# Life cycle assessment of biodiesel production from microalgae oil: effect of algae species and cultivation system

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**Abstract**

Different microalgae are widely studied as alternative sources for biodiesel production. They show higher oil productivity values (per area) than oilseed crops and are not used for food industry. For the evaluation of the energy and environmental feasibility of biodiesel coming from microalgae, life cycle assessment (LCA) methodology provides a very useful tool. In this work, we have used it to evaluate the biodiesel production from the microalga *Nannochloropsis gaditana* cultivated in three different systems: tubular and flat-plate photobioreactors and raceway ponds. Results indicate that tubular reactor has a very high energy demand leading to the lowest net energy ratio (NER). Despite the better NER results of the cultivation step when using flat-plat configuration and race-way ponds, harvesting and lipid extraction necessary for biodiesel production lead to an important reduction of NER increasing also $CO_2$ emissions.

## 1 Introduction

Biodiesel production has become a very intense research area because of the growing interest on finding new resources and alternatives for conventional transport fuels [1-3]. As known, in the last few years various kinds of biomass have been identified as possible sources for biodiesel production, e.g. bio-wastes (food wastes, municipal wastes or agricultural wastes), edible and non-edible oil seeds and various aquatic plants (microalgae) [4]. Microalgae are basically a large and diverse group of simple, typically autotrophic organisms ($CO_2$ is their carbon source), ranging from unicellular to multi-cellular forms [1]. These have the potential to produce considerably higher amounts of biomass and lipids per hectare than any kind of terrestrial biomass. Traditionally, microalgae are cultivated in closed systems or open ponds, however another steps are involved in biodiesel production as harvesting, drying, lipid extraction, and lipid esterification /transesterification to obtain the fatty acid methyl esters (FAMEs). For each step, there are many variables with high influence on the energy demand and environmental impacts such as the kind of cultivation systems, the method selected for micralgae harvesting and drying or the necessary chemicals for the extraction and esterification processes. Likewise, the use of algae wastes produced in the extraction and the re-utilization of nutrients and other chemicals allow increasing the net energy ratio (NER) of the process and reduce its total environmental impact. Therefore, all these aspects must be evaluted in order to know if the production of biodiesel from microalgae is an effective alternative to solve problems associated with the growing energy demand and global warming. In this context, life cycle assessment (LCA) methodology provides a useful tool for the evaluation of different cultivation systems. In this work, three different cultivation systems have been evaluated: open raceway ponds, tubular photobioreactors and flat-plate photobioreactors. Since LCA evaluation of this work is focused on Spanish conditions, we have selected *Nannochloropsis gaditana* as the most significant alga to carry the assessment out. It has been previously cultivated [5] in the south of Spain and presents high oil content.

## 2 Methods

The assessment was carried out with Gabi 4.3 software by using the database Ecoinvent 2.1. The considered functional unit was 1 kg of biofuel ready to be used in a diesel engine; the boundaries include extraction and production of raw materials, facility construction and dismantling, biodiesel elaboration from microalgae, distribution and use in the engine. Figure 1 shows the inputs and output of steps considered for biodiesel elaboration from *Nannochloropsis gaditana.*

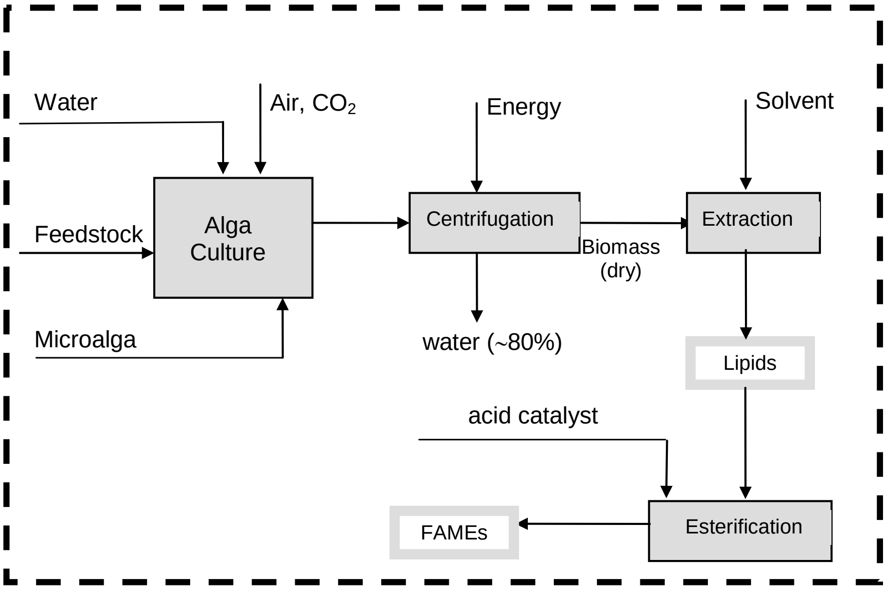


**Fig.1: Diagram of the production of biodiesel from *Nannochloropsis gaditana*.**

For LCA inventory, productivity, energy demand and building materials of cultivation systems were obtained from the work reported by Jorquera et al. [6] Culture medium for *Nannochloropsis gaditana* was the f/2 recipe and requeriments of $CO_2$ were 3.5 kg $CO_2$/kg dry mass [7]. Microalgae harvesting was carried out by means of conventional centrifugation removing 80 wt % of water, then, a drying process under room temperature was supossed. For the oil extraction, the principal inputs were energy and hexane leading to a yield of 40 % [8, 9]. Due to the high content of free fat acids (FFAs) of the oil coming from *Nannochloropsis gaditana*, its transformation into biodiesel must be carried out by means of an acid esterification reaction. In this case, sulphuric acid was used as catalysts [10].

For evaluation of environmental impacts the following parameters were analyzed: greenhouse gases emissions (GHG) expresed as kg $CO_2$ eq. and calculated according to the CML-2001 method (at 100 years), energy consumption of each step and net energy ratio (NER: MJ produced by 1 kg of biodiesel/MJ used).

## 3 Results and discussion

In order to compare the behaviour of the different cultivation systems, Figure 2 shows GHG emissions of each step involved in the biodiesel production. As can be seen, $CO_2$ emissions of tubular photobioreactor is widely higher than those corresponding to flat-plate photobioreactor and raceway ponds. In fact, these two last systems present negative values of GHG emissions in the cultivation step (-2.1 kg eq. $CO_2$ for flat-plate and -3.4 kg eq. $CO_2$ for raceway ponds) indicating that $CO_2$ fixation of microalgae compensate the emissions.

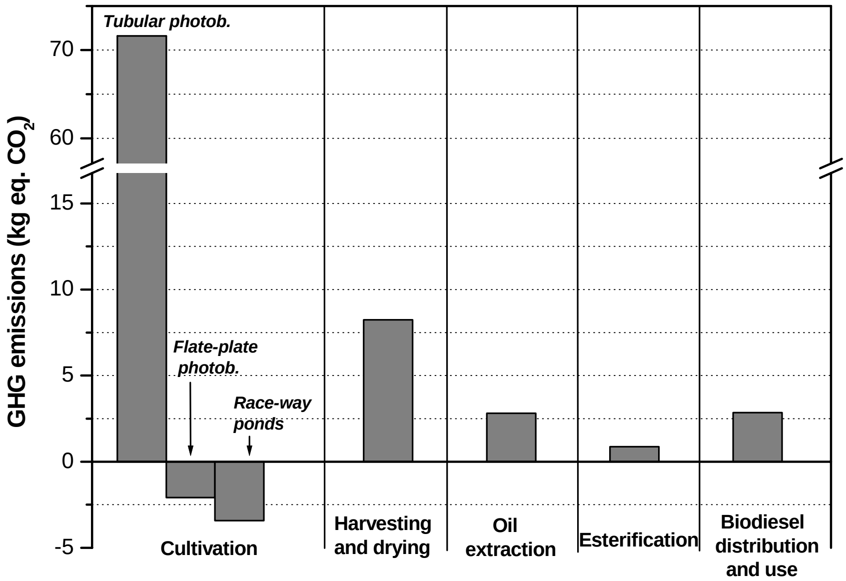


**Fig.2: GHG emissions of processes for biodiesel production from microalgae**

As known, $CO_2$ emissions are a direct consequence of fossil fuel consumption for energy requirements. In this sense, power supply and NER values were also estimated by Gabi and represented in Figure 3. As expected, tubular reactor shows the highest energy consumption value (~1,730 MJ/kg biodiesel). These results are in agreement with others previously reported [11, 12] which describe that the required power for an adequate mass transfer in tubular photobioreactors is more than 30 times higher than the necessary for flat-plate ones. The configuration of each kind of reactor leads to different mixing and aireation systems which are the principal responsible of the energy consumption (tubular photobioreactor consists of an array of plastic or glass tubes whereas flat panel photobioreactors are constructed by vertically translucent flat plates). Regarding to the cultivation open system, it presents the lowest energy requeriments because of it is the most simple configuration (raceway ponds are open systems with a closed loop recirculation channel with paddlewheel for mixing and circulation).

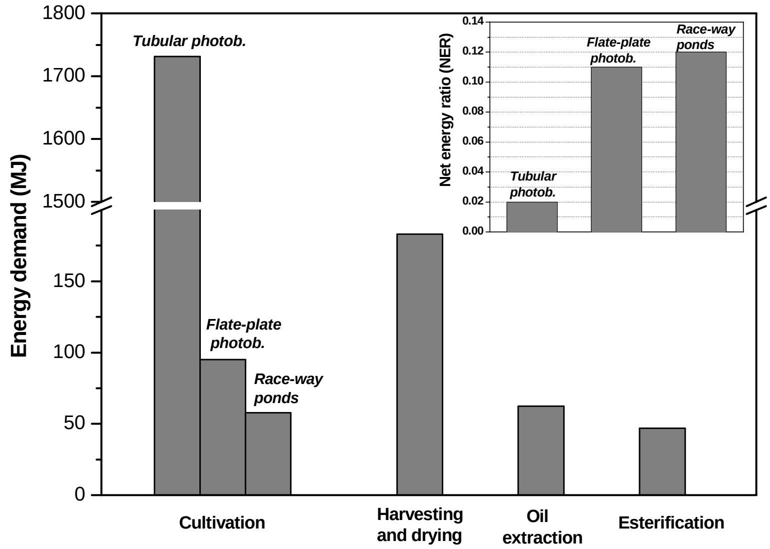


**Fig.3: Energy consumption and NER values of processes for biodiesel production from microalgae**

Analyzing NER values for all the systems, they are very low (~0.12 for raceway and flat-plate and 0.02 for tubular system). This is mainly due to the centrifugation process which is necessary for eliminating the larger part of water. However, these low values do not include the combustion of the dry biomass obtained after the extraction of the lipids for energy production (increasing NER). The similar values of the ratio produced/consumed energy for both raceway and flat plate systems can be explained by comparing the required energy for the construction of the raceway ponds to that required in the flat panels for mixing and aireation of the system.

In conclusion, tubular photobioreactors are not efficiently systems for biodiesel production from microalga *Nannochloropsis gaditana* while flat plate reactors are the most remarkable configuration due to the lower power supply (lower $CO_2$ emissions) and the lower contamination of the microalga culture in comparion to the raceway one.

Finally, alternative processes for microalgae harvesting and drying with lower energy requeriments seems to be indispensable for increasing NER values and, subsequently, the feasibility of biodiesel production from algae oil.

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