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Environmental Evaluation of a Palm-based biorefinery under North-Colombian Conditions

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Biorefinery concept is currently applied to increase the process sustainability and resources conservation, however, in not all cases the use of process residues for obtaining high value products yields in a topology with lower environmental impacts. For this reason, it is necessary to know the environmental performance of novel biorefinery topologies. In this work, a topology of palm-based biorefinery was developed for the production of crude palm oil, bio-hydrogen and palm kernel oil under North-Colombian conditions. Environmental assessment was performed using software WARGUI, which use Waste Reduction Algorithm, in order to quantify the total generated and output environmental impacts for the biorefinery for 4 different case studies taking into account energy source and products under 8 categories. Results shows that, in general terms, the process is environmentally beneficial. The total generated PEI is negative and 10^{-1} order. Moreover, the palm-based biorefinery has a high environmental sensitivity to energy source derived of energy requirements in hydrogen production unit, so that if the 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 considerably.

1. Introduction

The biorefinery concept refers to the biomass transformation and integration as raw material for the production of green products, such as biofuels and biochemicals (Puccini et al., 2016). A biorefinery based on African Palm as raw material can be lead to obtain three products, being the palm oil the main one and palm kernel oil and hydrogen the valuable products. The importance of palm oil lies on it is the most used in the world and its cultivation is more profitable than its hypothetical substitutes, such as soybean oil or coconut oil (Garcia et al., 2016). The profitability of this product remains on its solid condition at room temperature and its unctuous texture, which allows substituting the butter or hydrogenated fats of many processed products. Regarding palm kernel oil, this is more unsaturated than palm oil, so it can be hydrogenated to achieve a wider range of products for the food industry (Hu et al., 2017). Finally, hydrogen is one of the main inputs in the oil industry due to its use in the production of diesel and naphtha, as well as on enriching CH_4 biogas in order to improve the quality of gas combustion (Cavinato et al., 2016). This large demand and applications is leading palm growing countries to seek and implement optimal and efficient processes that can ensure a better use of raw materials and high oil yield (Martinez et al., 2016). In this sense, implementation of environmental assessment allows determining the degree of pollution generated by the biorefinery, because it identifies the toxicological and atmospheric impacts that the process may have. Some of the methodologies and tools used to develop an analysis of the environmental impacts are the Waste Reduction (WAR) Algorithm (Petrescu et al., 2015), Environmental Impact Minimization Method (MEIM), Atmospheric Hazards Index (AHI) methodology, Environmental Fate and Risk Assessment Tool (EFRAT) and Life-Cycle Assessment (LCA), (Bicer et al., 2016). Regarding WAR algorithm, this is useful because allows quantifying the generation of potential environmental impacts based upon several different impact categories (Barrett et al., 2011). In this work, an environmental assessment of a palm-based biorefinery using the software WARGUI, which is based on WAR

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algorithm, is presented in order to quantify eight impact categories that can lead to possible optimization thereof.

2. Materials and methods

2.1 Process description

A biorefinery is defined as an industrial facility that employs a wide range of technological processes (mechanical, physical and bio-or thermochemical) capable of separating biological sources or renewable raw materials into their main constituents (carbohydrates, proteins, triglycerides, etc.), so that these can be converted into high value products (chemicals and/or materials) and energy vectors (fuels, energy gases, electricity or heat), minimizing the amount of waste. At the same time, each component of the process is converted or used in a way that increases its value, thus improving the sustainability of the plant. In this sense, when applying this concept to the design of a palm fruit-based biorefinery, Figure 1 presents the topology of palm fruit biorefinery proposed.

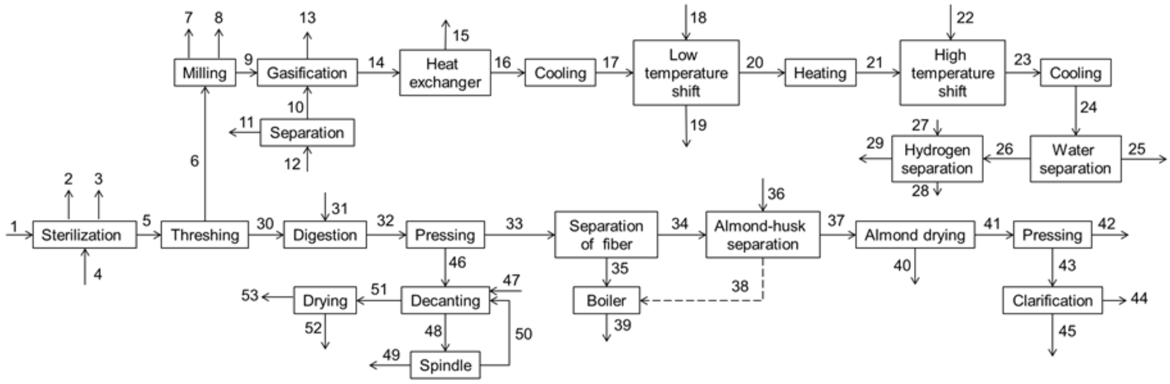

Figure 1: Topology of palm fruit-based biorefinery

2.1.1 Section of crude palm oil extraction process

The biorefinery from the palm fruit was developed taking into account local conditions found in North-Colombia (colored region in Figure 2), according to cultivated area, reference average temperature, freshwater availability and industrial services. Process starts with palm fruit sterilization where steam (stream 4) is used to sterilize 30 t/h of palm fruit (stream 1) to prevent the effect of lipase enzyme on free fatty acids, obtaining sterilized bunch (stream 5) and saturated steam (stream 2 and 3). Then, the sterilized fruit passes through a rotating drum to separate the fruits (stream 30) and rachis (stream 6) which goes to digestion step and to hydrogen production section respectively. In digestion, fruits are heated to release the nuts pulp by maceration that includes the inlet of steam (stream 31). Subsequently, the fruits (stream 32) are pressed, where the palm kernel cake (stream 33) is separated and goes to the palm kernel oil production section, and the liquor (stream 46) containing a large amount of oil is extracted and sent to a decantation, centrifugation and drying process in order to eliminate the most of moisture and impurities, to obtain the palm oil (González-Delgado et al., 2016).

Figure 2: Influence area of palm-based biorefinery (North-Colombia).

2.1.2 Hydrogen production section

The rachis that leaves the section of extraction of palm oil (stream 6) enters to a pretreatment step (milling and drying) from a wet basis of 55.6 % (101 °C), in order to increase the heat transfer area and the gasification efficiency. In the gasification stage enters oxygen (stream 10), from an air (stream 12) separation unit (nitrogen leaves the unit in stream 11). Air enrichment with oxygen is used in gasification because of its lower cost and less complex engineering needed to provide the current following the requirements of the gasification reaction. Biogas obtained (stream 14) is cooled using a heat exchanger (stream 16) and an electric cooling (stream 17) decreasing the temperature in order to condition the biogas for shift reactor, where hydrogen concentration will be increased. The gas (stream 20) is heated (stream 21) to condition the stream to the second shift reactor. The synthesis gas obtained (stream 23) in the reactor goes through a cooling stage, so at the exit (stream 24) will have a high water content that is separated by condensation. The resulting stream (26) is mixed with Selexol solvent (stream 27) to dissolve the undesired components (CH_4, CO and CO_2) (Peralta-Ruiz et al., 2016).

2.1.3 Palm kernel oil production section

The palm kernel oil is extracted from the palm kernel cake (stream 33) that comes out from the palm oil extraction process. The cake enters to an almond conditioning processes, where the excess fiber is removed and the almond is separated from the husk to enter to a pressing process where the palm kernel oil and other impurities are extracted and separated. Finally, the oil goes to a clarification stage using water.

2.2 Environmental assessment using WAR algorithm

Waste Reduction Algorithm (WAR) methodology was selected for environmental evaluation using the WARGUI Software, this tool was selected taking into account the open availability of the software and its ability of identify how fast an environmental impact from the process might possibly be in the environment which cannot be performed using other methodologies as Life Cycle Assessment (LCA) because of the large amount of information handled to perform the environmental assessment. A base case without taking into account neither the energy sources nor the product stream (Case 1), and 3 cases where was considered the product (case 2), the impacts from energy utilization (Case 3) and the impacts of the flow of energy and products (Case 4). The WAR algorithm introduces the concept of potential environmental impact (PEI), which involves the flow of an environmental impact across the boundaries of the system, due to the mass or energy that crosses these limits. This index is considered from two points of view, the production of PEI and the generated PEI. The first measures the impact of PEI emitted by the process to the environment, and its main use is to solve questions about the external environmental efficiency of the process, that is, the capacity of the process to obtain final products to a minimum potential of discharge of impact environmental. As for the second, the generation of PEI is measured within the limits of the process and its importance lies in knowing the internal environmental efficiency of the process, is how much potential environmental impact is consumed in the process. The lower the value of these indices; the more environmentally efficient the process is. impact categories considered by the WAR algorithm are classified into two major groups: toxicological impacts which can be local on humans (HTPI, HTPE) or ecological (ATP and TTP) and atmospheric impacts which can be global (GWP and ODP) and regional (AP and PCOP), where HTPI and HTPE are potential Human toxicity by ingestion and by inhalation or dermal exposure, respectively; ATP and TTP are Aquatic Toxicity Potential and Terrestrial Toxicity Potential, respectively, GWP and ODP are Global Warming Potential and Ozone Depletion Potential, respectively; Finally, AP and PCOP are Acidity Potential and Photochemical Oxidation Potential, the combination of global impact analysis, impacts by category and effect of energy flow and energy source, allows an integral diagnosis of environmental viability of a single process, or can be used for comparison of technological alternatives within a process or for comparison of different processes (González-Delgado and Peralta-Ruiz, 2016).

3. Results and discussion

3.1 Total Potential Environmental Impact (PEI): generated and output

As it is observed in Figure 3, the PEI generated was negative for all 4 cases ($-7.92x10^{-1}$, $-3.31x10^{-1}$, $-6.14x10^{-1}$ and -0.153 PEI/h, respectively), which indicates that, the process within it, has a good environmental performance. Regarding PEI output, it can be observed PEI output per kilogram of product and PEI output per hour are in a similar proportion, which shows that the influence obtained by energy and products inclusion does not generate general environmental impacts.

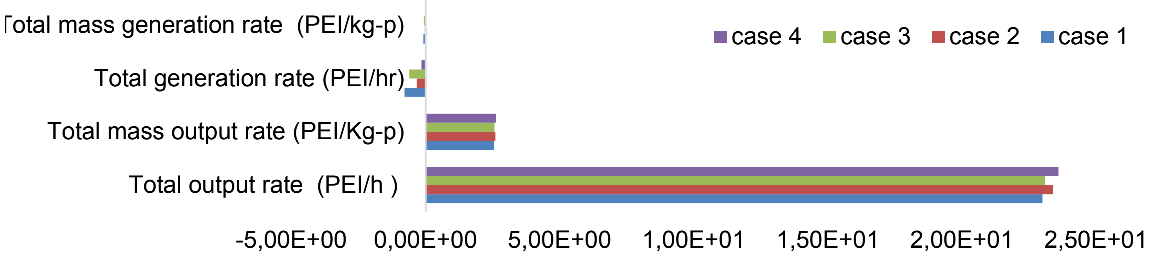

Figure 3: Total PEI generated and output of the system for a palm-based biorefinery.

3.2 Local toxicological impacts of the process: generated and output

Figure 4 shows the local toxicological impacts generated and output of the process, which includes humans (HTPI y HTPE) and ecological (ATP y TTP) impacts. It can be observed that the output impacts directed on human are more significant for the 4 cases studied compared to the ecological output impacts. In addition, output TTP and HTPI value is the same ($5.59x10^3$ PEI/h) for cases 2 and 4, and slightly higher than presented for cases 1 and 3 ($5.50x10^3$ PEI/h). Values for PEI output under ATP impact category are considerably lower ($1.81x10^3$ PEI/h for cases 1 and 3; and $1.98x10^3$ PEI/h for cases 2 and 4) compared to TTP and HTPI, 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, 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.

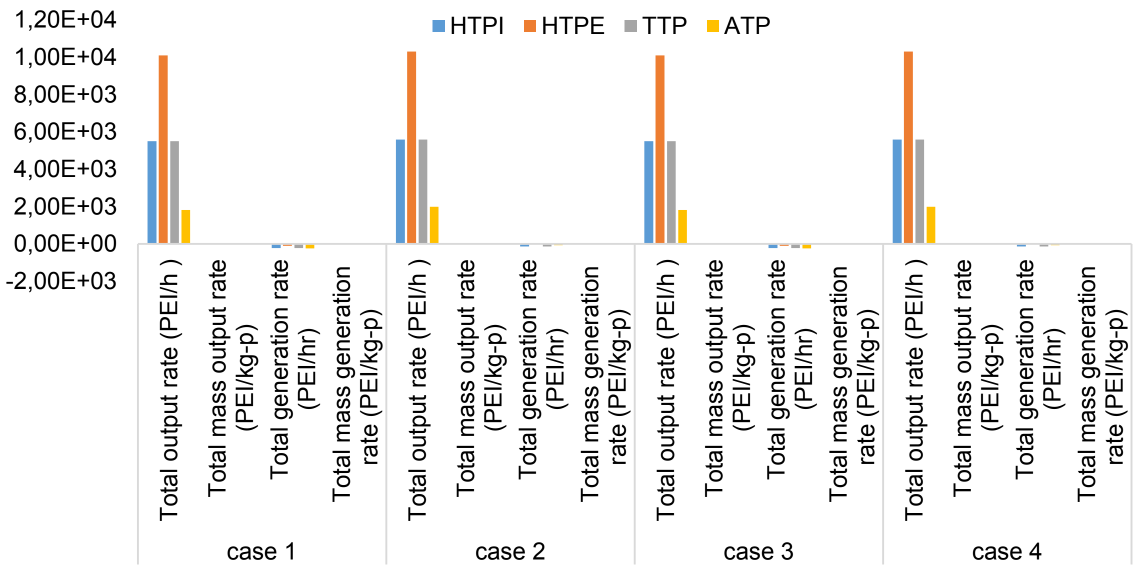

Figure 4: Local output and generated toxicological impacts of a palm-based biorefinery.

3.3 Atmospheric impacts of the process: generated and output

Figure 5 shows that atmospheric impacts are composed for global (GWP y ODP) and regional (AP y PCOP) ones. It is observed that values for ODP and AP in cases 1 and 2 are zero, which leads to the conclusion that this process is environmentally neutral under these categories, so the contribution to PEI output for atmospheric categories comes from the use of fuels in the process as energy sources, as occurs in cases 3 and 4. The PEI output for GWP ($1.93x10^1$ PEI/h) and AP ($1.60x10^2$ PEI/h) impact categories in cases 3 and 4, 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 owing to chemical products obtained presents reduced ability to degrade themselves in the environment.

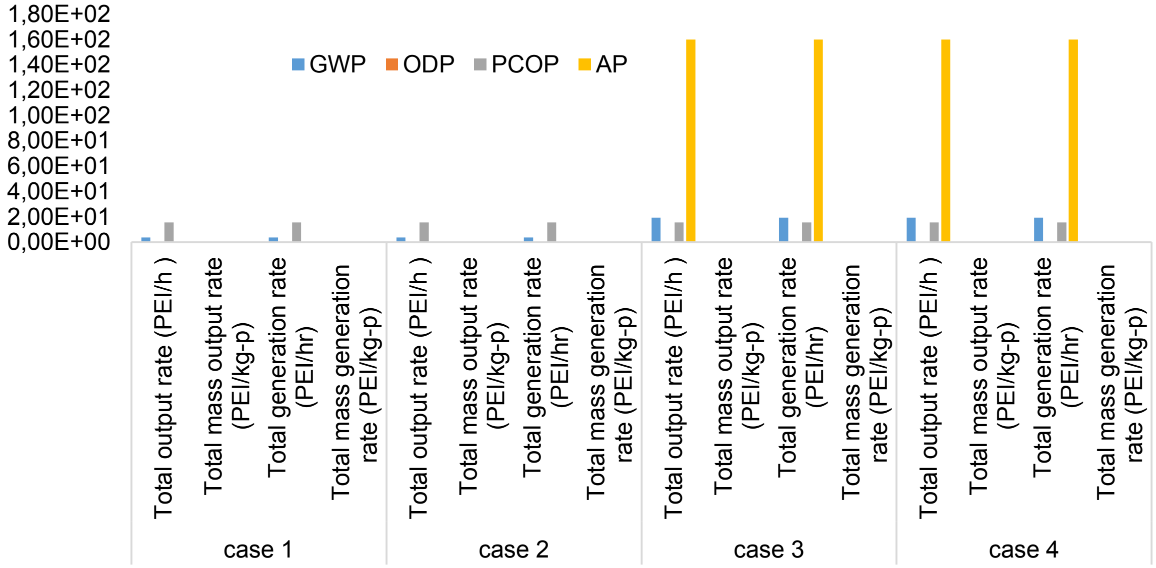

Figure 5: Output and generated atmospheric impacts of a palm-based biorefinery.

3.4 Effect of energy source

Under this scenario, three types of fuel (gas, coal and oil) were evaluated for each impact category, including the energy and excluding the product stream. Figure 6 shows the change in PEI output based on the type of fuel used in hydrogen production unit. It is observed that carbon usage increases the impact in the AP ($9.64x10^2$ PEI/h) and PCOP ($1.14x10^3$ PEI/h) categories compared with the other fuels, while decreasing it significantly in other categories as ODP (almost zero PEI/h) y HTPE ($1.97x10^1$ PEI/h). In the case of gas and oil, it can be observed that their performance is very similar under all impact categories.

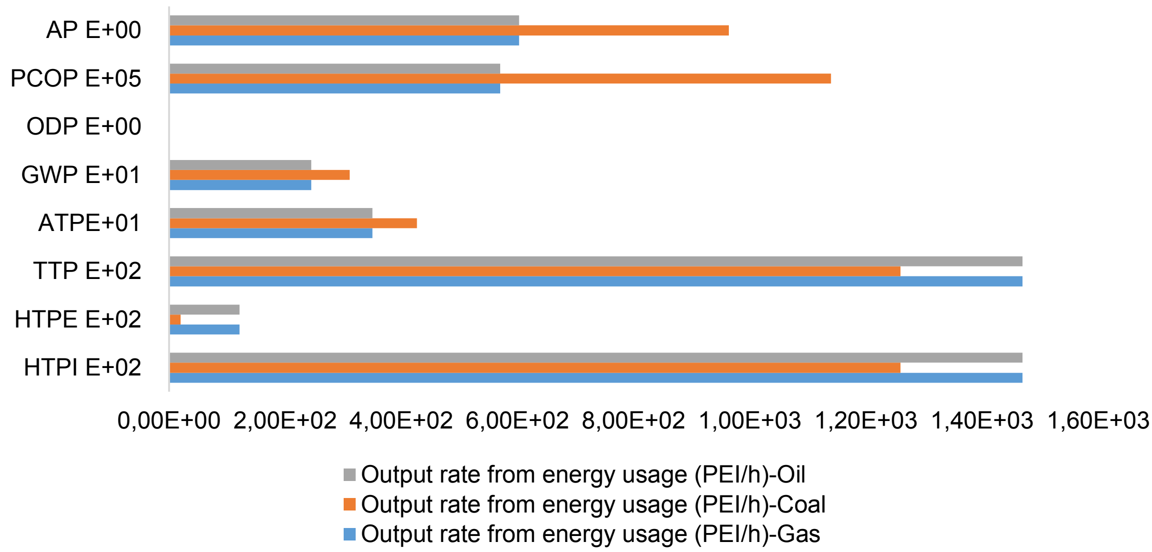

Figure 6: Effect of energy source on output rate from energy usage for a palm-based biorefinery

4. Conclusions

Waste Reduction Algorithm was implemented for environmental analysis of a palm-based biorefinery under North-Colombian conditions where the main products are oil palm, palm kernel oil and hydrogen. From results obtained, it can be said that the process is beneficial in environmental terms, which is reflected in a total PEI generated negative for all cases studied. In addition, the atmospheric impacts were lower than toxicological impacts, it can be said that the obtained products do not contribute to the increase of atmosphere deterioration. Finally, the different output environmental impacts of the process are influenced by the type of fuel used in hydrogen production unit, so comparing the three options leads to conclude that coal usage is not recommended because of increase impact under AP and PCOP categories. From the environmental point of view, the use of gas or liquid fuel are the most suitable due to their impacts are the same for all categories analyzed, taking into account resources availability in North-Colombia, use of gas as energy source is recommended.

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References

Barrett W.M., Van Baten J., Martin T., 2011, Implementation of the waste reduction (WAR) algorithm utilizing flowsheet monitoring, Computers & Chemical Engineering, 35(12), 2680-2686.

Bicer Y., Dincer I., Zamfirescu C., Vezina G., Raso F., 2016, Comparative life cycle assessment of various ammonia production methods, Journal of Cleaner Production, 135, 1379-1395.

Cavinato C., Gottardo M., Micolucci F., Bolzonella D., and Pavan P., 2016, Ammonia concentration and ph control in pilot scale two-phase anaerobic digestion of food waste for hydrogen production: focus on start-up, Chemical Engineering Transactions, 49,151-156.

Garcia J., Rodriguez D., Fontanill C., Silva E., Frear C., Stockle J., Garcia M., 2016, Evaluation of alternatives for the evolution of palm oil mills into biorefineries, Biomass and Bioenergy, 95, 310-329.

González-Delgado A.D., Peralta-Ruíz Y.Y., 2016, Environmental Assessment of a Crude Palm Oil Production Process under North-Colombian conditions Using WAR Algorithm, International Journal of ChemTech Research, 9(12), 833-843.

Hu P., Xu X., Lucy Yu L., Interesterified trans-free fats rich in sn-2 nervonic acid prepared using Acer truncatum oil, palm stearin and palm kernel oil, and their physicochemical properties, 2017, LWT - Food Science and Technology, 76, 156-163.

Martinez D., Puerta A, Mestre R, Peralta-Ruiz Y, González-Delgado A. D., 2016, Exergy-based evaluation of crude palm oil production in North-Colombia, Australian Journal of Basic and Applied Sciences, 10(18), 82-88.

Peralta-Ruiz Y.Y., Saavedra D., González-Delgado A.D., 2016, Exergy based evaluation of large-scale hydrogen production from African palm rachis, Australian Journal of Basic and Applied Sciences, 10(16), 168-175.

Petrescu L., Cormos C.C., 2015, Waste reduction algorithm applied for environmental impact assessment of coal gasification with carbon capture and storage, Journal of Cleaner Production, 104, 220-235.

Puccini M., Licursi D., Stefanelli E., Vitolo S., Raspolli Galletti A.M., Heeres H.J., 2016, Hydrothermal treatment of orange peel waste for the integrated production of furfural, levulinic acid and reactive hydrochar: towards the application of the biorefinery concept, Chemical Engineering Transactions, 50, 223-228.