type of fuel, values for PEI output for atmospheric environmental impacts categories could be reduced considerable.
Keywords : WAR algorithm, Environmental evaluation, crude palm oil.

Introduction

The palm oil is a vegetable oil obtained by pressing the mesocarp of *Elaeis guineensis* palm fruit[1]. The yield of oil palm cultivation is six to ten times higher than the aforementioned cultures, producing 39% of vegetable oil in the world, which is used in the food industry, cosmetics and as a raw material for biofuel production[2]. In 2010, Colombia was the first Latin American country producer of palm oil and the fifth in the world after Indonesia, Malaysia, Thailand and Nigeria, with domestic production of 753,000 tonnes, and since 2012, has about 500,000 hectares of oil palm[3]. In addition, in Colombia there are plans to increase production to six times by 2020, which would require 3 million hectares for plantations[4]. This large production demand is leading palm growing countries to seek and implement optimal and efficient processes that can ensure a better use of raw materials, high oil yield, reducing environmental impacts. An environmental assessment provides an orderly, replicable and multidisciplinary analysis of possible environmental impacts that a process can have on the ecosystem, either causing an ecological imbalance or exceeding the limits and conditions set forth in the applicable provisions to protect, preserve and restore the environment. Some of the methodologies and tools used to develop an analysis of the environmental impacts are the Waste Reduction (WAR) Algorithm[5], Environmental Impact Minimization Method (MEIM), AHI methodology, EFRAT tool and Life-Cycle Assessment[6]. Regarding WAR algorithm, this is useful because allows quantifying the generation of potential environmental impacts based upon several different impact categories[7]. In this work, authors present an environmental assessment of a production process of crude palm oil in the northern Colombian region using the software WARGUI, which is based on WAR algorithm, in order to quantify eight impact categories that can lead to possible optimization thereof.

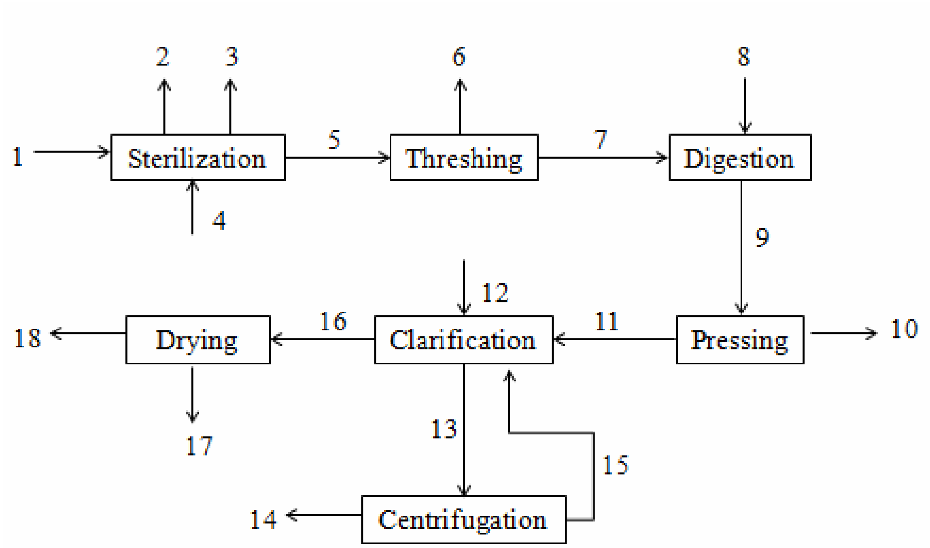
Experimental

Process Description

The process was evaluated using as references two extraction plants of crude palm oil located in North Colombia in Bolivar and Cesar departments; furthermore, this process is similar to that reported in the literature[8]. Figure 1 shows that extraction process simulation of crude palm oil starts with steam ingress (stream 4) by a boiler to sterilize the bunch of African Palm (stream 1), previously transported from a hopper to a horizontal cylinders closed by trucks. This sterilization is performed in order to prevent the effect of lipase enzyme on free fatty acids and hydrolyzing the palm rachis to soften the pulp tissues. From this step, the sterilized bunch (stream 5) and saturated steam (stream 2 and 3) out. The sterilized cluster passes through a rotating drum to separate the fruits (stream 7) of bunches (stream 6). The fruits pass to the digestion step, where the fruit is heated to facilitate the oil expulsion in the pressing and to release the nuts pulp by maceration that includes the entry of steam (stream 8) through a heat exchanger. Subsequently, the digested fruits (stream 9) are pressed by a horizontal perforated basket cylindrical shape, where a liquor (stream 11) containing large amount of oil is extracted. This liquor is generated through the mechanical action of two augers regressive step, which rotate parallel in the opposite direction, by outputting in the top the presscake (stream 10). Then, water (stream 12) is added to the liquor to dilute it, facilitating the oil separation and purification. In static clarification stage is separated by static clarification up to 90 % oil (6.81 t/h), which it is collected by overflow and is pumped (stream 16) to a drying process.
After this, the dynamic clarification by centrifugation is carry out, where 10 % recovery of oil is achieved.

At this stage enters the heavy fraction from decantation (stream 13), obtaining water and heavy sludge as outputs by nozzles (stream 14), oil and light sludge are concentrated in the center and discharged by a collector tube. This last outlet stream is recirculated (stream 15) to the static clarification with the press liquor. As last step, the oil is subjected to another drying in order to minimize the moisture and residual impurities (stream 17) still contain this. Due to high temperature of oil outlet, the drying is performed under vacuum, by reducing the pressure of the stream, causing evaporation of the remaining water. Dry Crude Palm oil (6.757 t/h) is pumped (stream 18) from this stage as final product to its respective storage.

Figure 1. Block diagram of crude palm oil extraction process



Environmental assessment using WAR algorithm

Software WARGUI was used to perform the environmental analysis of a real crude oil extraction process from African Palm (30 t/h of palm bunch and 20 kW of energy consumption per ton palm bunch were taken as calculation basis) found in North Colombian. The WAR algorithm introduces the concept of balance Potential Environmental Impact (PEI), which involves the flow of an environmental impact throughout system boundaries, due to the mass or energy that crosses these limits. This index is considered from two points of view, PEI output and PEI generated. The first measures the PEI impact emitted by the process around, and its main use consists in solving questions about the external environmental efficiency of the process, i.e., the ability of the process to obtain final products to a minimum potential environmental impact discharge. As regards the second, it measures the generation of PEI within the limits of the process and its importance lies in find out the internal environmental efficiency of the process, i.e., how much environmental impact potential is consumed in the process. The smaller is the value of these indexes, the process is more environmentally efficient. In addition, the WAR algorithm considers eight categories where it is evaluated the PEI of chemicals and process. These categories can be classified into two major groups: local toxicological impacts on humans (HTPI, HTPE) and ecological (ATP y TTP), and global (GWP y ODP) and regional (AP y PCOP) atmospheric impacts atmospheric impacts.

Human toxicity potential by ingestion (HTPI)[9]. This indicator assesses the toxicity of chemicals and approximates the value of lethal ingestion dose that will kill 50% of a sample population of rats, LD_{50}. Using equation 1 can be calculated HTPI, where LD_{50} is generally reported in units of mg of chemical / kg rat. In this system, a highest value of LD_{50} represents a less toxic substance.

$$HPTI=\frac{1}{LD_{50}} \quad (1)$$

Human toxicity potential by inhalation or dermal exposure (HTPE)[9]. HTPE value was considered as the appropriate measure for chemical comparison that poses a threat to human health through inhalation and dermal exposure. This is approximated by using threshold values 8 hours (TLV) as recommended by OSHA, ACGIH, or NIOSH. Using Equation 2 can be calculated the HTPE, where units for TLV are mg/m^3.

$$HPTE=\frac{1}{TLV} \qquad (2)$$

Ozone depletion potential (ODP)[10]. It is determined by comparing the rate at which a unit mass of a chemical product reacts with ozone to form molecular oxygen and the rate at which a unit mass of CFC-11 (trichlorofluoromethane) reacts with ozone to form molecular oxygen. In general, a chemical must contain an atom chlorine or bromine to have ODP. These values take into account the decomposition of chemicals in the atmosphere. ODP (kg CFC-11-equiv.) can be calculated by equation 3, where $\delta[O_3]_i$ is the global ozone depletion produced by one unit of the gas i, $\delta[O_3]FCKW\text{-}11$ is the global ozone depletion produced by one unit of CFC-11 and m_i is the mass (kg) of a gas i.

$$ODP=\frac{\delta[O_3]_i}{\delta[O_3]FCKW\text{-}\mathbf{11}}m_i \qquad (3)$$

Global Warming Potential (GWP)[10]. GWP is determined by comparing the amount of infrared radiation that a unit mass of a chemical and a unit of mass of carbon dioxide can absorb in 100 years. This impact category also takes into account the chemicals deterioration in the atmosphere during this same period. GWP (kg CO_2-equiv.) can be calculated by equation 4, where a_i is the heat radiation absorption per unit concentration increase of a greenhouse gas i, a_{CO_2} refers to this same absorption but per unit of carbon dioxide, $c_i(t)$ is the concentration of the greenhouse gas i at time t after release, $c_{CO_2}(t)$ is refered to carbon dioxide, t is the number of years over which GWP is calculated, and m_i is the mass (kg) of a gas i.

$$GWP=\frac{\int_0^t a_i c_i(t)\,dt}{\int_0^t a_{CO_2} c_{CO_2}(t)\,dt}m_i \qquad (4)$$

Photochemical Oxidation Potential (PCOP)[10]. This impact category is also called Smog Formation Potential (SFP) and is determined by comparing the rate at which a unit mass of chemical reacts with a hydroxyl radical (OH^-) to the speed at which a unit mass of ethylene reacts with OH. PCOP (kg C_2H_4-equiv.) can be calculated using equation 5, where a_i is the change of ozone concentration due to a change in the emission of a volatile organic compound (VOC) i, $a_{C_2H_4}$ refers to this same change regarding ethylene emissions, $b_i(t)$ is the integrated emission of VOC i up to that time t, $b_{C_2H_4}(t)$ refers to this latter condition for ethylene and m_i is the mass (kg) of the VOC emitted.

$$PCOP=\frac{\frac{a_i}{b_i(t)}}{\frac{a_{C_2H_4}}{b_{C_2H_4}(t)}}m_i \qquad (5)$$

Acidification potential (AP)[10]. Potential acid rain or acidification potential is determined by comparing the H^+ release rate in the atmosphere promoted by a chemical, respect to the H^+ release rate in the atmosphere promoted by SO_2. AP (kg SO_2-equiv.) can be calculated by equation 6, where V_i is the acidification potential of component i, V_{SO_2} is the AP of SO_2, M_i is the unit mass of substance i, M_{SO_2} is the unit of the mass of SO_2 and m_i is the mass (kg) of significant component i emitted.

$$AP=\frac{\frac{V_i}{M_i}}{\frac{V_{SO_2}}{M_{SO_2}}}m_i \qquad (6)$$

Aquatic Toxicity Potential (ATP)[9]. It is estimated by using the toxicological data of one representative species of fish, *Pimephales promelas* (fathead minnows). This specie was chosen because of its acceptance as a universal indicator water and prevalence data. The data for this assay are in the form of LC_{50}, a lethal concentration that kills 50% of the test samples. The data used in this database specifically come from an exposure time of 96 hours. ATP value can be obtained by equation 7, where units for LC_{50} are mg/L

$$ATP=\frac{1}{LC_{50}} \qquad (7)$$

Terrestrial toxicity potential (TTP)[11]. It is determined by using toxicological data of rat as terrestrial specie. This one was chosen due to its acceptance as an indicator terrestrial and prevalence data. The TTP is presented in the form of a lethal dose that kills 50% of the specimens by oral ingestion, LD_{50}. This is the same value used to estimate human toxicity potential by ingestion in exactly the same manner as it is shown in equation 8.

$$TTP=\frac{1}{LD_{50}} \qquad (8)$$

This work presents the environmental assessment of production process under 4 scenarios: First, were evaluated the total impacts based on 4 conditions (a base case and three another cases taking into account the product stream, energy process and the amount of energy-product stream), second, the toxicological impacts, third, the atmospheric impacts and finally, the effect of three energy sources.

Results and Discussion

Composition of process streams

Table 1 shows the compositions in mass fraction of various streams present in the Crude Palm Oil production process, which includes lignocellulosic material, moisture, ash and oil.

Regard operating conditions, temperature was measure in a range of 303.15 and 420.15 K and pressure between 0.966 and 4.402 atm. In addition, Table 2 shows in detail this information as well as the flow mass for each of the process streams.

Table 1. Composition of currents of the crude palm oil extraction process

Component	1	2, 3, 4, 8, 12, 17	5	6	7	9	10	11	13	14	15	16	18
Water	30.1	100	21.463	23.166	20.764	26.039	24.557	28.346	91.218	91.216	91.218	0.881	0.098
Ash	3.533	-	3.998	7.721	2.433	2.269	1.361	3.177	5.489	5.491	5.491	-	-
Silica	0.195	-	0.217	-	0.306	0.286	0	0.572	0.989	0.989	0.989	-	-
Cellulose	17.835	-	20.042	32.819	14.796	13.811	27.624	-	-	-	-	-	-
Hemicellulose	9.985	-	11.22	16.409	9.09	8.485	16.971	-	-	-	-	-	-
Lignin	12.12	-	13.62	16.409	12.474	11.644	23.289	-	-	-	-	-	-
Palmitic acid	0.549	-	0.617	0.078	0.837	0.782	0.036	1.528	0.052	0.052	0.052	2.23	2.248
Stearic acid	0.053	-	0.06	0.008	0.081	0.076	0.002	0.149	0.005	0.005	0.005	0.218	0.22
Oleic acid	0.515	-	0.579	0.073	0.786	0.734	0.042	1.426	0.048	0.048	0.048	2.081	2.098
Linoleic acid	0.092	-	0.103	0.013	0.14	0.131	0.004	0.258	0.009	0.009	0.009	0.377	0.38
Myristic acid	0.019	-	0.022	0.002	0.03	0.028	0.022	0.034	0.001	0.001	0.001	0.05	0.05
Lauric acid	0.023	-	0.026	-	0.036	0.034	0.067	-	-	-	-	-	-
Tripalmitin	1.416	-	1.59	0.203	2.16	2.016	0.065	3.967	0.135	0.135	0.135	5.791	5.837
1,3-Dipalmitoyl-2-oleoylglycerol	7.217	-	8.107	1.035	11.01	10.277	0.329	20.224	0.686	0.686	0.686	29.52	29.753
1,2-dioleoyl-3-palmitoylglycerol	6.218	-	6.985	0.892	9.486	8.854	0.283	17.424	0.591	0.591	0.591	25.433	25.634
1-Palmitoyl-2-oleoyl-3-linoleoyl-rac-glycerol	2.608	-	2.93	0.374	3.979	3.714	0.119	7.309	0.248	0.248	0.248	10.669	10.753
1,2-Dipalmitoyl-3-lauroylglycerol	2.397	-	2.692	0.344	3.656	3.413	0.109	6.716	0.228	0.228	0.228	9.802	9.88
Triolein	1.598	-	1.795	0.229	2.437	2.275	0.073	4.477	0.152	0.152	0.152	6.535	6.586
1-Palmitoyl-2-oleoyl-3-stearoyl-rac-glycerol	1.568	-	1.761	0.225	2.392	2.232	0.071	4.393	0.149	0.149	0.149	6.413	6.463
1,2-Lauroyl-3-miristoylglycerol	0.491	-	0.552	-	0.779	0.727	1.454	-	-	-	-	-	-
Trilaurina	0.863	-	0.971	-	1.369	0.866	1.732	0	-	-	-	-	-
1,3-Lauroyl-2-oleoylglycerol	0.272	-	0.306	-	0.432	0.403	0.806	0	-	-	-	-	-
1,2-Miristoyl-3-Lauroylglycerol	0.333	-	0.374	-	0.527	0.492	0.984	0	-	-	-	-	-

Table 2. Current operating conditions of the crude palm oil extraction process

Stream	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
T (K)	303.15	420.85	358.15	420.85	358.15	343.5	343.5	420.85	368.15
P (atm)	1.000	4.402	1.000	4.402	1.000	1.000	1.000	4.402	1.000
ṁ (t/h)	30	1.416	10.062	8.175	26.697	7.77	18.927	1.35	20.277
Stream	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
T (K)	368.15	368.15	358.15	365.35	363.35	365.35	363.35	363.35	363.35
P (atm)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.966	1.000
ṁ (t/h)	10.138	10.139	2.535	7.33	5.864	1.466	6.81	0.053	6.757

Environmental assessment

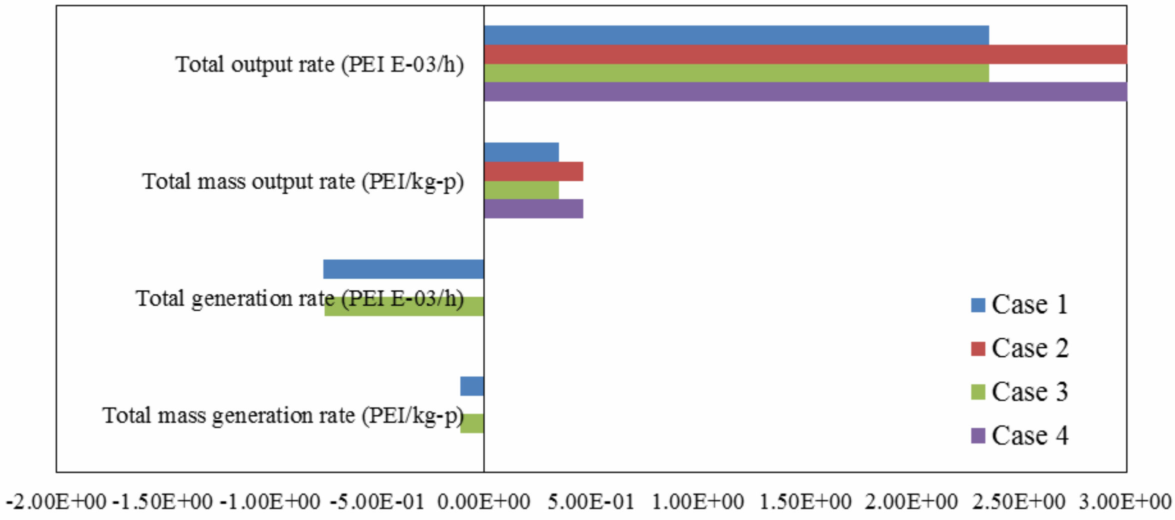
In order to carry out a global analysis of the process, this was considered as a single block or stage, taking into account only the overall inputs and outputs of the process. That is, the currents from 1 to 4, 6, 8, 10, 12, 14, 17 and 18, as is showed in Figure 1.

Total Potential Environmental Impacts of the process: Generated and output

This scenario was evaluated under 4 conditions, a base case having into account all energy sources present in the process (Case 1), and 3 cases where was considered the product stream (Case 2), the energy process (Case 3), and the amount of energy-product stream (Case 4). As it is observed in Figure 2, PEI out per hour is higher in cases 2 and 4 (3.11 PEI/h for both of them), because of the product stream generated in the process. This same trend is presented for the case of PEI output per kilogram of oil produced, however the latter is lower (4.6×10^{-1} and 4.61×10^{-1}, respectively) due to product quality, which has low toxicity for being edible nature; in addition, not aggressive chemicals solvents were used, such as hexane in the oil extraction process from wastewater microbiota using a mixture ethanol/hexane (EHE) to obtain biodiesel (257.200 PEI/h)[12].

The fact that PEI generated values were negative for all 4 cases indicates that the process within it, has a good environmental performance. For cases 1 and 3, the PEI values are similar ($-7.52\text{x}10^{-4}$ and $-7.50\text{x}10^{-5}$ PEI/h), leading to the conclusion that the amount of product does not represent a significant influence on the value thereof. For cases 2 and 4, the PEI generated increased ($-4.08\text{x}10^{-3}$ and $-1.70\text{x}10^{-3}$ PEI/h, respectively) due to it was taken into account the product stream, however, being less than zero suggests that the process within itself no generates environmental impact.

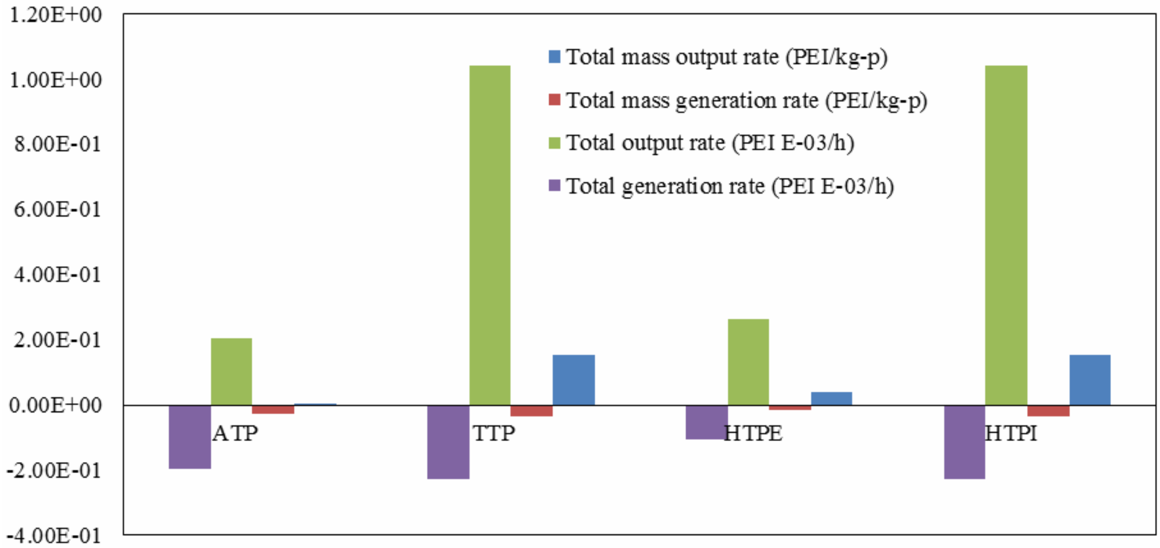
Figure 2. Total PEI generated and output of the system for crude palm oil production process



Local toxicological impacts of the process

Figure 3 shows the local toxicological impacts generated and output of the process, which includes humans (HTPI y HTPE) and ecological (ATP y TTP) impacts. Figure 3 shows that for ATP and HTPE impact categories, the contribution is minimal under situations studied, however, PEI output ($2.03x10^{-4}$ and $2.62x10^{-4}$ PEI/h, respectively) values are considerably lower compared to TTP and HTPI ($1.04x10^{-3}$ PEI/h for both cases), indicating that the impacts generated by this process on aquatic systems as well as the mass flow which is ejected into the atmosphere are low. Furthermore, the PEI generated for the 4 impact categories is minimal ($-1.94x10^{-4}$, $-2.26x10^{-4}$, $-1.05x10^{-4}$ and $-2.26x10^{-4}$ PEI/h, respectively), suggesting that the process have in the product streams, less toxic chemicals with tolerance values limits (TVL) lower than those fed to the system. However, this value only increases (HTPI) if it is considered oil output as product stream due to its possible impact on the environment.

Figure 3. Local output and generated toxicological impacts of crude palm oil production process



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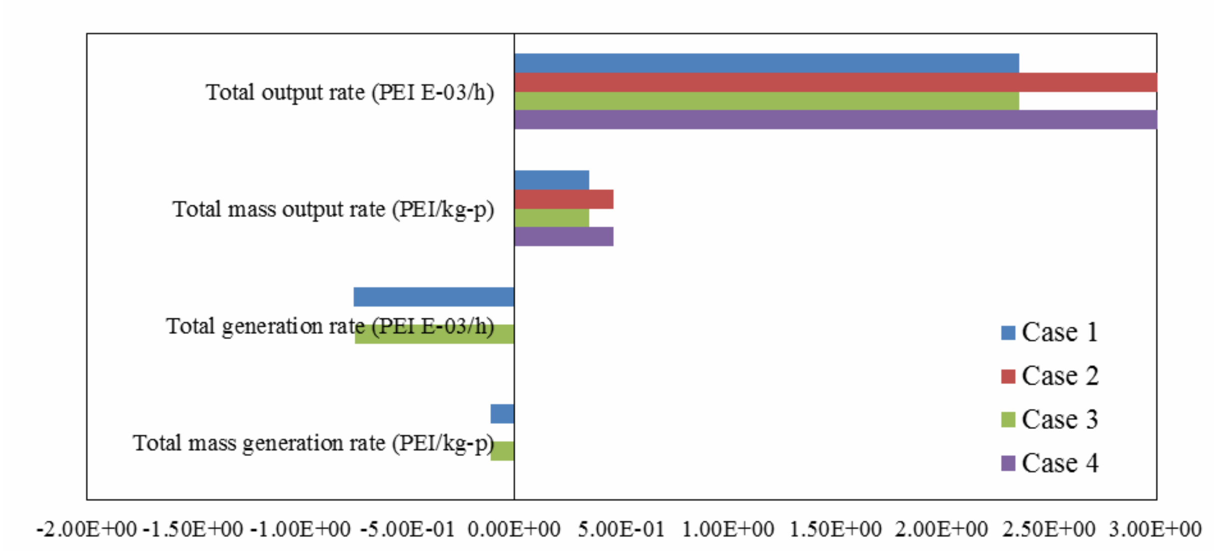

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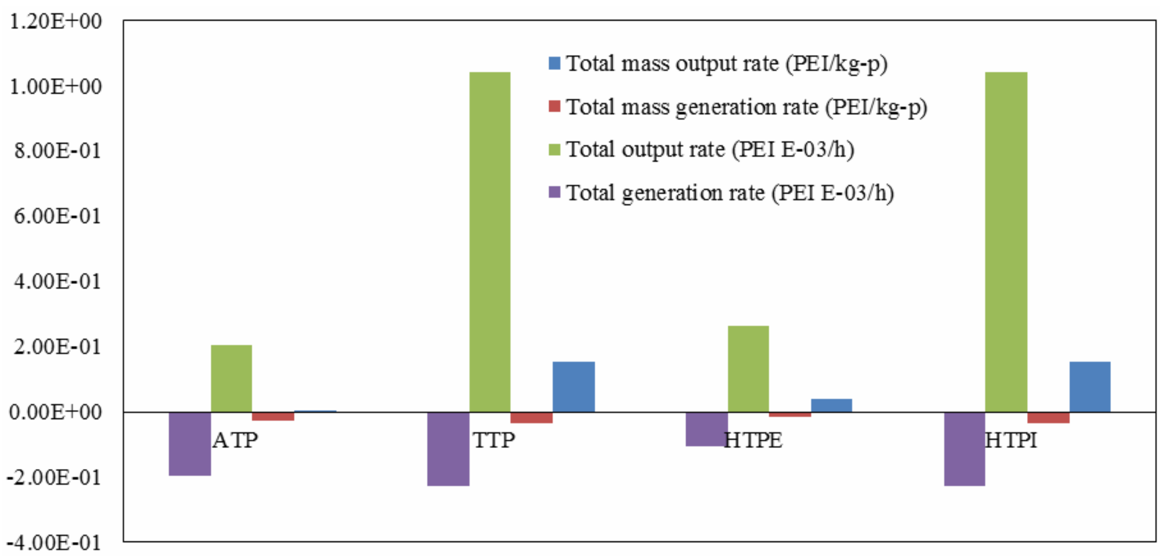
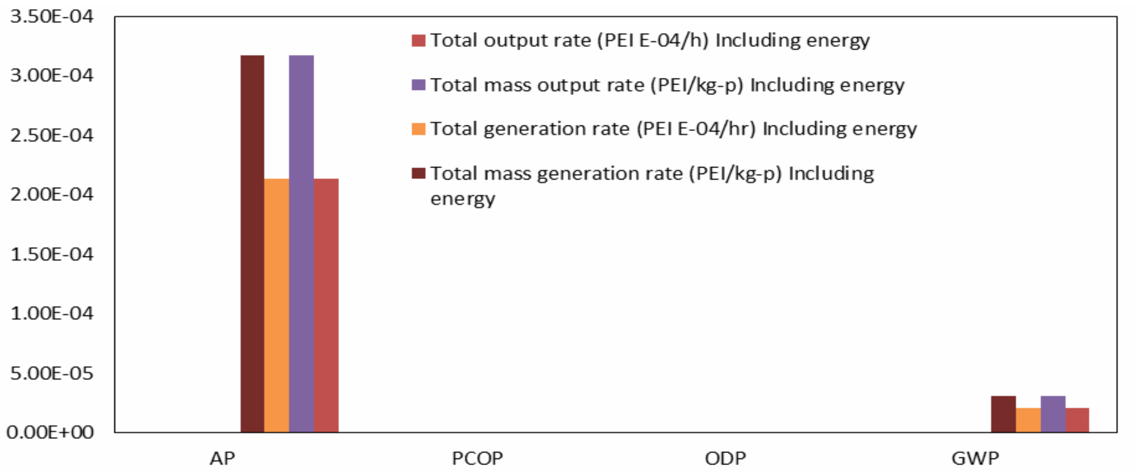


Atmospheric impacts of the process

Figure 4 shows that atmospheric impacts (analyzed including energy) are composed for global (GWP y ODP) and regional (AP y PCOP) ones. For this particular process, it is observed that all values for ODP and PCOP impact categories are zero, which leads to the conclusion that this process is environmentally neutral under these categories, so the only contribution to PEI out for atmospheric categories comes from the use of fuels in the process as energy sources. The PEI output for GWP and AP impact categories indicates that this process emits chemicals that persist longer in the environment due to its low oxidation and also can contribute to the generation of acid rain. The fact that the PEI generated and PEI output values are very similar is because of in the process are generated chemicals products with reduced ability to degrade themselves in the environment as a result of combustion in boiler.

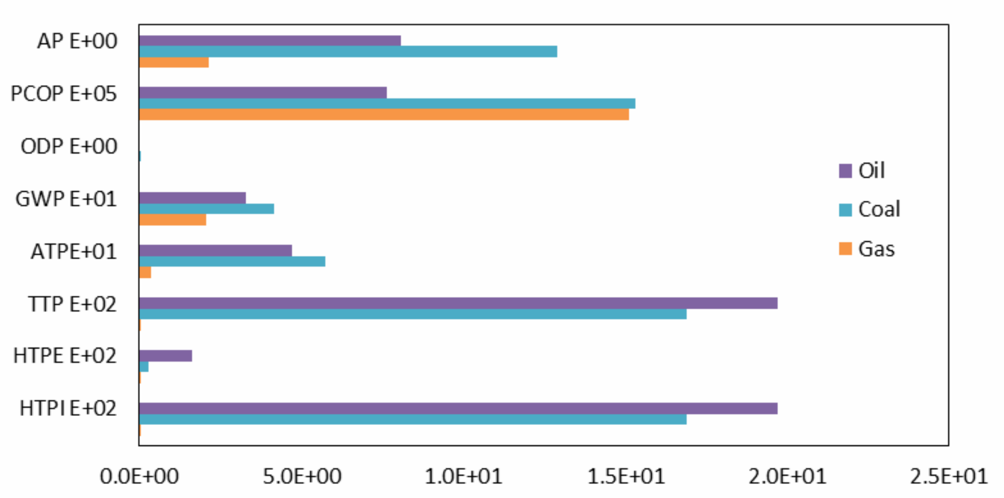
Figure 4. Output and generated atmospheric impacts of crude palm oil production process



Effect of energy source

Under this scenario, three types of fuel were evaluated for each impact category, including the energy and excluding the product stream. Figure 5 shows the change in PEI output based on the type of fuel used. It is observed that there are categories under which is more convenient to use oil derivates and others where is more convenient to use coal. In this process, gas is used as fuel, which has low impact on all categories except for PCOP (1.51×10^5 PEI/h), due to changes caused by the concentration of ozone wake of volatile organic compounds emissions.

Figure 5. Effect of energy source on output rate from energy usage for palm oil production process



Conclusions

Waste Reduction Algorithm was implemented for environmental analysis of crude palm oil production process in North-Colombia. In general, it can be said that the process is beneficial in environmental terms, which is reflected in a total PEI generated negative. In addition, the product obtained (crude oil) and its derivatives is used for human consumption so its toxicological impact is low. Although PEI output is presented, this is low compared to the PEI output of an oil extraction process with chemical solvents. Moreover, high emissions of greenhouse gases are not present, so atmospheric impact categories are not affected and in the case of GWP, the value obtained was 2.07×10^{-9} PEI/h. Finally, the different output environmental impacts of the process are influenced by the type of fuel used in the boiler for steam generation. If energy improvements are implemented to the process, by changing the type of fuel or using the heat of gases emitted into the atmosphere, these values may decrease.

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