Carbon and nutrient recovery in the cultivation of *Chlorella vulgaris*: a Life Cycle Assessment approach to comparing environmental performance

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Mixotrophy is a trophic way that allows microalgae to be grown via photoautotrophic and heterotrophic pathways by using both inorganic and organic carbon sources. Microalgae cultivated in a mixotrophic mode showed an improvement in their growth rate, a reduction in growth cycle and biomass losses in the dark hours, and an augmentation in biomass productivity due to the supplementation of photoautotrophy with carbon substrates. Cheese whey is the main waste product of the dairy industry: every year 120 million Mg of cheese whey are produced in the world. Agriculture and livestock sectors produce large amounts of effluents that could produce severe pollution issues if not properly managed. Creating value from waste and by-products represents an interesting solution in recovering low-cost C-sources for the mixotrophic approach. Microalgae-based processes may represent a chance to recover nutrients (C, N and P) which would otherwise be wasted, promoting both the circular economy and more sustainable production systems.

LCA is a method of analysis for calculating the input/output of a system including the environmental effects (GHG emissions, eutrophication, acidification, etc.) and categorizing the analysis output into a format which is easy to interpret and compare.

*The **aim** of this work was to evaluate the environmental impacts of the cultivation of microalgae in autotrophy and mixotrophy and to define under what conditions mixotrophic cultivation gives the best environmental performance. This work describes an LCA study which was carried out to highlight the environmental benefits in recovering both C (cheese whey) and N (digestate derived-N) through producing algae under mixotrophic conditions.*

Fig. 1 showed a significant decrease of all the Eco-indicators considered in mixotrophic cultivation, due to the higher biomass productivity of mixotrophy (scenario 3) compared with autotrophy (scenario 1). In scenario 3 cheese factory wastewaters, i.e. wastewater derived from factory cleaning containing diluted cheese whey, was considered. Cheese whey wastewaters could be proposed for growing algae, avoiding the need for the wastewater depuration process and/or its transportation for discharge. In this case, as wastewater has no economic value, the environmental burdens of the organic carbon provided to the microalgae were entirely accounted for in the cheese production.

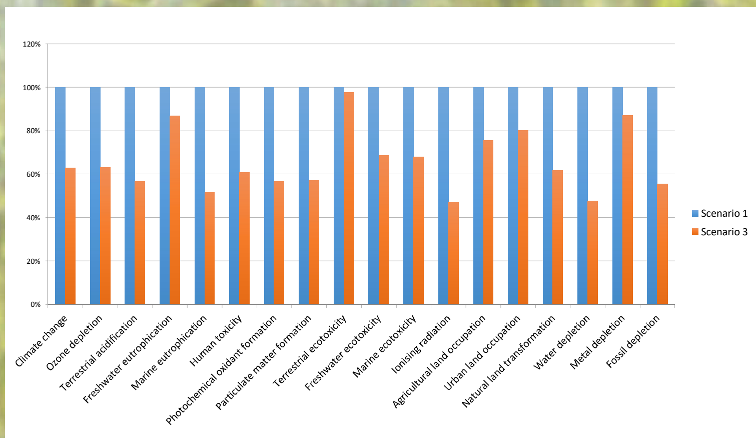

Fig. 1: Primary data of Chlorella vulgaris cultivation in autotrophy (scenario 1) and mixotrophic cultivation on cheese whey wastewater without commercial value (scenario 3).

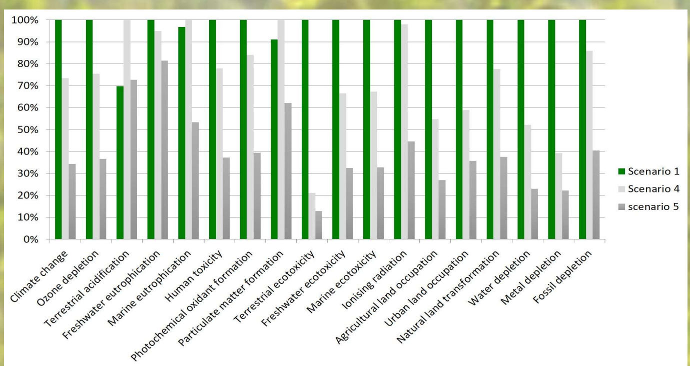

Fig. 2: Comparison between nitrogen recovery scenario (Scenario 4) and, combined nitrogen and carbon recovery scenario (Scenario 5) respect to the control (Scenario 1).

To highlight the effect of nitrogen recovery to produce microalgae biomass, the growing process was modelled assuming that N was provided by digestate (Scenario 4 and 5) according to the previous assumption made regarding N consumed by biomass and N efficiency.
The recovery of N from digestate (Scenario 4) and of both N (from digestate) and C (from cheese wastewater) (Scenario 5), led to a strong decrease of all Eco-indicators considered in comparison with autotrophy based on using synthetic fertilizers (scenario 1) (Fig. 2).

The Life cycle Analysis showed that mixotrophic growth of microalgae was an environmentally effective process, mainly when the recovered carbon had no alternative use, so that it could be considered burden-free.
Electricity and nitrogen supplies represented the production inputs causing the main environmental impacts of mixtrophic microalgae cultivation. The cultivation of microalgae on recovered nitrogen and carbon decreased CO_2 emission by almost 60% and lowered the other Eco-indicators in comparison with autotrophy. CO2 emission value achieved was of 1.05 kg CO_2eq. kg^{-1} of microalgae biomass, i.e. of 53 g CO_2 MJ^{-1}, which was an outstanding value compared to an LCA reference that used lower value for energy consumption.

This study is part of DANCE project , financed by Fondazione Cariplo (2014-0587) has the aim to recover renewable carbon and nutrient sources from lombardy agro-industry to be used to produce microalgal biomass rich in high added-value molecules by developing mixotrophic bio-technology.