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EMERGY AND LCA EVALUATION OF SUGAR INDUSTRY IN VERACRUZ, MEXICO

Evaluación Emergy y LCA en la agroindustria azucarera de Veracruz, México

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ABSTRACT. The sugar industry in Veracruz Mexico participates with 37,3 % of the national production of sucrose and integrates agricultural activities as growing, harvesting and transportation of sugarcane with industrial production in sugar mills. However, it faces challenges related to the fall in agricultural productivity practices derived from conventional crop management, the climate change and other socio-economic issues that threaten the conversion and diversification of sugar industry. So it requires innovative methodologies of analysis to determine critical points that threaten the environmental and economic sustainability. The goal of this term paper was to evaluate the production of the sugarcane in the supply areas of Veracruz Mexico by emergy analysis and LCA by analyzing several non-renewable and natural inputs related to the production of sugarcane per hectare. It was determined that the environmental and economic inputs for sugarcane system in Veracruz demand is high for nitrogen and phosphate fertilizer with a percentage of 27,2 %, labor 12,1 % and services 40,78 % of the total. The remaining 19,92 % is in order of the importance to fuels and operation of agricultural machinery in the process of planting and management, pesticides and potassium fertilization, and the stage of harvesting and transportation are the most significant with 64,65 % of total CO_2 emissions which establishes the need of restructuring the sugarcane crops field to reduce production costs and environmental impacts to increase profitability.

Key words: sugar, soil productivity, rofitability, fertilization, agricultural machinery

RESUMEN. La agroindustria azucarera de Veracruz, México participa con el 37,3 % de la producción nacional de azúcar e integra actividades agrícolas, de cosecha y de transporte de caña de azúcar con la producción industrial en ingenios azucareros. Sin embargo, enfrenta retos relacionados con la caída de la productividad agrícola derivados de las prácticas convencionales de manejo del cultivo, el cambio climático y otros aspectos socioeconómicos que ponen en riesgo la reconversión de la agroindustria, por lo que requiere metodologías multidisciplinarias de análisis para determinar puntos críticos que amenazan la sostenibilidad ambiental y económica. El objetivo de este trabajo fue evaluar la producción de caña de azúcar en las zonas de abastecimiento de los ingenios de Veracruz, México por el análisis eMergy y LCA mediante el análisis de los insumos naturales y no renovables por hectárea de caña de azúcar. Se determinó que la carga ambiental y económica del sistema cañero veracruzano es elevada en la demanda de fertilización nitrogenada y fosfórica con un porcentaje de 27,2 %, mano de obra 12,1 % y servicios 40,78 % del total. Posteriormente, el 19,92 % corresponde en orden de importancia a combustibles y operación de maquinaria agrícola en la etapa de siembra y manejo, pesticidas y fertilización potásica y las etapas de cosecha y transporte que son las más significativas al totalizar el 64,65 % de emisiones de CO_2, lo que establece la necesidad de reestructurar el campo cañero veracruzano para disminuir costos de producción y la carga ambiental para incrementar la rentabilidad.

Palabras clave: azúcar, productividad del suelo, rentabilidad, fertilización, maquinaria agrícola

INTRODUCTION

The sugar agroindustry, as a socio-ecological system, is one of the most important enterprises worldwide, with a high social, economic and spatial impact to produce a commodity useful as food for human beings, that has a high quality and purity; in addition to the diversification of the sugarcane use and byproducts like biorefineries and also for its contribution

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to thes generation of employment, particularly in rural areas with a sustainable development and national economies. However, the gradual increase of production costs, harvest and sugarcane manufacturing in the sugar sector, the challenges of global, regional and local competitiveness (productivity, diversification, innovations, management, environmental services, R + D, etc), the necessary development of biorefineries and productive conversion into sugar mills, distilleries and sugarcane production units together with the environmental impacts on the soil, air and water of this agroindustry, make imperative the search for new effective production alternatives, new knowledge and development of new technologies that significantly contribute to its sustainability, all of which include the establishment of new sugarcane production systems and new approaches of organizational structure and analysis of the sector to formulate action alternatives at short, medium and long term as well as differentiated public policies (1) (Figure 1).

In this regard, the crop is attractive from the point of view of the potential to produce electric energy, foods, biofuels and chemicals derived on a renewably basis through ethanol, sugar and the electric cogeneration due to the high efficiency of this plant C4 in the production of biomass from solar energy. However, the primary productivity of the sugarcane (Saccharum spp.) as raw material, is restricted by several environmental and socioeconomic factors, and in this case, the conventional methodologies for measuring the sustainability of the neo-classic economy and its results, have not reached potential productivity (>150 t ha^{-1}), that is, the research on this multicausal effects are still poor in Mexican sugarcane growing areas, since determining critical points of the agroindustrial system is essential to take decisions in the short and medium terms.

Agricultural systems in general, and sugarcane in particular, depends on Nature's contributions (rainfall, soil, radiation, winds, etc.) and on the economy of intensive agriculture (inputs like agrochemicals, manpower, agricultural machinery, fuels, etc.) usually of high quality, imported and non-renewable. Therefore, it is necessary to take into account the need of methodological tools to compare resources and inputs of different agricultural systems to have a holistic and integrating vision, of the applied inputs and limiting factors of great spatial dispersion and impact (social, cultural, economic, energetic, biological, climatic, geophysical, etc.) (2, 3, 4, 5).

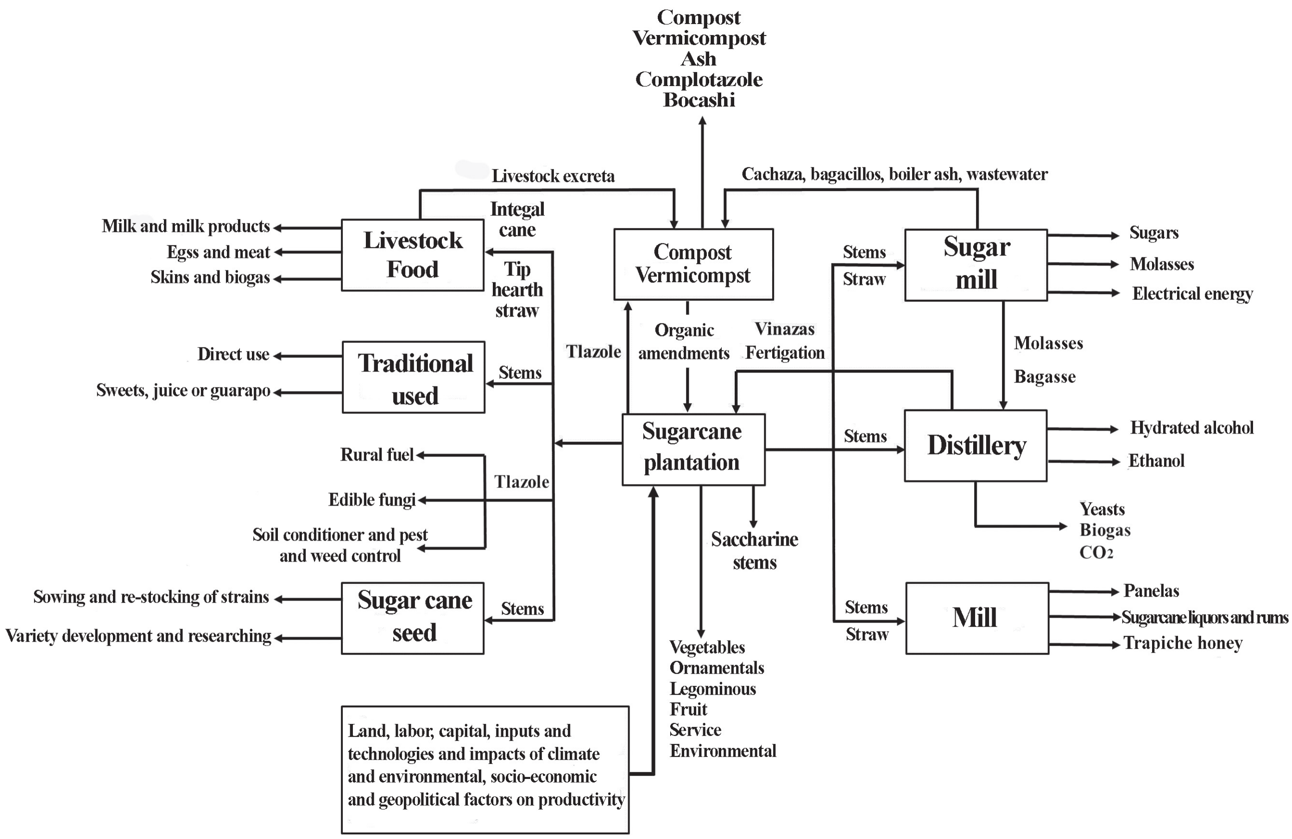

Figure 1. Productive integration of the sugarcane agroindustry

Thus, an essential step to maximize opportunities, comparative and competitive regional advantages based on diversification or productive conversion is to provide follow-up to evaluating procedures as major toods for decision taking. Likewise, Ecological Economy is a science using the General System Theory, Systemic Ecology and Thermodynamics of Open Systems to look at reality, explain its complexity and shows its dynamics through different methodologies like Emergy or emergetic synthesis, life cycle analysis (LCA) and Multicriteria Evaluation (EMC), among others. In the sugar agroindustry, the objective of these methodologies of environmental management is analyze sugarcane production with energy wise criteria to identify sustainable systems with less inputs and emissions during planting, crop, harvest and transportation of seed cane, first-cut sugarcane and second or third-cut sugarcane, crop, harvest and transportation making and inventory of energetic inputs used converted into their equivalents in energy and energetic efficiency values, comparing traditional systems (comprehensive harvest with burning, hand planting and the use of agrochemicals), green sugarcane (comprehensive harvest without burning, hand planting, the use of stubble for coverage and biofertilizers), energetic (comprehensive harvest without burning, mechanical planting, the use of filter-press mund and biofertilizers) and ecological for the production of straw and other byproducts (6).

Emergetic synthesis or eMergy, is based on the study of biogeophysical and socioeconomic flows of matter and energy exchanged among the elements making up socio-ecological systems under the same basis (7, 8). That is, the term EMergy is defined as the quantity of energy directly or indirectly used in the generation of a certain good or service in order to analyze the different contributions of energetic flows (Nature and economy) under a common unit emjoule solar (seJ).

The Emergetic intensity is equal to the actual value of the product, that is, all the energy used in the production of a certain quantity of products. There are three main types of Emergetic Intensity: Transformation (in $seJ.J^{-1}$), Specific Emergy (in $seJ.g^{-1}$) and Emergy by Monetary Unit (en $seJ.\$^{-1}$). The transformation of a product measures the energy quality and its hierarchical position in universal energy, which is attained by adding all entries of the solar emergy of the process (in seJ) divided by the energy coming out from the final product (in J). As higher the number of transformations of necessary energy to manufacture a product or the execution of a process, the higher will be the value of that transformation, and also the importance of the resource for ecosystems and human beings will be higher too (9). This approach makes possible to dynamically visualize and quantify the flows of natural resources, environmental services of Nature and the impacts of human activities, thus allowing the understanding of limits in each ecosystem and the setting of goals to guarantee the capacity of the support, that is, to determine the sustainability of systems (Figure 2).

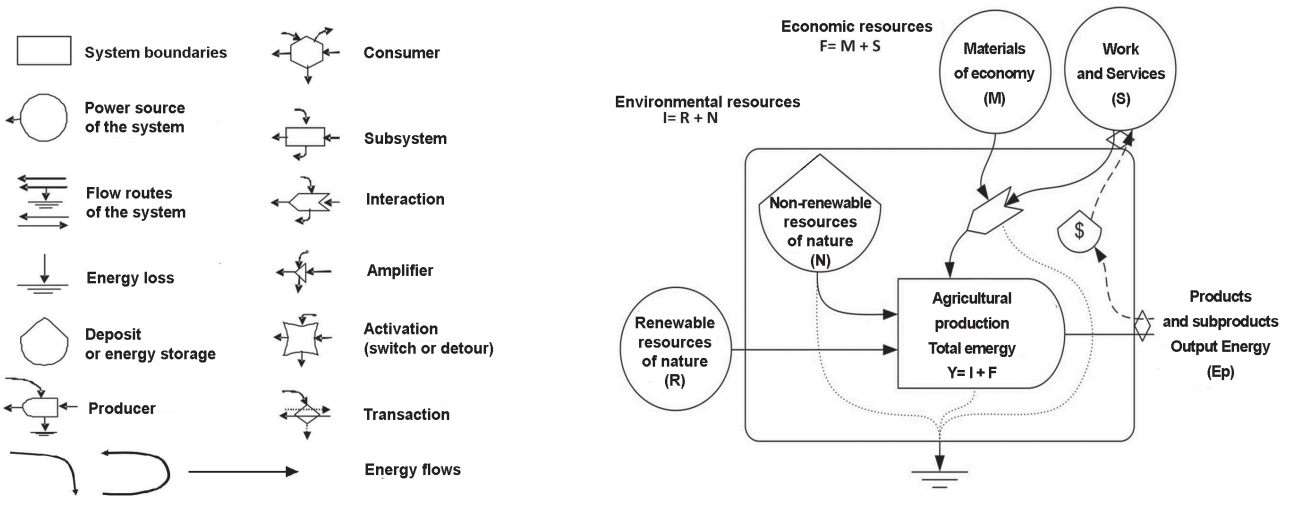

Figure 2. Emergetic Symbols and diagram of agricultural systems[A] (10)

[A] Huertas, P.L.L. *Aportaciones de la sintesis emergética a la evaluación multi-escalar del empleo de los servicios de los ecosistemas a través de casos de estudio* [Disertación Doctoral], Universidad Autónoma de Madrid, Madrid, España, 2009, 269 p.

For sugarcane, the studies of emergetic[B, C] (11, 12) 16] have mostly focused on the production of ethanol with the conventional agricultural system.

Life cycle analysis (LCA)

Different methodologies have been developed as to environmental management is concerned, namely, the life cycle (LCA) concept that involves the analysis, documentation and quantification of environmental load of the complete life of a product and its associated service. The LCA methodology allows a follow up of each of the steps of the sucarcane and byproducts production process, it also determines which are the most important impacts to quantify allocating ecopoints (ecological trace); therefore, LCA provides a holistic and comprehensive evaluation of the environmental impact of goods, process and products considering the emission of greenhouse effect gasses, acidification potential, equivalent eutrophyzation per tonne of sugarcane, etc, in order to identify the critical points of the system and in the particular case of sugarcane agroindustry, looking at productive diversification purposes and transition to biorefineries (13, 14, 15, 16, 17, 18, 19).

The sugarcane agroindustry in Veracruz, Mexico

The sugarcane agroindustry in Veracruz, Mexico, integrates agricultural activities of growing, harvest and transportation of the sugarcane with the industrial production of sugar mills. However, it faces challenges related to agricultural productivity fall due to the conventional practices of crop management, climate change and other socio-economic aspects that endanger food security and conversion of the agroindustry into biorefineries, relative to this basic carbohydrate for the population. In the 2013/2014 season, sugarcane was the main perennial and agroindustrial crop of the state, contributing 37.7 % (20,506,054 t) of the domestic total sugarcane production; 40.7 % of the harvested planted area (322,324 ha) and 37.3 % (2,244,154 t) of the sugar produced domestically in the last ten years; with a field yield of 63.56 t ha^{-1}. It is located in 173 municipalities and 50,596 production units that account for 22 sugarcane supply areas for sugar mills and sugarcane crushers in the state of Veracruz and neighbor municipalities like San Luis Potosí and Oaxaca (Figure 3), However, the productivity shown in this ten-year period was from medium to low (Table I).

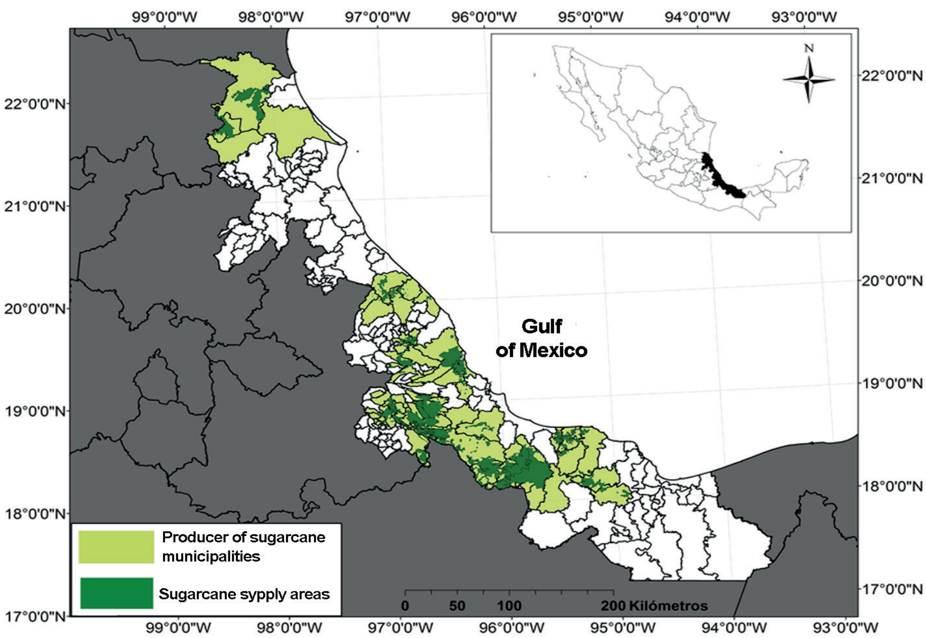

Figure 3. Sugarcane growing areas in Veracruz, Mexico

[B]Alonso-Pippo, W.; Rocha, J.D. y Mesa-Pérez, J.M. ‘‘Emergy evaluation of bio-oil production using sugarcane biomass residues at fast pyrolysis pilot in Brazil’’, *Proceedings of IV Biennial International Workshop ‘‘Advances in Energy Studies’’*, Unicamp, Campinas, SP, Brazil, 2004, pp. 401–408.

[C]Ometto, A.R.; Roma, W.N.L. y Ortega, E. ‘‘Emergy life cycle assessment of fuel ethanol in Brazil’’ [en línea], (eds. Ortega, E. y Ulgiati, S.), En: *Proceedings of IV Biennial International Workshop «Advances in Energy Studies»,* Unicamp, Campinas, SP, Brazil, 2004, pp. 389–399, [Consultado: 15 de junio de 2015], Disponible en: <http://www.unicamp.br/fea/ortega/energy/Ometto-1.pdf>.

Table I. Productivity indicators of the sugarcane industry in Veracruz[D]

Indicator/Season	2000/2001	2010/2011	Difference (%)
Sugarmills	22	19	-13,64
Field yield (t/ha)	74,17	59,707	-19,50
Agroindustrial yield (t/ha)	8,111	6,984	-13,89
Harvested planted area (ha)	241,256	270,902	+12,29
Sucrose in sugarcane (%)	13,490	13,982	3,65
Fiber in sugarcane (%)	13,14	13,495	2,70
Field operation			
Cutting crews (#)	21	19	-9,52
Cane cutters (#)	1,732	1,719	-0,75
Transportation vehicles (#)	270	329	21,85
Mechanically harvested sugarcane (%)	7,110	9,709	36,55
Mechanically hauled sugarcane (%)	76,281	85,309	11,84
Net sugarcane price ($/Ton)	308,26	719,48	133,40
Sugar mill			
Net ground sugarcane (t)	17,262,712	15,618,455	-9,52
Sucrose lossesarosa (%)	2,25	2,318	3,02
Sugarmill efficiency (%)	82,883	83,429	0,66
Sugarmill yield (%)	11,01	11,70	6,27
Total waste time (%)	25,90	17,33	-33,09
Sugarcane byproducts production (Coproducts and byproducts)			
Sucrose (t)	1,956,940	1,892,096	-3,31
Refined (t)	807,053	696,354	-13,72
Standard (t)	1,121,062	1,150,391	2,62
Mascabado (t)	28,825	45,351	57,33
Ethanol (L)	41,778,451	5,196,380	-87,56
Ethanol yield(L /t of molasses)	290,75	231,695	-20,31
Molasses (t)	618,105	577,929	-6,50
Molasses at 85º Brix per ton. of sugarcane	36,048	35,730	-0,88
Molasses at 85º Brix for alcohol manufacturing (t)	70,907	22,428	-68,37
Filter-press mud (t)	741,761	742,867	0,15
Filter-press mud in sugarcane (%)	4,487	4,593	2,36
Bagasse (t)	5,175,583	4,740,284	-8,41
Industrialized bagasse (t)	437,117	603	-99,86
Electric energy from bagasse burning (KWH)	268,846,821	272,440,824	1,34
Steam generation from bagasse burning (t)	10,664,242	9,370,163	-12,13
Thermal and energetic balance			
Electric energy consumption Of CFE (KWH)	15,031,898	11,074,065	-26,33
External fuel consumption (L oil)	296,437,388	65,441,521	-77,92
Oil consumed in the sugarmill per ton of sugarcane (L)	13,575	3,490	-74,29
External electry energy consumption per ton. of sugarcane	16,527	17,528	6,06
Steam consumption per ton. of sugarcane	0,610	0,579	-5,08

For a sucessful conversion to biorefineries in Veracruz, Mexico, it is necessary to take as a point of departure the primary production sector, that is, the sugarcane field, where the problem of of the agroindustry in the rural sector shows, on a generic basis, a phenomenon with the following features, among others: Low incomes and yields per production unit, deficient fertilization, sugarcane growers from small production units (3 ha/grower), resistance to the technological change due to cultural values and beliefs, social relations, absence of bylaws and phytosanitary regulations, organization forms that determine the existence of vicious circles of low-yields-low-incomes-poverty-social, economic, environmental and political marginality. The objective of this research has been evaluating the application of metodologies for environmental, economic and ecological management: eMergy and life cycle (LCA) to analyze sustainability in sugarcane growing areas in the state of Veracruz.

[D]*Sistema Infocaña* [en línea], 2014, [Consultado: 15 de junio de 2015], Disponible en: <http://www.campomexicano.gob.mx/azcf/reportes/reportes.php?tipo=AVANCE>.

MATERIALS AND METHODS

The study area is located in the 22 sugarcane supply areas of Veracruz, Mexico (El Potrero, El Modelo, Providencia, Tres Valles, Zapoapita, La Gloria, Central Motzorongo, El Higo, Mahuixtlan, Central Progreso, Constancia, San Miguelito, San Nicolás, San Cristóbal, San José de Abajo, San Pedro, El Carmen, Cuatotolapam, Nuevo San Francisco, Independencia, La Concepción and San Gabriel) where climate is semiwarm humid, with annual mean temperatures of 25ºC. Annual mean rainfall shows a gradient from 1,200 to 2,000 mm. Humidity is mainly distributed in the summer. The rainy period starts in May and ends in October. The highest rainfall volume is from June to September being August the rainiest month.

For the emergetic analysis of Veracruz's sugarcane growing area, that is, the inventory of inputs and outputs or material and energy exchange status, each of the sugarcane production based on an average yield of 65 t ha^{-1} average in the last five seasons. Data from the conventional management (rainfed) sugarcane cycle taken from the Mexican Sugarcane Handbook for the seasons 2005 – 2012 were used. The Emergetic methodology applied in sugarcane consisted in:

Collecting information from the sugarcane supplying areas and sugarcane transformation; renewable resources (sunlight, rains) and non-renewable (eroded soil), acquired resources (fuels, agrochemicals and manpower for production, annual practices performed by the grower), annual yields and incomes of production systems; rainfall and eroded soil data per year based on the georeferenced soil sampling according to the Official Mexican Standard that establishes the Fertility, Salinity and Soil Classification Specifications. Studies, Sampling and Analysis (NOM-021-RECNAT-2000) reported by the Agrofood and Fishing Information Service and the Characterization Study of Potential Areas for Mechanization in the Sugarcane Supply Areas from the Postraduate College -SAGARPA and sugarcane production statistics[E].

Preparing a diagram of the emergetic system or Modelling of the socio-ecological system as the representation, through diagrams, of raw material and energy flow, using energetic symbols of the interaction of external and internal sources of the system, and the ecological and socio-economic factors, as well as the output flows of the system and the feedback. Likewise, other flows that are key and/or limiting factors in sugarcane or components, inputs and interactions.

Calculating the eMergy and transformations, quantifying annual inputs of each system at basic units (J, hours) to reach values per year (J/year, h/year), which were multiplied by the transformed value (in sej/J), resulting in the value of eMergy in jules of solar eMergy per year or sej/year. Inputs and products were converted into emergetic units (20). In order to standardize data per surface unit, the value of sej/year was dived by the sugarcane planted area in Veracruz to attain the eMergy value in sej/ha per year. eMergy totals were estimated for sections of Renewable and Non-Renewable Resources, Acquired Resources (Purchased) and Exported Resources.

The equations (Table II) and rates used were:

- Transformation (Tr) is the relationship between total incoming emergy to the system (Y) and the emergy of the products coming out (Ep), it is expressed in seJ. This indicator reveals a quality of the systemas higher Tr is, more energy is required to generate products. It can be interpreted as the inverse value of the efficiency of an agroecosystem. (Y) incorporated emergy by the system and (E) energy of the resource.
- Renewability (%R) is the relationship between renewable inputs of Nature (R) and the total emergy coming into the system (Y), it is expressed in percentage.
- Emergetic Yield Rate (EYR) is the relatiohsip between total emergy coming into the system (Y) and economy's contribution (F). This indicator is adimensional and allows to know, in general, the net benefit the system offers to global economy.
- Emergetic Investment Rate (EIR) is the relationship between economy's contributions (F) and Nature (I), it is also adimensional. This indicator helps to understand the "bought" emergy intensity used in the agro-industrial systems.
- Environmental Load Rate (ELR) is the relationship between the sum of non-renewable resources of Nature (N) and those of the economy (F) for Nature's renewable resources (R), it is also adimensional. When the value of the indicator is high, the environmental impact of the system will be also high. It also indicates that production costs are higher, so the final price will increase, making the product and growing areas less competitive market wise with a lower environmental load (22).

[E] *Estadísticas de la Agroindustria* [en línea], 2014, [Consultado: 15 de junio de 2015], Disponible en: <http://www.caneros.org.mx/estadisticas.html>.

Table II. Equations for the sugarcane eMergy analysis forn a conventional rain-fed system (21)

Input	
	General equation: eMergy $\left(\frac{sej}{año.\,ha}\right)$ = Annual energy xTransformation $\left(\frac{sej}{J}\right)$
	Specific Equations
Sun	eMergy Sun $(J/((año.\,ha))$ = Solar energy $(J/((año.\,ha))$ xSolar transformation Solar energy $(J/((año.\,ha))$ =Sugarcane area (m2) x average insolation $sej/(año.\,ha))$. 1-Albedo
Rainfall	eMergy Rain $(sej/(año.\,ha))$ = Energetic potential of the rain xTransformation rain $\left(\frac{g}{m^3}\right)$ Energetic potential rain $\left(\frac{m}{año.\,ha}\right)$ = Rainfall $\left(\frac{g}{m^3}\right)$ .Sugarcane area (m2).water density $\left(\frac{g}{m^3}\right)$. (1-runoff coefficient). Gibbs' free energy
Evapo transpiration	eMergy by evapotranspiration $\left(\frac{m}{año.\,ha}\right)$ = Annual energy m xTransformation $\left(\frac{m}{año.\,ha}\right)$ Energía anual m = Evapotranspiration $\left(\frac{m}{año.\,ha}\right)$. Sugarcane area (m2) x water density . Gibbs' free energy
Erosion	Soil loss = Planted area (m2).erosion rate $(g/((año.\,m^2))$ Organic matter in agricultural soils = Soil. Organic matter (%) Energy loss (J)= Organic matter loss. Energy (J)/organic matter (g)
Fuels	eMergy fuels $(sej/(año.\,ha))$ = Average hours of machinery use .Average fuel consumption .Energy of the fuel x Transformation
Agricultural machinery	eMergy agricultural machinery $(sej/(año.\,ha))$ = $$\frac{energia\ Incorporada\left(\frac{MJ}{año.\,ha}\right) x\ Transformicidad\ Maquinaria\left(\frac{sej}{kg}\right)}{Transformicidad\ Maquinaria\ incotporada\left(\frac{MJ}{kg}\right)}$$
Potassium fertilization	Annual consumption = (g of active ingredient fertilizer) (78 gmol K/94 gmol K_2O) eMergy Potassium $\left(\frac{sej}{-}\right)$ = Annual consumption x energy fertilizer $\left(\frac{sej}{J}\right)$ Transformation $\left(\frac{sej}{J}\right)$
Phosphorus fertilization	Annual consumption = (g of active ingredient fertilizer) (31 gmol P/132 gmol DAP) eMergy Phosphoruso $\left(\frac{sej}{año}\right)$ = Annual consumption x energy fertilizer $\left(\frac{sej}{año}\right)$ Transformation $\left(\frac{sej}{año}\right)$
Nitrogen fertilization	Annual consumption = (g of active ingredient fertilizer)(28 gmol N/132 gmol DAP) eMergy Nitrogen $\left(\frac{sej}{año}\right)$ = Annual consumption x energy fertilizer $\left(\frac{sej}{J}\right)$ Transformation $\left(\frac{sej}{J}\right)$
Pesticides, fungicides and herbicides (agroquímicos)	Annual consumption eMergía (sej) = Energy xTransformation $\left(\frac{sej}{J}\right)$
Manpower	Manpower (J) = (working hours/ha/yearo).(2500 kcal/day per metabolized energy.(4186J/Cal) / (# persons hrs/day)
Services	Services $ por ha = ($ /year)(sej/$) eMergy $\left(\frac{sej}{e}\right)$ = Services xTransformation $\left(\frac{sej}{\$}\right)$

Life cycle analysis

This research used the methodology developed by the intergovernmental panel on climate change IPCC environmental and associated socio-economic impacts[F] (17, 23, 24, 25), for the balance of emissions of greenhouse effect gasses (or carbon trace) on a productive cycle of five seasons average (2007 - 2011) during the production stage of sugarcane and four cycles of second-cut sugarcane till being industrially processed (Figure 4), with statistics used in the emergetic analysis of Veracruz's sugarcane growing area in Mexico. Field preparation stages were considered for establishing the crop, management and planting, production and transportation of agricultural inputs, harvest, stalk hauling to the sugarmill.

RESULTS AND DISCUSSION

Figure 5 shows the emergetic diagram with the flow of inputs and outputs of the sugarcane field in Veracruz, Mexico, where the fllow shows how Nature's inputs like sun, rainfall and raw material incorporate into the system. All of them, are local renewable resources; inputs to the economy (resources) and manpower are imported non-renewable resources. Also shown are the storage devices of energy, like the soil. The outputs of the system are presented like eroded soil, which is considered a non-renewable resource, energly loss (by entropy) and in the systems production (exported goods), among others.

When conceiving this flow diagram, the main components and energy flows representing the sugarcane system in the studied period, were identified (Table III).

The energetic evaluation carried out showed that the environmental load of the sugarcane system in Veracruz, Mexico, first cut cycle, high emergetic values by having a relationship of non-renewable / renewable inputs of only 7 %, mainly for the demand of nitrogen and phosphoric fertilization with a value of 429 and 217 E+13 sej/year followed by manpower values of 289 E13 sej/year, and in service costs 969 E+13 sej/year which are extremely high. It reflects in the high production costs of sugarcane in Veracruz, as seen in the value of 13 for the investment relation, something opposite to what happens with pesticides and herbicides. It fixes a low chemical control to the phytosanitary status of the crop with a drastic field productivity fall, where the current average yield (61.676 t ha^{-1}) in the 2011/2012 season has gone down to 12,9 t sugarcane/ha (16,9 %) since the 2000/2001 season.

[F] Chohfi, F.M.; Dupas, F.A. y Lora, E.E.S. "Balanço, análise de emissão e seqüestro de CO_2 na geração de eletricidade excedente no setor sucro-alcooleiro" [en línea], *Procedings of the 5th Encontro de Energia no Meio Rural*, Campinas, SP, Brasil, 2004, [Consultado: 15 de junio de 2015], Disponible en: <http://www.proceedings.scielo.br/scielo.php?pid=MSC0000000022004000100031&script=sci_arttext&tlng=pt>.

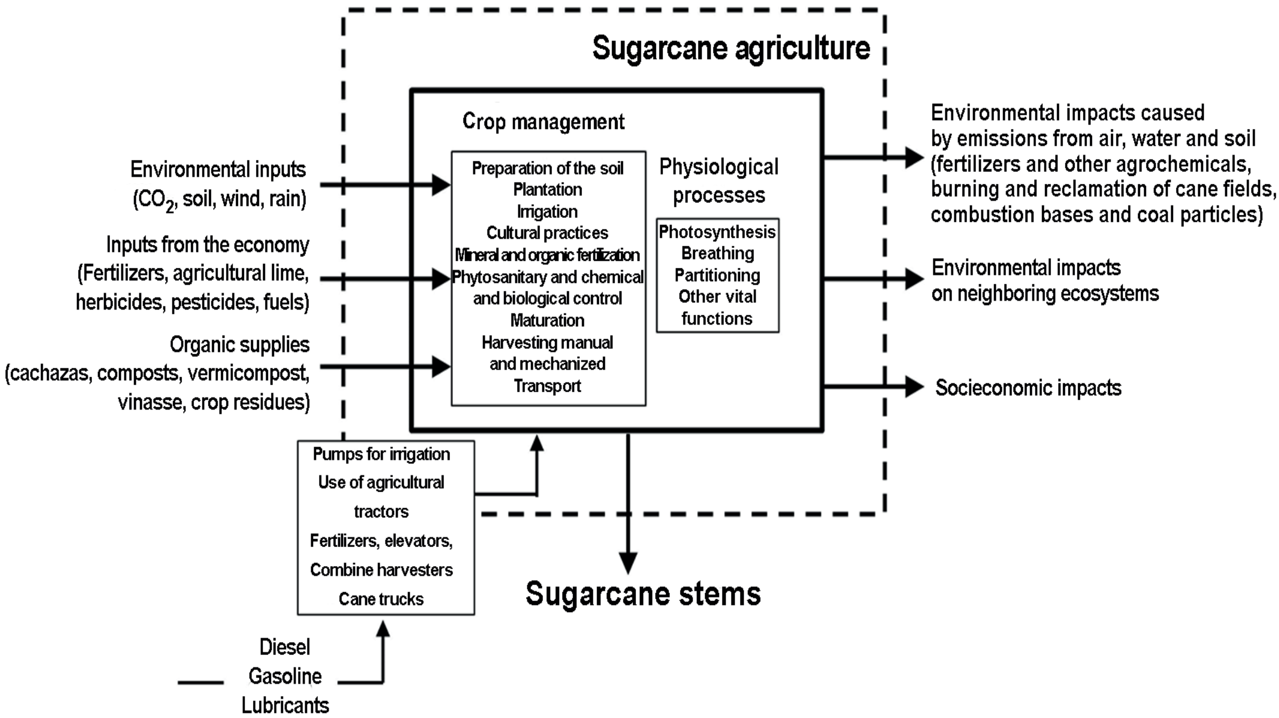

Figure 4. Conceptual diagram of the life cycle of sugarcane production and associated impacts

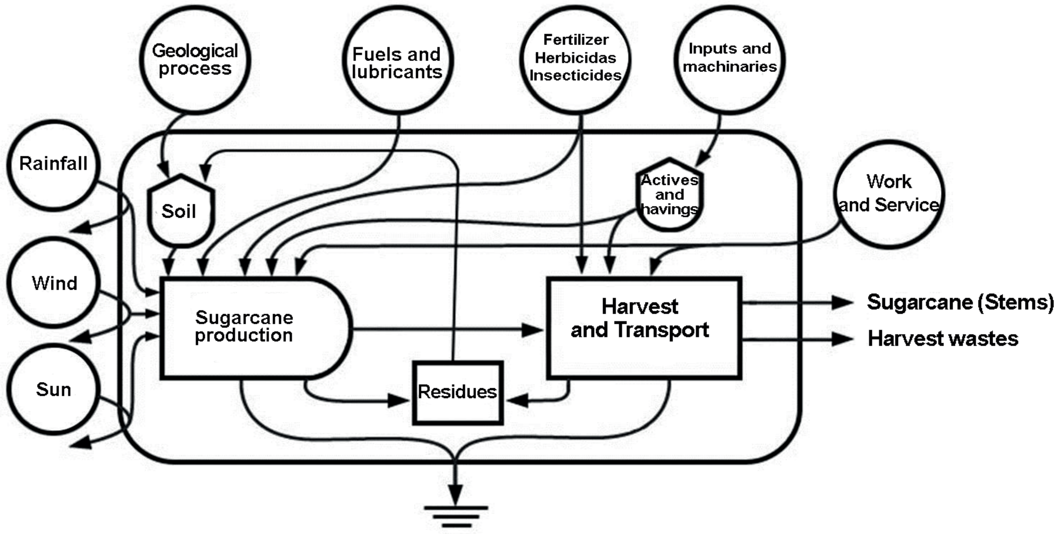

Figure 5. Diagram of the ecological-economical interphase of a sugarcane ecosystem and eMergy flow[G]

It can be seen in the increased planted area needed to produce one tonne of sugar that used to be 241,256 and now it is 271,884 ha (30,628 ha increase) and also in the fall of sugar and ethanol production that do not consistently impact on the local balance between "supply" and "demand" which means that the sugarcane system has economic and environmental losses with an Investment Emergetic Rate (EIR) of 13, since a lower value means a better use of renewable resources, that is, for Veracruz sugarcane areas deliver more energy than the emergy value received by the market and Nature (pressure of the economic system to the environment at local level) and therefore, it is less competitive.

The agroecosystem, with a value for the Emergetic Sustainability Index (EIS) lower than 1 (0.08) and with an ESR of 0.072, indicates a high consumption level of economy inputs (external), while EIS values higher than 1 are indicative of systems with a net contribution that does not greatly affect the balance of the environmental system. Though it has an Emergetic Yield Rate (EYR) higher than 1.07, it indicates its capacity to provide net energy to the economy, but it is produced at the expense of the environmental balance equivalent to an intensive use of industrial inputs, equipment and fossile fuels mainly, so yields are low. These results are important when compared to the biofuel alternatives and are partially explained by the incompatibility of Nature's resources in Veracruz with the supply and demand market of sugarcane that does not consider sun, rainfall, evapotranspiration and other environmental services as limited and free, and therefore they are underestimated. However, the total transformation value of 2,376 E+16 sej/J is higher than the reported values in Brazil (9,43 E+15 sej/J and 4,83 E+15 sej/J) for agroecological and conventional systems, and in Florida (1,11E+16 sej/J) which established the non-planned use of natural and economy's resources with a value of 13 in the relationship of external/natural resources (environmental load), in spite of a lower use of agricultural machinery and chemicals in Veracruz, which can be seen in the use of less fuel, but in a higher manpower use for crop and harvest management, transportation to the sugarmill and services to produce one tonne of sugarcane (26).

The emergy indicators LSR, LER and EER were used to evaluate the intensity and characteristics of the manpower used in sugarcane agriculture. LSR is the relationship between manpower and total used services. The value of 0,23 indicates less manpower use by the agroindustrial system and at the same time, more use of services since it is marked by the intensive use of machinery and chemicals that replace human manpower and cultural practices for crop management. The LER relation is the proportion of manpower to total energetic performance of the sugarcane system. Value 0.12 indicates that the energy derived from the manpower use is high and should be optimized as to the use of machinery and current services. The relationship between external factors and energetic

[G] Lanzotti, C.R.; Ortega, E. y Guerra, S.M.G. "Emergy analysis and trends for ethanol production in BraziL", (ed. Brown, M.T.), en: *Emergy Synthesis 1: Theory and Applications of the Emergy Methodology*, *Proceedings of the 1st Biennial Emergy Conference*, edit. Center for Environmental Policy, University of Florida, Gainesville, 2000, pp. 281-288.

Table III. Emergy rates in sugarcane production in Veracruz, Mexico

Input	Units	unit/year	Transformation	E13 sej/año	%
Nature's renewable resources (R)					
Sun	J	5,70E+13	1	6	0,240
Rainfall (chemical potential)	J	5,90E+10	3,02E+04	178	7,510
Evapotranspiration	J	6,51E+10	2,59E+04	168	7,086
Total		5,71E+13	5,61E+04	352	14,836
Nature's non renewable resources (N)					
Erosion (soil loss)	J	3,16E+08	1,24E+05	4	0,165
Nature's inputs (I= R+N)*		6,54E+10	1,50E+05	172	7,251
Materials of the Economy (M)					
Fossil fuel	J	1,57E+10	1,11E+05	174	7,322
Agricultural machinery	g	5,54E+04	1,12E+10	62	2,611
Potassium	g K	1,24E+05	1,85E+09	23	0,968
Pesticides, fungicides and herbicides	g	1,59E+04	2,52E+10	40	1,686
Phosphorus	g P	5,87E+04	3,70E+10	217	9,133
Nitrogen	g N	1,06E+05	4,05E+10	429	18,073
Total		1,57E+10	1,17E+11	945	39,793
Services (S_N)	$	2,40E+03	4,03E+12	969	40,795
Manpower (S_R)	J	6,49E+08	4,45E+06	289	12,152
Services of the economy ($S = S_R + S_N$)		6,49E+08	4,03E+12	1258	52,947
Resources of the economy (F = M + S)		1,63E+10	4,15E+12	2203	92,74
Emergy (Y=I+F)				2376	99,992
Emergy (Y)		2,376 E16 sej/año			
Transformation (Tr) $ELR = \frac{(N+F)}{R}$			6,58E6 sej/J solar energy equiv./J of cane		
Renewability (%R) $ELR = \frac{(N+F)}{R}$			7		
Emergetic Yield Rate (EYR) $ELR = \frac{(N+F)}{R}$			1,07		
Emergetic Investment Rate (EIR) $ELR = \frac{(N+F)}{R}$			13		
Environmental load rate (ELR) $ELR = \frac{(N+F)}{R}$			13		
Energetic sustainability rate $LER = \frac{Sr}{v}$			0,08		
Relation of Energetic self-sustainability $LER = \frac{Sr}{}$			0,072		
Energetic relation of labor services $LER = \frac{Sr}{Y}$			0,23		
Relation of work development $LER = \frac{Sr}{Y}$			0,12		
Relation of energetic external factors $ExER = \frac{Sn}{Y}$			0,41		

*For the calculation of rates, sun and rainfall contribution is not considered because in the energetic balance, both inputs are considered in the evaporation process performance ExER indicates that the sugarcane system generates negative external factors (0.41) since it should tend to be cero to be sustainable, that is, sugarcane production in Veracruz, México shows a high index of environmental load (ELR), a low self-energetic relationship (ESR) and a low emergy yield relationship (EYR) in its time variation which shows a weak sustainability characteristic of an agroecosystem going through a deep transition from the traditional one intensive in manpower use, to a modern agroindustry based on the consumption of non-renewable resources (27, 28, 21, 29).

Life cycle analysis

The methodology used shows a global emission balance in all the stages of the sugarcane system of Veracruz, Mexico (Table IV)

Therefore, the analysis confirms that sugarcane production in Veracruz greatly contributes to the capture of greenhouse-effect gasses due to the emission values of CO_2 which are lower to those reported in the literature (30, 31, 32); it comes from the smaller productive planted area and a low use of agricultural technology, mainly in planting and harvesting; however, in Veracruz, the stages of cutting, harvest and transportation are the most significant ones by totalling 64.65 % of emissions in technified systems.

Other stages do not have a significant contribution to environmental problems of the agroindustry, only the soil and biological processes with 14.56 %, however, differentiated actions are required for each sugarmill be able to minimize the environmental impact and jump into an agroecological sugarcane agriculture.

Table IV. Emission balance of sugarcane crop in Veracruz, Mexico

Emission stage, process, operation or activities emitting CO_2	First-cut cycle ($kgCO_2$/ha 1º cut)	Five-cuts cycle ($kgCO_2$/ha)	Total emission ($kgCO_2$/ha/life cycle)	%
1) **Field preparation for planting**				
1.1)) Production and maintenance of equipment and agricultural machinery	3,675		3,675	2,44
1.2) Tractors and agricultural machinery	0,947		0,947	0,63
2) **New planting**				
2.1)) Transportation of seed cane to the plantation site	2,274		2,274	1,51
2.2) Planting operations	0,254		0,254	0,17
3) **Administration and management of the crop and plantation**				
3.1) Application (tractors and agricultural machinery)				
Agricultural lime	0,020		0,020	0,01
Herbicides	0,020	0,098	0,117	0,08
Filter press mud	1,332		1,332	0,88
Nasty wine	1,723	8,605	10,327	6,85
Fertilizers	0,449		0,449	0,30
3.2) Production of agricultural inputs				
Agricultural lime	0,820		0,820	0,54
Herbicides	1,762	8,810	10,571	7,01
Insecticides	0,098		0,098	0,06
3.3) Transportation of agricultural inputs				
Agricultural lime	0,029		0,02	0,02
Herbicides	0,029	0,146	0,12	0,12
Filter press mud	0,029		0,02	0,02
Nasty wine	0,029	0,146	0,12	0,12
Fertilizers	0,029		0,02	0,02
Insecticides	0,029		0,02	0,02
3.4) Soil emissions			21,963	14,56
4) **Harvest**				
4.1) Machinery (hoist and harvesting machines)	0,225	1,635	1,860	1,23
4.2) Stalk transporting trucks	14,871	61,862	75,855	50,29
5) **Transportation of sugarcane stalks**				
5.1) Transportation to the sugarmill	3,299	16,496	19,796	13,13
Total			150,826	100 %

- Development of varieties by breeding, each of them specific for a type of soil and for certain climatic conditions and water availability for different productive environments, in addition to be very resistant to the main diseases and with scenes of climate change, ENSO, that will cover future needs like the production of alcohol from sugarcane biomass.
- Increased productivity in supplying areas to cover the grinding needs in sugarmills and other enterprises, that is, vertical growth of sugarcane production (more production in the same planted area).
- Mechanized planting to reduce the necessary seed volume, transportation costs, and the consumption of fossil fuels and oil byproducts.
- In the agricultural field, increase the inputs efficiency, machinery and manpower to produce more with quality and with the lowest possible cost, that is, redesign and resize sugarcane fields.
- Fertigation, sustainable water and nasty wine, incorporation of good management practices to widen the useful and productive life of the sugarcane plantation.
- Favor pest, weed and disease control through mechanical, plant protection and biological control techniques using natural enemies, chemicals with low toxicity insecticides.
- Using precision agriculture techniques (Remote perception, GPS and SIG) to determine the suitability of sugarcane growing lands, and based on this information, to perform an agroecological adaptation of supplying areas, improve irrigation systems, mechanization (harvest mainly), fertilizers, the use of composts and green manure, pest and weed management with the use of specialized softwares; biological control by using natural enemies, chemical control with low toxicity insecticides; make management processes extensive to sugarcane growers to increase the productivity of raw material with greater relative advantages or, at least, with the lowest disadvantages derived from physical factors (climatic, edaphological, etc.) and biological; and from economic forces limiting the possibilities of sugarcane productive units like enterprises.
- Green harvest, mechanization, soil compression reduction, elimination of the burning and re-burning approaches, optimization of the harvest process with the straw and cane conditioning centers, development of storage system for the further use the stored product as mulching to control pests and weeds, and using straw as a source of energy, rural fuel and co-generation, and even the generation of additional ethanol, furfural and boards in the near future.
- The massive use of metal containers in the harvest would reduce the impact caused by land and foreign matters in the sugarmill: wearout of grinding units, pumps, fans and a drastic reduction of POL losses in filter-press muds and others.
- Incorporation of tools like FODA, cleaner productions, good management practices, life cycle analysis, ecological or carbon trace, eMergy, participative cartography, Surveillance and Monitoring Platforms, among others, to sugarcane management. From the synergy point of view, go into conventional econometric systems to establish the hazardous points of the agroindustrial system at local, regional and national scales to reduce costs, recommend differentiated technologies and maximize profitability.
- Improvement of the logistic infrastructure of roads and secondary ways, thus encouraging sugarcane transportation by railroad to redeuce costs and renew transporting trucks.
- Reconversion to flexible sucro-alcohol producing sugarmills (simultaneous production of different types of sugar as brown sugar, refined, white sugar, etc, and alcohols alcoholes as hydrated and anhydrous, electric co-generation and compost for horticulture) associated in the first sugarmills with potential and capacity taking into account the contraction of the market demand, mainly in the food and sofdrink sectors, due to the replacement of sucrose by corn fructose and non-caloric sweeteners, most of them imported, to quickly adjust to national and international prices.
- Implementation of the electric co-generation (first to meet electric, mechanic and thermal needs) in all sugarmills through reconversion of fuel boilers to bagasse boilers that also work with harvest residues with a low to high working pressure. In this way, local power lines are supplied continuously throughout the year so that sugarmills are self-sufficient during the season.

CONCLUSIONS

- The evaluated methodological instruments allowed describing more accurately the sustainability of Veracruz's sugarcane industry as a complex system and establish the great challenges it faces with from environmental protection point of view, productivity, productive diversification and competitiveness to perform conversion in the mid term. It should also execute prospective analysis in each industrial plant to insert itself into the new productive schemes using environmental management methodologies as the life cycle analysis (LCA), exergetic and energetic analyses, ecological and water trace, among others, in addition to conventional econometric approaches.

- ♦ It was possible to determine the different high emergetic rates of the environmental and economic loads of the sugarcane system in Veracruz regarding nitrogen and phosphoric fertilization with a percentage of 27,2 %, manpower 12,1 % and services 40,78 % out of the total. The remaining 19,92 % belongs, in order of importance, to fuels, agricultural machinery operation (tractors) during planting; pesticides and potassium fertilization which in turn, is determined by the life cycle analysis (LCA) where the stages of cutting, harvest and transportation are the most significant with a total of 64.65 % of CO_2 emissions. The need to restructure and redesign the sugarcane field in Veracruz is established in order to reduce production costs and the environmental load to increase profitability and competitiveness.

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