Multicriteria decision applied to Biorefineries

Situation of not toxic *Jatropha Curcas Linnus* in Sinaloa, Mexico

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Abstract – Our finite global ecosystem is within an unstable equilibrium due to obvious demographic growth that has been set as the main engine for the pressure of resources, and the constant need to seek new forms of energy. In this framework, the biorefineries have a special impact through the use of biomass. Non-toxic *Jatropha Curcas Linnus* is assumed as a good alternative, since the applicability has a wide range in different types of services, such as medical, food, agricultural and energy. Since 2007, *Jatropha* is cultivated in Sinaloa, Mexico Republic and subject to biorefinery processes. The choice of the best biorefinery in Sinaloa between three of them, is the main focus of this dissertation. The Biorefinery I is understood as an energy producer, Biorefinery II produce balanced food for cattle and Biorefinery III comprises both energy production and balanced food. The select of the biorefinery is assisted by three tools: first, Life-Cycle Assessment, used to get the materials and energy inputs and outputs on the system and economic analysis; the second methodology employed, Strategic Environmental Analysis, was used to define the critical factors of decision for a sustainable development of the region; the final, application of M-Macbeth software as a decision support model between biorefineries from the data collected by the two previous analyzes. The Biorefinery II, presented as a producer of animal feed was selected as the most functional choice because it has a certain advantage on social needs felt in the region and has meager impact on the atmosphere.

Keywords: *Jatropha Curcas Linnus*; Biorefinery; M-Macbeth; Sinaloa; Sustainability assessement

1. Introduction

According to Ghatak, H.R. [1], the essential ecological goal in our planet is to optimize the use of resources and minimize the waste created, leading to a maximization of the benefits and profitability. In this context biorefineries importance have been increasing by the use of biomass, involving a variety of conversion processes and different types of facilities due to the scope and system variability in question. Biomass is defined as a renewable energy source made up of organic animal or vegetable matter and as a direct fuel or by its indirect use through biorefineries [2].

This study aims to find practical application for non-toxic *Jatropha Curcas Linnus* (JCL) plant in the region of Sinaloa, Republic of Mexico with special attention to the implementation consequences for the region's sustainable development.

Among the available scenarios for this bush, there are three biorefineries with dissimilar processes, different from each other for their final products and by-products corresponding to animal food, energy or the two of them combined. To discover the best scenario were applied three methods, they were: Life-Cycle Assessment (LCA) which estimate an optimization of resource use in plant production, involving the reduction of atmospheric emissions and waste, thereby increasing the yield of each of biorefinery; Strategic Environmental Assessment (SEA) methodology in order to perform a study on sustainable development in the region and detection of critical factors of decision to serve on foundation to a multicriteria analysis; and implementation of M-Macbeth® Academic Beta 2.4.0. software for its support function to multicriteria decision.

Currently, JCL is a good choice for farming because it grows widely in tropical and subtropical areas and is considered a species with multiple benefits such as:

- Control of soil erosion [3];
- Use and recovery of wastelands, infertile or degraded land and effective phytoregulator with development of soil fertility [4, 5];
- Low agronomic needs for its development and rapid development [6];
- Good properties for clean and renewable energy production with high conversion yields [4, 6, 7];
- Traditional medicinal uses [5];
- Promoting employment rate and work for women [8];
- Animal feed supplement production with improvement in their development [9].

Within the topic of energy production from *Jatropha,* it can be done by transesterification [10, 11], anaerobic digestion [12], pyrolysis [13], pelletization [14] and detoxification and physical refinery [15] generating in all cases notable findings yield from JCL seed oil, husk, shell or seed cake.

Regarding the production of balanced animal food throughout detoxification and solvent extraction from JCL seed cake [16, 17] it appears feasible in some areas and for some animals like fish and cattle.

2. Methods

First of all it is important to know which processes were deliberated on each biorefinery considering that main products will be used *in situ*, on the other hand the by-products were supposed to be sold in Mexico. Biorefinery I produces only energy and the courses are specified on Figure 1:

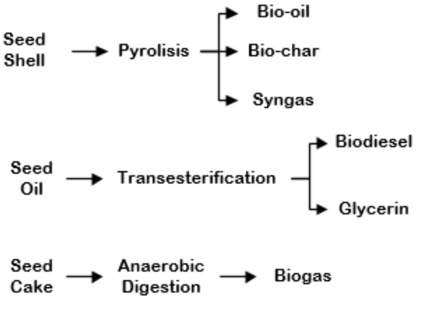

Figure 1 – Biorefinery I

It is considered that biodiesel is the main product on this biorefinery. The Biorefinery II, is represented on Figure 2 and defined as a producer of balanced animal food which is precisely the main product in this case:

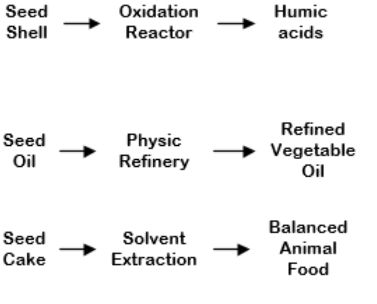

Figure 2 - Biorefinery II

Concerning Biorefinery III, producer of animal food and energy is showed in Figure 3, and in this situation it will be considered two main products, biodiesel and balanced animal food:

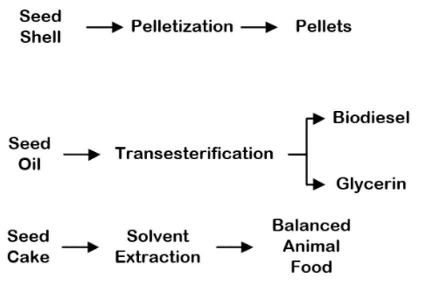

Figure 3 – Biorefinery III

2.1. Life-Cycle Assessment

This analytical tool addresses the eco-friendly aspects and potential environmental impacts throughout the product life cycle and is significant to provide numerical and analytical environmental information for the model implemented later. It comprises some stages such as: definition of functional unit and boundaries, inventory analysis, impact and improvement assessment phase [18].

2.1.1. Funtional Unit

The functional unit used is a hectare of *Jatropha* cultivation in a year.

2.1.2. Borders

The borders surrounding the plant Life-Cycle can be differentiated from economic and environmental borders. The first covers the process from the *Jatropha* production cycle in the biorefinery to the sale of by-products, in contrast, environmental border analyzes environmental impacts between the end of the pretreatment to the use of main products of the biorefinery *in situ*. The boundaries are presented in Figure 4, environmental border is represented by the orange line, and the economic is presented as blue.

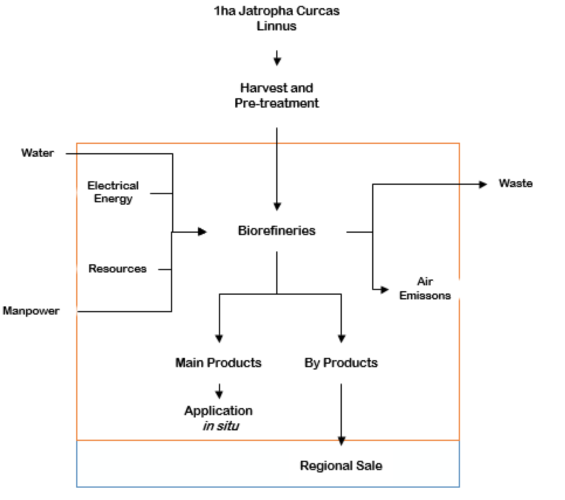

Figure 4 - Borders

2.1.3. Life Cycle Inventory & Impact

The Life Cycle Inventory (LCI) determines the emissions that occur, raw materials and energy involved during the product life cycle. This step includes data collection and calculation processes of the relevant inputs and outputs to the production cycle. This process is iterative and is aimed at a synthesis of the closed system.

Life Cycle Impact Assessment allows exploration of the information surrounding the LCI results of the system to understand its impact throughout the life cycle. This phase of LCA is aimed at evaluating the significance of potential influences the life cycle imposes on the environment and natural resources, thus associating inventory data with the impact categories and indicators relevant to the scope of the study. In this case the achieved indicators were: used electric power, direct heat and natural gas, equivalent carbon dioxide (CO_2eq), energy obtained from main products and revenues from by-products (Appendix I).

2.2. Strategic Environmental Analysis

For the foundation of multicriteria model was used as technical methodology the Strategic

Environmental Assessment (SEA), developed by Partidário M.R. [19], and in particular, the tool of Critical Factors of Decision (CFD) integrated in this methodology. SEA it's distinguished from other models of multicriteria evaluation because it contains part of a strategic long-term evaluation obeying the set objectives and sustainable development, integrating the three pillars of sustainability, environmental, economic and social component, thus contemplating a deliberate vision and conjugated regional growth.

In this methodology it is essential to recognize the intentions together with strategic issues on the system analysis. Identifying fundamental factors that define Sinaloa, their weaknesses and what you can improve through biorefineries are essential to define the CFD to ensure the strategic focus and provide a framework for further evaluation. These CFDs are important to establish the evaluation of the structure and the technical studies, ensuring a strong convergence on the most important issues of decision contemplating a vital integration for the purpose of this work and is an "observation window [...] following the principle of parsimony" [19].

It is necessary to recognize the objectives on the region with the implementation of each of biorefineries and identify the preponderant strategic issues for the vital decision problem as a way to prioritize and meet the aspects that may interfere with these marked goals, or even those which increase the desired dynamic sustainability. The following are the defined objectives for the region:

- Promotion of economic development in Sinaloa region, as well as the generation of rural employment associated with the education of the population;
- Increased purchasing power and/or animal food in the region;
- Improvement pattern of life of the population taking into account their education and their current work;
- Promotion of the reduction of atmospheric emissions;
- Utilization of vacant land for crops.

The following can be identified the foremost difficulties in the regions that conflict with the objectives: socioenvironmental vulnerability, involving poverty and social inequity, low level of education and soil degradation; pressure on resources concerning unequal access to energy and availability of resources; and in a technological level thus low technological development.

However, as a major potentiality, the state has a plan to reduce air emissions, significant amount of uncultivated and fertile land that do not serve to produce another type of culture, compliance with government incentives to agriculture and the renewable energy sector and prospective energy production taking into account their renewable resources.

2.3. M-Macbeth

The M-MacBeth® tool was used as a model to support the multicriteria decision making. This instrument aims to use a qualitative judgment between the differences of attractiveness of each criterion in order to ensure the creation of value ranges for options for each criteria, and weighting each of them in relation to the prime objective [20]. More specifically, this software evaluates each biorefinery option depending on stated criteria and their respective scores, to consequently choose between the three biorefineries.

First of all it's necessary to structure a criteria model, or criteria tree, based on the CFDs, through their respective performance. Additionally it is necessary to add upper and lower references to mark these performance levels, respectively good and less good or neutral score taking into account the differences between the attractiveness options for each criteria ensuing on a weighting reference. Then, it's necessary to generate rating scales and a judgement matrix to compare the attractiveness of the choices based upon the individual criteria. Afterwards, it's required fill a performance criteria table to locate each biorefinery on the respective criteria. Lastly, is needed to weight quantitative judgments to order the level of attractiveness of the different criteria.

All the information is then compiled in a table of scores that give the outcomes with easy scrutiny of each option together with sensitivity and robustness analysis.

3. Results and discussion

LCA was used exclusively to understand some of the economic and environmental impacts throughout the production cycle that *Jatropha* submitted and was used to comprehend how these processes influence quantitatively the region social, economic and environmental level.

The results of a year of production of one hectare of *Jatropha* were: emitted equivalent CO_2 [ton]; fixed operating costs and revenues of by-products [pesos], direct electrical energy used [kWh], direct heat used [MJ], amount of Natural Gas used in each biorefinery [m^3] and energy corresponding to the main products [MJ]. With the LCA it was possible to acquire Table 1 and Table 2, environmental and economic indicators respectively. From these tables it can be possible to recognize that Biorefinery II showed a lower amount of CO_2eq emitted and less natural gas used, however it was also the scenario that generated less power from the main products and benefited from lower profit from its economic analysis. Biorefinery III proved to be the most advantageous guarantee of energy from the main products, remaining second in the other indicators. Finally, the Biorefinery I was presented as the most polluting and the largest consumer of natural gas, however, it was the scenario that monetized greatest profit of the three.

Table 1 – Environmental Indicators

Environmental Indicators	Biorefinery I	Biorefinery II	Biorefinery III
Electric Power [kWh/yr]	2,723.72	737.42	1,836.60
Direct Heat [MJ/yr]	1,349.59	608.51	1,349.59
Σ CO_2eq [ton/yr]	1.62	0.45	1.12
Natural Gas [m^3/yr]	43.54	19.49	43.29
Energy from the main products [MJ/yr]	65,669	4,108.69	69,778.29

Table 2 – Economic Indicators

Economic Indicators	Biorefinery I	Biorefinery II	Biorefinery III
Operational costs [pesos/yr]	5,977.525	1,461.873	2,480.738
Revenues from by-products [pesos/yr]	44,823.300	9,501.667	19,035.317
Gross Profit [pesos/yr]	38,845.776	8,039.794	16,552.579

In order to define the criteria to be used in the multicriteria evaluation two critical factors were recognized in the decision reviewing strategic priorities needed for a well-structured goal previously identified.

The first CFD, named "Energy Availability and Use of Resources" was obtained with the objective to assessment of energy and environmental components in the region and the consequent emissions. It assumed the needs of primary goods to an underdeveloped society, cautioning the level of regional health and the need for goods and energy resources.

On Table 3 is represented the first CFD with three evaluation criteria, self-explanatory, which define and synthesize the characteristics of the evaluation. They were defined, respectively, in order to reduce atmospheric gas emissions, increase energy/food resources depending on the need of acquisition of each one and to reduce the use of natural gas for energy purposes and reduce the energy intensity employed. The chosen ones were: "Climate Change", "Energy Resource Management" and "Energy intensity used". The respective indicators of the criteria were numerically determined by the previous LCA.

Table 3 - CFD #1 – Energy Availability and Use of Resources

Evaluation criteria	Indicators
Climate Change: Evaluation of the emissions framework, control and monitoring	CO_2eq emissions [ton / yr]
Energy Resources Management: Assess the need for essential goods and resources in comparison with what is used	Equivalent amount of energy obtained by the main products [MJ / yr] Use of Natural Gas [m^3 / yr]
Energy intensity used: Consideration of dilemma between the need and use of energy. Specifically the two types of energy used	Electrical energy used [kWh / yr] Direct heat used [MJ / yr]

The second and last CFD, named "Livelihood Improvement" was achieved by marking an objective of analysis of socio-economic needs and perspective about an inherent change of the regional way of life with the implementation of each biorefinery. Assuming about the future of *Jatropha* in the presence on the region of the duel between the eternal rivals, energy vs. food.

On Table 4 characterizes the second CFD to consider, that includes three evaluation criteria: "Labor Activity", "Social Needs" and "Exploitation Yield" with related indicators. These criteria were used respectively in order to find which of biorefineries changed to a lesser extent the current labor activity in the region, which scenario most enjoyed the evident social needs and between the three biorefinery which could extract more profit.

The indicators presented were relevant to sustainable development of the area as it makes a potential management workforce and goes against the increase in per capita income and involves the community in the workplace.

Table 4 - CFD #2 –Livelihood Improvement

Evaluation criteria	Indicators
Labor Activity: Assessment of the type of changes in regional activity practiced with the implementation of biorefineries and modified habits	Type of production relative to regional unemployment and social equity
Social needs: Evaluation of energy and food social deficiencies that may feel face every type of biorefinery	Duality Energy / Food where the need for energy or animal food prevails
Exploitation Yield: This is a purely economic assessment under the operations of biorefineries and sale of its products, it is involved in the economic frontier of the study compared to the region's economy and the country	Income obtained through the profit from sales of by-products with the discount of fixed operating costs [pesos / year]

These two CFDs were used as a base for M-Macbeth tool. Evaluation criteria and utilized to be the foundation of the decision tree, generating a series of connections corresponding with their indicators as performance levels.

To indicate how the values of LCA and organization of CFDs, was arranged a performance table, showed on Figure 5, that was taken from the software. It was considered that the difference in attractiveness between the criteria was the same, however, it portrayed that the criterion of "Income" was more attractive compared to the "Climate", followed by "Needs", "Equivalent Energy", "Electricity,", " Labor "," Natural Gas" and finally " Direct heat ".

M-Macbeth software gave marks on each biorefinery on every single criteria, depending on the weight of each criterion and the position in relation to reference in each of them.

The results of the application of this tool are represented on Figure 6 which show that Biorefinery II obtained more points on the global score. The sum of all the criteria is represented in yellow. This tool can individually represent each score, representing what may change with the variation in weight of each criterion.

Tabela de performances

Opções	Clima	Gás Natural	Energia equivalente	Energia elétrica	Calor direto	Labor	Rendimentos
Biorrefinaria I	1.62	43.54	65669.6	2723.72	1349.59	Boa	38845.776
Biorrefinaria II	0.45	19.49	4108.69	737.42	608.51	Muito Boa	8039.794
Biorrefinaria III	1.12	43.29	69778.29	1836.6	1349.59	Neutra	16552.579

Figure 5 – Performance Table

Tabela de pontuações

Opções	Global	Clima	Gás Natural	Energia equivalente	Energia elétrica	Calor direto	Labor	Necessidades	Rendimentos
Biorrefinaria I	54.55	-6.86	21.53	90.16	-16.78	43.36	66.67	66.67	117.69
Biorrefinaria II	65.25	64.28	101.70	-28.89	113.13	92.77	100.00	133.33	24.32
Biorrefinaria III	45.22	21.71	22.36	99.50	41.34	43.36	33.33	33.33	53.11
[tudo sup.]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
[tudo inf.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fatores de escala:		0.1944	0.0556	0.1389	0.1111	0.0278	0.0833	0.1667	0.2222

Figure 6 – Scores Table

4. Conclusions

Biorefinery II presents as the most compatible indicators for sustainable development in Sinaloa region. This is the scenario that is distinguished by producing balanced food for use in the territory under study and consecutively the sale of its by-products, refined vegetable oil and identically humic acids in Mexican territory. Biorefinery II has a certain advantages compared to the other scenarios on a social level regarding the primary needs in the region that lacks animal food for all the emerging livestock activity. Biorefinery II's impact on the atmosphere also had a major effect on the choice of this scenario that might be employed in the region.

However, Biorefinery I presents itself as an alternative and is feasible, after the alteration by the scores of the criteria it´s possible to obtain a better score. Yet, Biorefinery III was unable to be elected to apply in the region.

After the investigation of the plant requirements, its production and development as well as all defined processes, state of the location in question and necessary investments it can be possible to conclude that the LCA as well as the SEA were partially exploited. They have so many more uses and possibilities of knowledge that they were not examined, however, their fragmented application was enough for an inaugural analysis before using the ultimate tool, the M-Macbeth. This has been fully explored and put into practice, only presenting the difficulty of placing equal since the issue of sustainable development that equals the three components likewise.

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Appendix I

Biorefinery I: Energy								
Pyrolysis			**Transesterification**			**Anaerobic Digestion**		
input	Quantity	Unit	input	Quantity	Unit	input	Quantity	Unit
Seed shell	1.8	ton	Seed oil	2,000	L	Seed cake	1.23	ton
Electric energy	1,952.68	kWh	Electric energy	674.35	kWh	Heat (thermostat)	85.417	kWh
			Catalyst (NaOH)	15.5	kg	Electric energy	11.28	kWh
			Alcohol (Methanol)	494.79	L			
			Steam	672.23	kg			
output	Quantity	Unit	output	Quantity	Unit	output	Quantity	Unit
Bio-oil	0.9	ton	Biodiesel	1,784.5	L	Biogas	137,145	m^3
Biochar	0.41	ton	Glycerin	79.76	kg			
Syngas	0.31	ton						

Biorefinery II: Animal Food								
Oxidation Reaction			**Physic Refinery**			**Solvent Extraction**		
input	Quantity	Unit	input	Quantity	Unit	input	Quantity	Unit
Seed shell	1.8	ton	Seed oil	2,000	L	Seed cake	1.23	ton
Electric energy	63.3	kWh	Phosphoric acid	1.25	kg	Electric energy	625.98	kWh
Potassium hydroxide (KOH)	216	kg	Sulfuric acid	3.57	kg			
			Nitrogen Gas	0.89	kg			
			Steam	303.1	kg			
			Electric energy	48.14	kWh			
output	Quantity	Unit	output	Quantity	Unit	output	Quantity	Unit
Humic acids	540	L	Refined Vegetable Oil	841	L	Balanced Animal Food	1,820	kg

Biorefinery III: Energy and Animal Food								
Pelletization			**Transesterification**			**Solvent Extraction**		
input	Quantity	Unit	input	Quantity	Unit	input	Quantity	Unit
Seed shell	1.8	ton	Seed oil	2,000	L	Seed cake	1.23	ton
Electric energy	536.27	kWh	Electric energy	674.35	kWh	Electric energy	625.98	kWh
			Catalyst (NaOH)	15.5	kg			
			Alcohol (Methanoll)	494.79	L			
			Steam	672.23	kg			
output	Quantity	Unit	output	Quantity	Unit	output	Quantity	Unit
pellets	1.5	ton	Biodiesel	1,784.5	L	Balanced Animal Food	1,820	kg
			Glycerin	79.76	kg			