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Chemical Engineering for Good Challenge
2019 Competition Submission

How Chemical Engineering Can Be Applied to Solve World Problems on a Micro Scale

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Lead AIChEChapter

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Title of Submission: Spirulina production as a protein supplement for the Manaure area, La Guajira Colombia.

Submission Type: _x__ underutilized technology ___technology toolkit

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A. Specific community problem being addressed.

World population has been steadily increasing, technology has been evolving at a dizzying pace, and the economy has become increasingly interconnected and globalized. Yet, more than 820 million people worldwide suffer from hunger [9]. Food security, intended as the physical and economic access to enough, safe and nutritious food that meets people's dietary need and food preferences for an active and healthy life [19] has been a concern for FAO and the UN, for this, it is important to search new ways to fight worldwide and local hunger.

It emerges as an alarming trend, that after decades of steady decline, world hunger has been increasing since 2015. This happens specially in middle-income countries and countries that rely heavily on international trade of primary commodities. Not only this was disclosed by 2019 FAO's report on world hunger, but also that even in high-income countries sizeable portions of the population lacked regular access to nutritious and enough food.

In Colombia, the country this AIChE chapter belongs to, 4,2 million people suffer from hunger [9]. It also is an example of a country in which food security was affected by an economic slowdown caused by the falling price of crude oil. Furthermore, Colombia has other problems that echo on food security as: forced displacement. It has a negative impact on food availability due to the abandonment of land and neglection of the crops [20].

One of the most striking cases of hunger in Colombia is that of la Guajira, and its indigenous inhabitants, the Wayuu. According to the Human Rights Watch Americas director, Jose Miguel Vivanco the situation is critical: "Wayuu children are starving to death at high rates in Colombia's northeastern province of La Guajira". Official figures speak about 193 children under 5 years dead between 2013 and 2017 due to malnutrition in the region [16]. In addition to hunger problems, La Guajira is also a very dry region which suffers from continuous draughts, that can last 2 years [15].

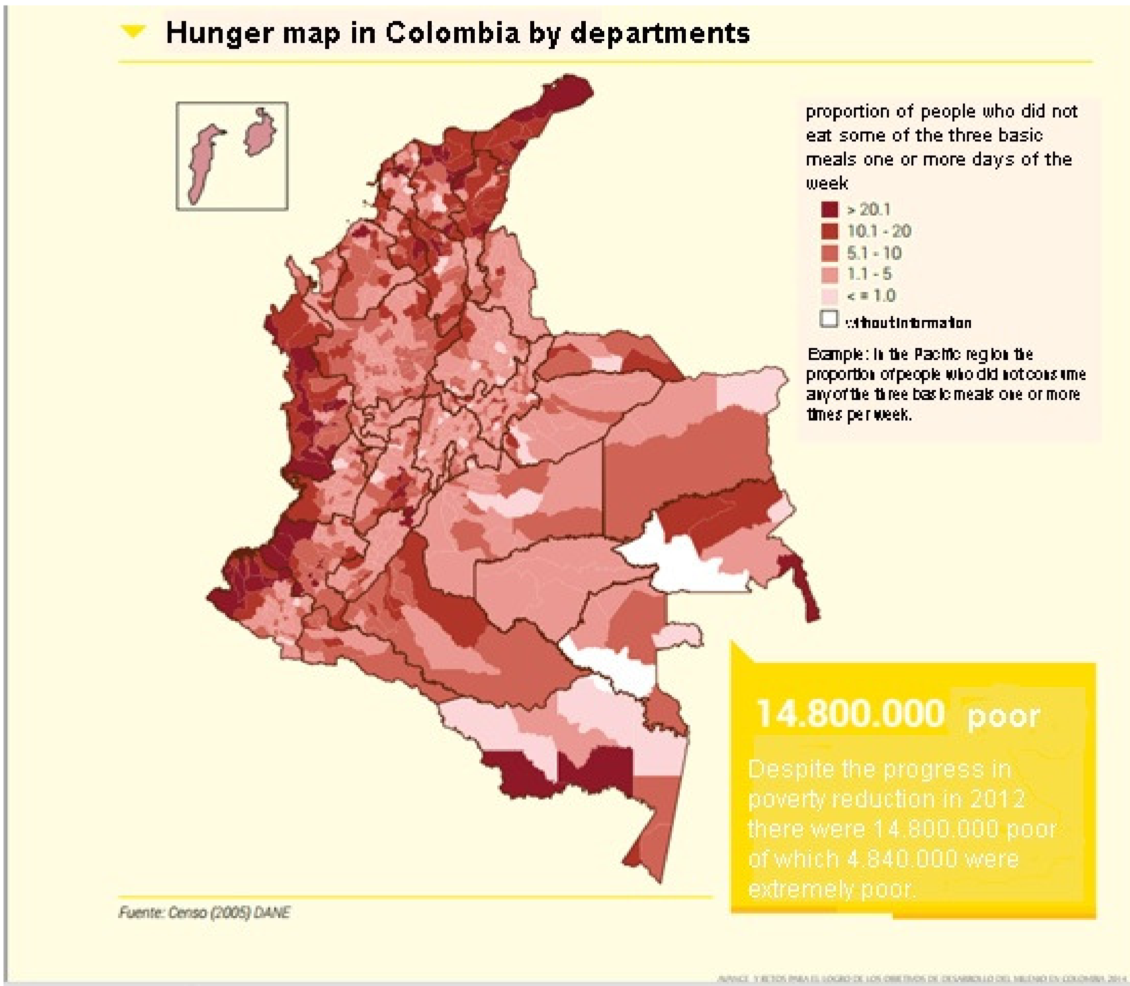

Figure 1. Hunger map in Colombia.

For our project it is important to select a place and a community in which the technology will be implemented. La guajira is a big state with at least 20.848km2. Even though the project is planned for people of low resources, it is still needed a minimal amount of infrastructure and the presence of salty and fresh water. Thinking about this, and the fact that, as seen in the map, the northern areas of the Guajira are the most affected by hunger a community in which all these requirements were fulfilled was selected: Manaure. Manaure is a city located to the north of La Guajira's capital: Riohacha. The city, with over 112.100 inhabitants [1], is famous for its salt flats which represent the main income source for the inhabitants, nevertheless, 85% of the population lives in state of poverty [16]. The region is hot, oppressive, windy and overcast, its temperature ranges between 24ºC and 31ºC. The average wind speed ranges from 15 km/h to 24.3km/h [2].

It is important for us, as a chapter, and as students of the biggest public university of Colombia (Universidad Nacional de Colombia.) to search a possible solution for this terrible problem as it is our duty to contribute to the country which grants our education.

B. Specific technology and how it is based on chemical engineering principles.

Spirulina is a photosynthetic cyanophyte belonging to the Oscillatoriaceae[4]. The most common species are Spirulina maxima and Spirulina platensis. These cyanophytes are composed by cylindrical cells and have a spiral shape when seen under the microscope. These bluish-green multicellular filamentous algae grow naturally in salty and alkaline water. the algae can be grown and processed easily. it is known for its outstanding protein contents, reaching high percentages such as 64 and 74%. It is also used in many countries as dietary supplement for it has a high content of antioxidants, fatty acids and vitamins. In addition, the alga has been used in Asia and Africa as a medium to fight malnutrition due to its rich nutritional content.

For these reasons, the use of Spirulina Maxima has been considered ideal for our investigation as a mean to fight the hunger situation in Colombia, more specifically in Manaure, la Guajira. The development of efficient growing techniques will allow a great profit to be made from its high protein and vitamin content.

Spirulina has facility growing in diverse culture media due to its autotrophic, mixotrophic and heterotrophic nature [10]. A great deal of its commercial production is autotrophic and is performed in ponds or free circulation canals where the solar energy is used to fix the carbon dioxide and transform it into hydrocarbons. Being an open medium, it presents poor light diffusion and is prone to biologic, chemical and physical contamination. These feats have been addressed by proposing its production via a photobioreactor (PBR), but it is not economically viable. If the culture is done in a heterotrophic medium, closed and controlled, the species get its energy from the organic compounds and so they increase the produces quantity of algae.However, in the literature [14] the mixotrophic method is further highlighted, which obtains a greater concentration of cells over time compared to the previous conditions, this type of culture is carried out in the presence of a source of carbon and light.

The culture medium that is to be implemented for the cultivation of the microalgae must supply the system with nutrients such as Phosphorus (P), Sulfur (S), Potassium (K), Magnesium (Mg); Nitrogen (N), Calcium (Ca), Iron (Fe) and a carbon source.

Salt and alkaline water should be used in the culture medium, preferably potable with little chlorine content, although rain, spring or drilling water is generally of adequate quality, it is only necessary to filter.

For situations in which economic support or access to chemical components is very limited, other purely organic cultivation strategies are set out in the Handcraft Culture Manual for spirulina production. Among them is the option of using natural bicarbonate, wood ash, 4 ml of urine per liter and cooking salt; It is clarified that this composition of the culture medium is normally used for the consumption of microalgae by animals, since the idea is not well received by people, but if you want to consume, you can sterilize the urine by dissolving 5 g of soda per liter a few hours before use. The implementation of seawater is also proposed, which can add calcium, magnesium and sulfur to the crop; however, be careful with precipitates that can form at high pH. The renovation allows the medium to contain insignificant concentrations of possible contaminants (chemical or biological) and guarantees the supply of trace elements. It is advisable to renew at least every 2 kg of Spirulina produced per m^2 of pool or pond, an approximate time is every 3 months.

Conditions for algae growth

The culture medium needs special conditions to obtain a good biomass growth, the factors involved are:

- Salinity: Minimum values are generally taken for reasons of economy, using for example a salinity concentration of 13g/L [13], this data can be doubled without inconvenience.
- Temperature: The recommended temperature is between 30ºC and 37ºC [16] approximately during the day and a little lower during the night so as not to favor the loss of biomass that occurs through breathing and other biological reactions that are still carried out.
- Lighting: a space can be used where sunlight enters but not in a powerful way, that is, a slightly shaded place. This is because exposure to strong sun rays can cause some algae filaments to be destroyed by photolysis. The light intensity for optimal growth varies between 37 $\mu mol/m^2s^1$ and 150–200 $\mu mol/m^2s^1$ [10].
- pH: This factor is very varied depending on the culture medium used and even changes during the growth process. The pH for Spirulina culture should be high, values are between 8.5 and 10.5 [17].
- Stirring: Stirring is necessary to homogenize, promote the elimination of oxygen and ensure a good distribution of lighting among all spirulinas. It can be manual or with pumps that do not damage Spirulina, such as propeller pumps, screws, vanes, diaphragm or vortex [9].

Spirulina harvest

In the cultivation of Spirulina, it is important to know the ideal time to harvest the algae, because when the growth exceeds its optimum amount, the algae can die suddenly. The optimum level for harvest is when the growth reaches 900mg/l, this value is determined using the seed method, which consists of a white disk of 2 cm in diameter stuck at the end of a graduated ruler, if it is not visible when immersed with 2.5 cm depth, the growth is 900 mg/l [18].

Spirulina intake

Its presentation of pure consumption is powder, with a strong dark green color and a slight smell of canned fish, which tends to disappear when mixed with other food; This presentation facilitates that multiple recipes can be made with the microalgae. Spirulina does not replace caloric foods such as cassava, rice or corn, but it is an ideal ingredient as a builder food, providing not only its proteins (65%), but also minerals (7%); Carbohydrates (20%), essential amino acids and many vitamins. For proper consumption of the microalgae it is important after harvesting, to go through a drying process and proper storage.

- Storage: Spirulina after harvest can be consumed fresh, dried (half effective), or cooked (third part effective), depending on the recipe or antibacterial care. Fresh biomass can be consumed directly after pressing or can be stored at low temperatures in a closed container, for a duration of 4 days at 1°C, 2 to 3 days at 5°C, one day at 8°C; The best way to store it is in the form of a sausage avoiding contact with the air. If you want to dry it is necessary to put it in the fridge before treatment. In case of doubt about the bacteriological quality of Spirulina, it should be cooked for one or two minutes. For a longer shelf life, biomass can be salted at 10% after pressing, it can be stored for a maximum of 4 months at 20°C [13]
- Drying: It is recommended to work with indirect dryers (it receives solar energy indirectly through the air that is heated by means of a collector that composes it) of passive solar energy to prevent the material to dry from deteriorating. The temperatures reached in indirect dryers 30-80ºC, approximately.

Based on the previous information collected, the knowledge acquired both in thermodynamics, as well as in transport, chemistry and biology phenomena, during our training as chemical engineers will allow us to design a more cost-effective method for the population of Manaure, as we must distinguish ourselves by seeking solutions with the elements and conditions provided by the environment and being able to even transform them with convenient and appropriate techniques for the benefit of the project. As Chemical engineers we will know how to understand what happens and how the cultivation and drying of Spirulina occurs, which will allow us to recognize which factors are beneficial and which are not so much for optimal growth and have control over the most important variants. Even, the understanding on the treatment of water will contribute in a convenient way to the project because it must be considered that in many communities of the country the drinking water can be scarce, so taking into account all the resources that the rivers and the sea can provide us, not It will be a problem to help yourself from these water sources.

The technology chosen to help reduce the low levels of nutrition of the Manauare population is the cultivation and consumption of the maximum Spirulina microalgae in the diet of the target community. It is intended that they perform an autotrophic culture based on sea and river water, since they are enriched waters with some necessary compounds in the culture medium, however it is necessary to add other components to keep the pH and salinity in a range of values adequate; the temperature parameter is donated by the conditions of the municipality; The agitation, to increase the production, will be done by means of a agitator propelled by wind energy, It is proposed to use the high wind speeds in the guajira and adapt a system with blades in the direction of the wind, which moves a wheel mechanism and gears and allow stirring. and the lighting and crop contamination protection variables are controlled with a greenhouse. The storage of the crop will be carried out in cement tanks with a filter that will allow an easy harvest; For the consumption of biomass, it is proposed to pass it through a drying process using sunlight.

C. Kind of data would be required to design / customize this technology for ISPprojects

To execute the project, it is necessary to comply with the conditions and parameters necessary for an adequate production and consumption of biomass, so it is very important to analyze the known data.

- Culture medium: As stated at the beginning the crop must contain Phosphorus (P), Sulfur (S), Potassium (K), Magnesium (Mg); Nitrogen (N), Calcium (Ca), Iron (Fe) and a carbon source; Therefore, a crop containing river water, sea water, bicarbonate is proposed to help photosynthesis and other components that complement it; to ensure that this mixture donates the basic nutrients, it is necessary to know the quality of the waters and the basic treatment that should be done on them.

  With respect to the Manaure River, the most recent research is published in June 2018 by the Luna Azul magazine, which announces the bacteriological quality of the river stating that there is presence of bacteria indicative of fecal contamination; however, their low concentration allows them to be profitable for crops [3]. The final report of the Regional Autonomous Corporation of César "CORPOCESAR" also presents data on the bacteria content and quantity of minerals in the Manaure River, affirming a good water quality [5]. You could even have as an option to take advantage of the water in the upper part of the channels, that is, where there are no discharges or discharges of domestic or agricultural wastewater, since the most affected part is the low due to human activity.

  On the other hand, seawater enriches the culture medium with elements such as Ca, Mg, K, S and provides the necessary salinity in the culture for the optimal growth of Spirulina. This water should go to a lesser extent to prevent excess elements such as Mg2 + and Ca from producing precipitation in the culture medium, which can affect the growth of Spirulina. Because a very elaborate water treatment is not required, since the water of the Manaure river as said can be used for cultivation and the seawater will only be used in small proportions, only a filtrate of suspended solids is required for eliminate possible contaminants that are not soluble. This mixed culture medium provides the necessary nutrients for the optimal growth of Spirulina, which favors the process, since the use of expensive or dangerous chemical compounds is not required for the community where it is desired to implement the cultivation and consumption of this microalgae For this, it is vitally important to know the percentage of current content of each element given by the waters to be used to know what should be complemented to form an adequate culture medium.

- Greenhouse: In the construction of the greenhouse, recycled plastic containers from the area will be used. It should be remembered that algae cultivation should not receive direct sunlight as this could cause photolysis. PET bottles are a good resource for building a greenhouse, with the function of controlling solar rays, mainly ultraviolet rays that are mostly absorbed or diverted by plastic. It will also allow to have a better control over the temperature, which, as stated above, is between 30ºC and 37ºC, although thanks to the area where the project is carried out, the temperature will not be a major problem since the average temperatures of the place are between these ranges. In the next figure is showing an example:

Figure 2. A bottle greenhouse

- Stir: Stirring is a factor capable of increasing production yield by preventing sedimentation and favoring light distribution and pH stability; however, its drying rate should be controlled, since if it is exceeded it could cause cell damage in the microalgae. Studies have been carried out to ensure that the most optimal speed range is 0.25-0.50 m/s [6] and the mixing energy consumption can be around 25W/m^3 [21]. The most common system of growth with agitation is High Rate Algal Ponds. Design information is needed for the proposed agitation system; the shape of the blades that go to the wind so that they monopolize the greatest amount of motive energy, length must have the rod where these blades will be placed, relation that the gears must meet to give the energy and optimum speed, average wind speed in Manaure, theoretical performance with this speed. On-site tests should be done to calculate the actual efficiency, with this data the viability of the proposal can be determined.

D. Why this technology would be appropriate for implementation in partner communities?

To describe whether this technology is appropriate for its implementation in the communities of the emerging world, an appropriate evaluation should be used for its selection. That is why, 20 criteria are considered to evaluate if you are going the right way [REFERENCE]. The following describes the technology described as a solution:

Table 1: Evaluation criteria.

N°	Standard	Followed path and evaluation
1	Energy Intensity	It must consume few amounts of energy: the solution represents the use of free energy such as solar energy for crop growth. In addition, mechanical work comes from people who invest little force in its construction and operation.
2	Work intensity	The production unit depends on the intensity of solar energy with high efficiencies compared to the energy supplied compared to the highly protein final product
3	Potential of the raw material	Easy availability of local raw material / material available: use of seawater (coastal zone), rainwater and materials from the area where the population is located. In addition to an energy source such as the free sun and available almost all year.
4	Productivity	High productivity
5	Ecological Stability	Although the production unit presents waste, these are biodegradable easily available.
6	Cost Intensity	Low cost: the unit can be made with materials from the same area, can be installed by people from the same community and trained for the operation and disposal of products.
7	Import substitution.	Imports of raw materials or installation materials do not have to be made.
8	Rural orientation.	Suitable for rural adoption: for example, aimed at people with low skill levels.
9	Decrease in the income gap.	Ability to reduce income gap: the unit is not designed as a business.
10	Durability.	Low maintenance oriented, because they are tanks with microorganism production, maintenance will be oriented to a schedule of washing, checking and fixing leaks and the hygiene of people who have direct contact with the product.

11	Learning capacity	The training for its installation, operation and obtaining of product must be done by designers to the beneficiary population so that the community can operate the unit together.
12	Recycling waste	Ability to use waste products
13	Possible small-scale use.	The production unit is intended for small-scale use and operation, only for community use.
14	Sectoral efficiency	It can contribute to food, health, family, rural planning, education.
15	Relocation	The unit is designed with materials available in most coastal areas with availability of sunlight most of the year.
16	Livelihood.	The community must be guaranteed to help collect the best quality materials available locally and an installation care campaign.
17	Population Stability.	The unit is not designed to generate stability in the population as a direct consequence.
18	Sociocultural stabilization.	The conditions to guarantee are first that people adopt in their diet a highly protein food that helps to improve their diet and secondly is that they are willing to work in their production.
19	Variety Reduction	Heterogeneity: the unit will only fulfill a function with respect to production but also involves manual labor, teaching and use of local resources.
20	Leadership Requirement.	The creation, installation, operation and consumption of the product must guarantee teamwork with adequate ideation, planning, control and evaluation.

It is proposed that the inhabitants build 2 rectangular tanks with rounded corners of shallow cement and with a longitudinal separation in the center so that the water circulates better, this design is called raceway, Figure 3. These tanks will have a capacity of 520 liters, the dimensions in order to obtain approximately 4 g / m2 daily and will be located inside a greenhouse made of ultraviolet-resistant polyethylene together with a solar tray dryer, made of wood.

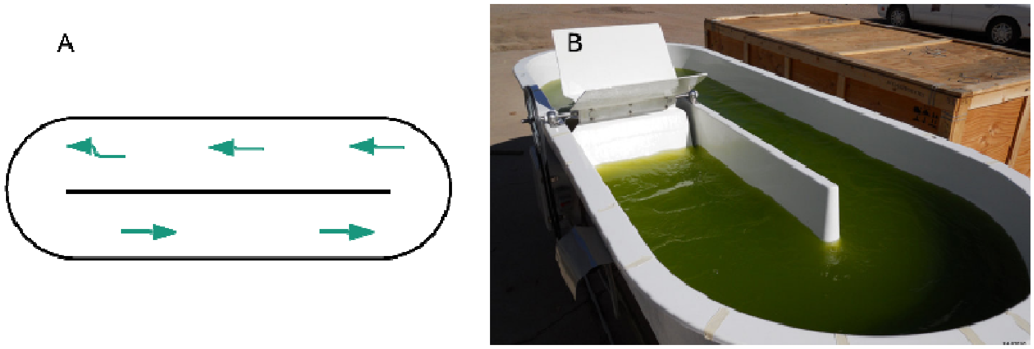

Figure 3. (a) Tank top view, (b) A open raceway pond with looped channels and a paddlewheel.

The complete process of obtaining the protein is explained below:

- Cultivation of the strain: In transparent polycarbonate bottles, which can be recycled, the algar mass is increased by making a preculture process from a sample of 25cm^3 doubling the daily volume, then deposited in the tanks to continue with the process.

Table 2: Media components

	To double the volume	In the tanks
Sea salt (g/L)	18,2	5
$FeSO_4$ (g/L)	0,01	0,005
KH_2PO_4 (g/L)	0,14	0,7
KNO_3 (g/L)	4,4	3,0
$NaHCO_3$ (g/L)	6,0	7,0

- Extraction: After sowing a white plastic disc of 2cm in diameter is used, attached perpendicular to a ruler, this system must be submerged in the pond and when the disc is not seen, the ruler will mark approximately 2.5cm and at this time it will have an optimal growth of 900 mg/L [9].
- Filtering: Cotton fabrics anchored to a wooden base will be used to filter the product extracted from the tanks, in this way the algae are retained while the liquid is allowed to pass, as shown in the figure:

Figure 3. Filtering process.

- Drying: Because the area is highly irradiated by sunlight, solar tray dryers are proposed, measuring 1m x 0.8m with a height of 0.3m built in wood.

In each tank of 2,6m^2 de área is possible to obtain 4g/m2 per day and this is equal to obtain 10,36g per day. With this amount of protein obtained per day, approximately 8 people can be fed.
In this section a brief economic study is analyzed. The following table shows the items that are associated with a cost in Colombian peso, the others that are not present do not generate any cost since they are available to the inhabitants of the region at no cost.

Table 3. Startup costs

Item	Cost in Colombian Peso (COP)
Tank	20,000
Plastic agitator	26,000
Cotton fabric	5,000
Drying trays	15,000
Spirulina	150,000
TOTAL	216,000= 62,90 USD

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Erratum-Corrections

As we were doing a posthumous revision of the sent work, we realized we had some issues with references. We wanted to do the right thing,an erratum, and in some way give these people the acknowledgement they deserve.

1. ***Graph 1****. Is not properly referenced in the text. Although parts from it were translated to english for better understanding of its contents, the original figure has its legends in spanish and comes from:* Moreno, L. Á., Toro, J. P., Acosta, C., & Herrera, F. (2014). Objetivos de Desarrollo Del Milenio, Colombia 2014. In Programa de las Naciones Unidas para el Desarrollo. Retrieved from http://www.undp.org/content/dam/undp/library/MDG/english/MDG Country Reports/Colombia/informeanualodm2014.pdf
2. **Figure 1.** *Is not referenced properly.* The image was obtained in the Directorate of Communication of Science of the Universidad Veracruzana (2019). Universitarioscrearonvivero con botellasplásticas (University students created a orchard with used plastic bottles) https://www.uv.mx/cienciauv/notas/vivero-pet-uv/

3. **Figure 2 (b).** *Is not properly referenced in the text, this picture was taken from:* Amini, Hossein. (2016). Numerical and experimental investigation of a microalgae cultivation system for wastewater treatment and bioenergy production.
4. **Figure3.** I*s not properly referenced in the text, this picture was taken from*: Mr. Reddy. (2018). Spirulina Farming, Cultivation Particles Details https://www.asiafarming.com/spirulina-farming-cultivation-practices
5. **Page 8.** *There is a space to reference the criteria used to evaluate the technology. These criteria were based on the ideas presented in the book* Evaluation of Innovation in Rural Development Programmes 2014-2020 (2017) for The European Evaluation Helpdesk for Rural Development.
6. **Table 1, 2 and 3** are the submitters' own elaboration.