Evaluation of the environmental benefits deriving from the use of waste CO_2 for microalgae production in a life cycle perspective

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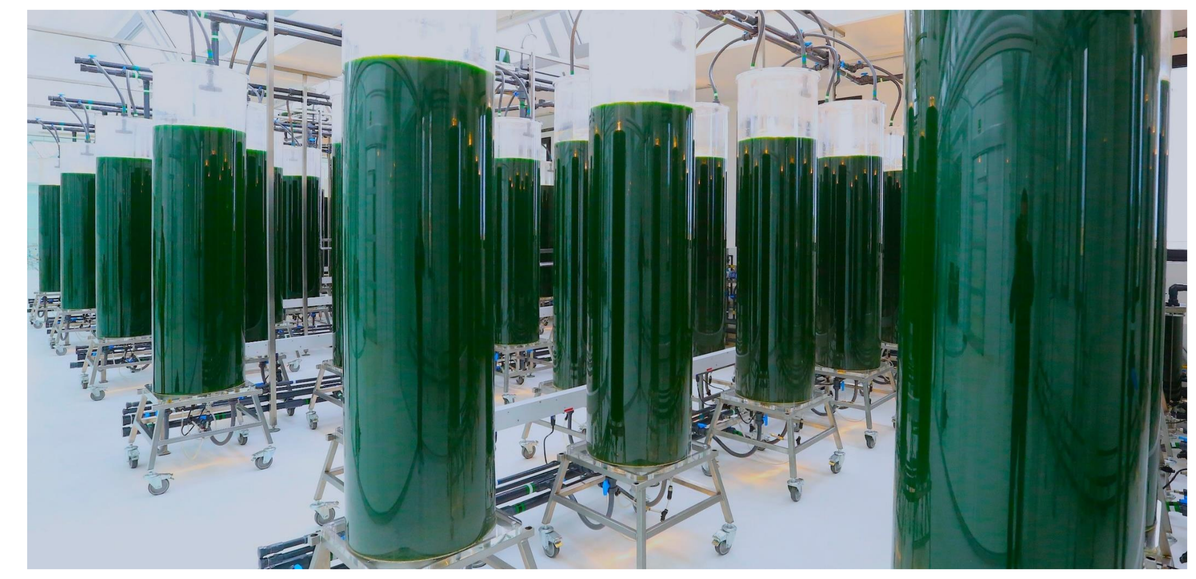
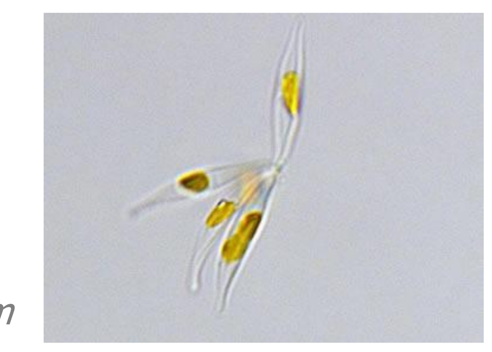
INTRODUCTION

Microalgae are photosynthetic microorganisms which can be used as a feedstock for a variety of biofuels and other value-added chemicals. Their ability to sequester carbon and at the same time synthesize valuable compounds with potential applications in nutraceutical, pharmaceutical and cosmetic industries makes them attractive for commercial deployment in a low carbon economy. Among microalgae, the marine diatom *Phaeodactylum tricornutum* is one of the most promising, due to its comparatively high growth rate and high content in bioactive compounds. Micoperi Blue Growth (MBG) is currently carrying out tests with this strain in order to demonstrate its commercial potential. In particular, both MBG and the University of Bologna are involved in the GoBioM project (POR-FESR 2014-2020), aimed at the technological optimisation of the biomethane supply chain. Among the project targets, there is the valorisation of CO_2 separated from CH_4 cultivating algae on an industrial scale, according to the need to include biomethane plants within biorefinery and circular economy concepts.

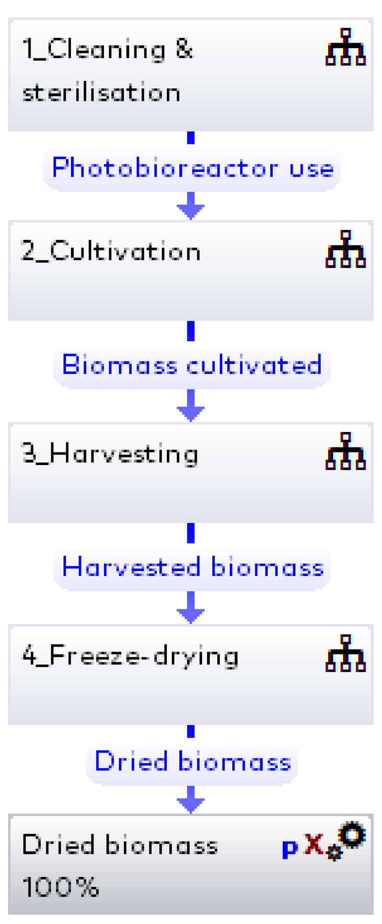
In the present study, the environmental profile of a microalgal production system is assessed, supported by experimental data on the production process, considering both the use of synthetic CO_2 and waste CO_2 from a biogas upgrading process.



Vertical bubble column photobioreactors (MBG plant)



Phaeodactylum tricornutum



Flow sheet (GaBi)

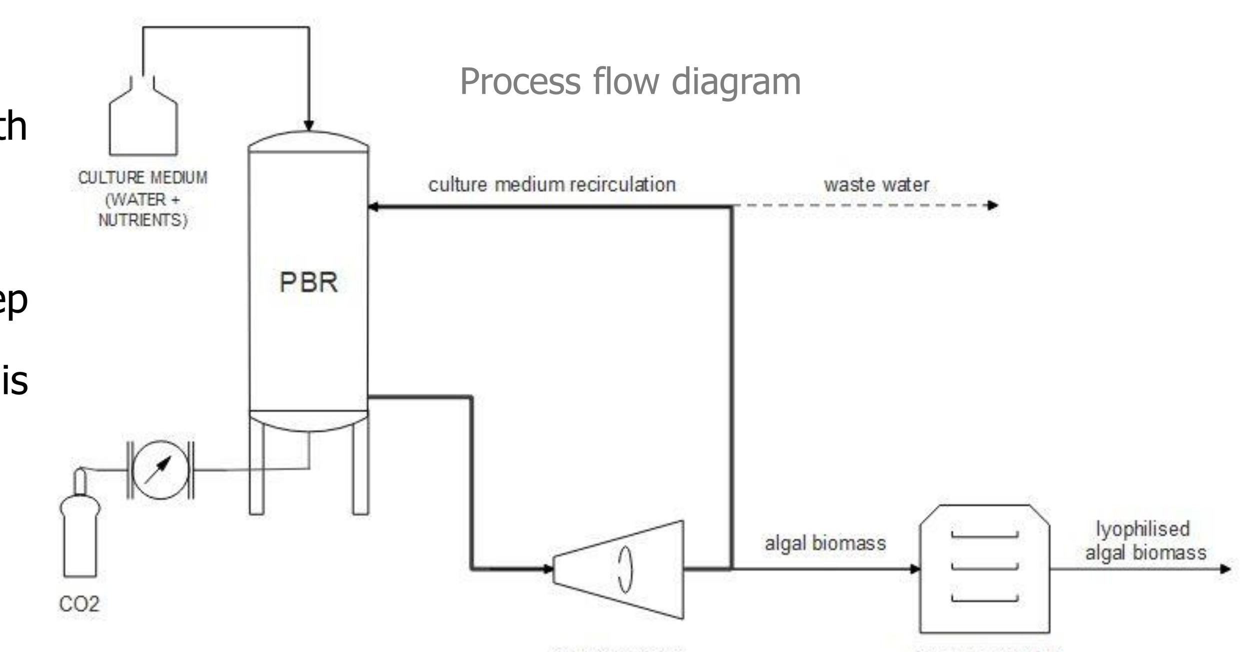
METHODOLOGY

The environmental evaluation of the production system was performed through Life Cycle Assessment (LCA) methodology, according to the ISO14040 standards. The software GaBi 8.0 was used for the computational implementation of the inventories. For the LCIA, the midpoint impact categories recommended in the ILCD Handbook (ILCD/PEF recommendations v1.09) were considered. The main goal of this attributional LCA study was to perform the comparative analysis of the environmental impacts associated with the production of *P. tricornutum* between the process using synthetic CO_2 and the process using waste CO_2 from the upgrading process of biogas to biomethane.

The production process was assessed at pilot scale, in a hypothetical scenario. The study was based both on laboratory data, with regard to algae growth rates, and primary data from a production plant, with regard to the equipment and its consumption.

The analysed process chain includes the stages of cleaning and sterilisation, cultivation, harvesting and freeze-drying. Cultivation step takes place in an indoor vertical bubble column photobioreactor with a working volume of 120 L, subsequently the culture is centrifuged to collect the biomass, which is stored at -20°C and finally lyophilised.

Process flow diagram



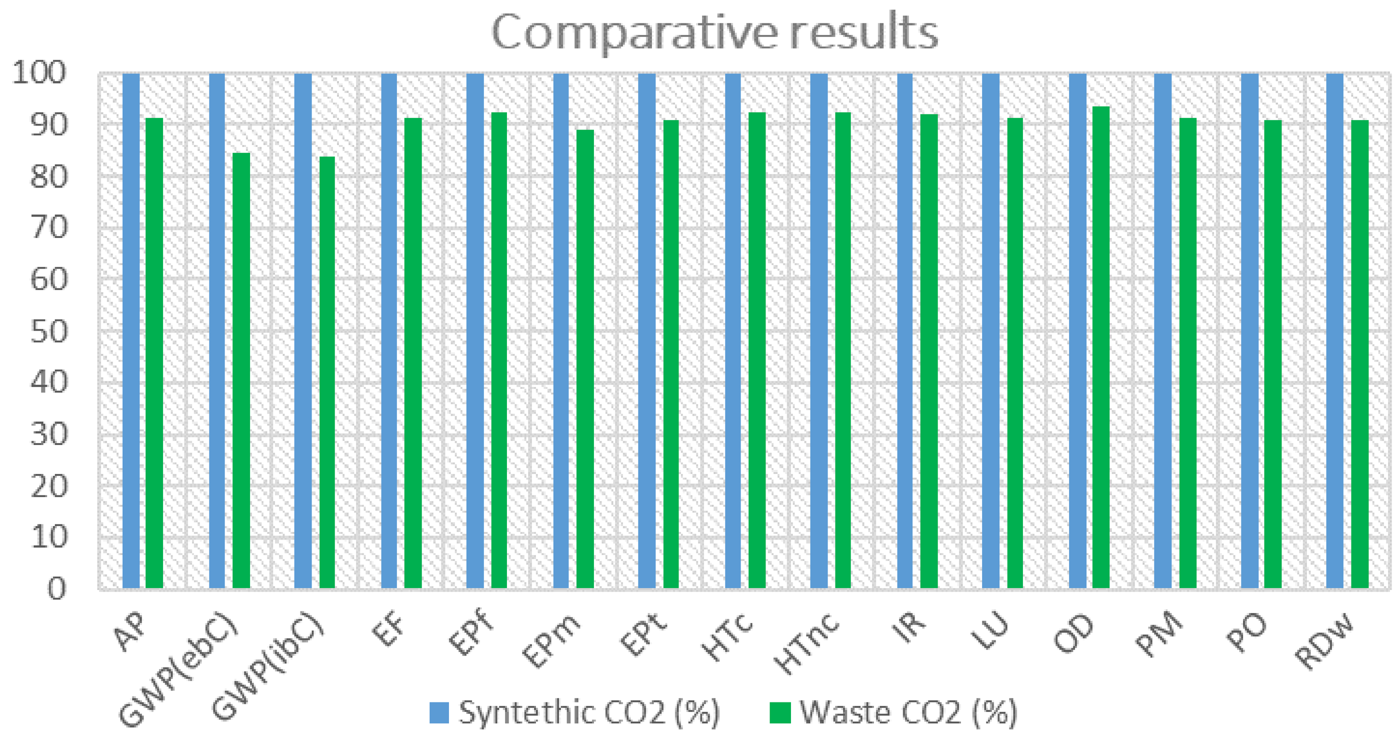
RESULTS AND DISCUSSION

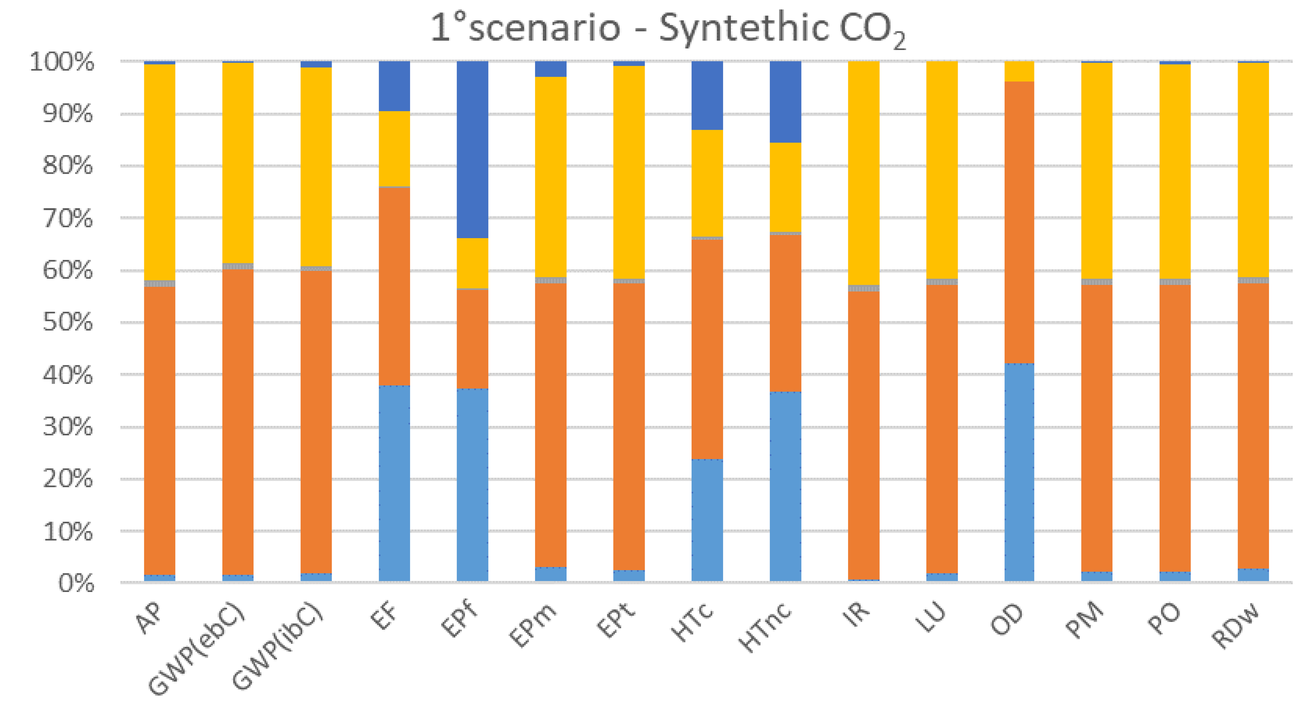
The results indicate that impacts for the "Waste CO_2" scenario are generally 10% lower than the "Synthetic CO_2" one, thanks to the absence of synthetic CO_2 production and to a slightly higher productivity in the cultivation process. In particular, it can be noted that for the GWP impact category the use of waste CO_2 allows a wider improvement, as CO_2 direct emissions from the cultivation process come from an input of biogenic CO_2.

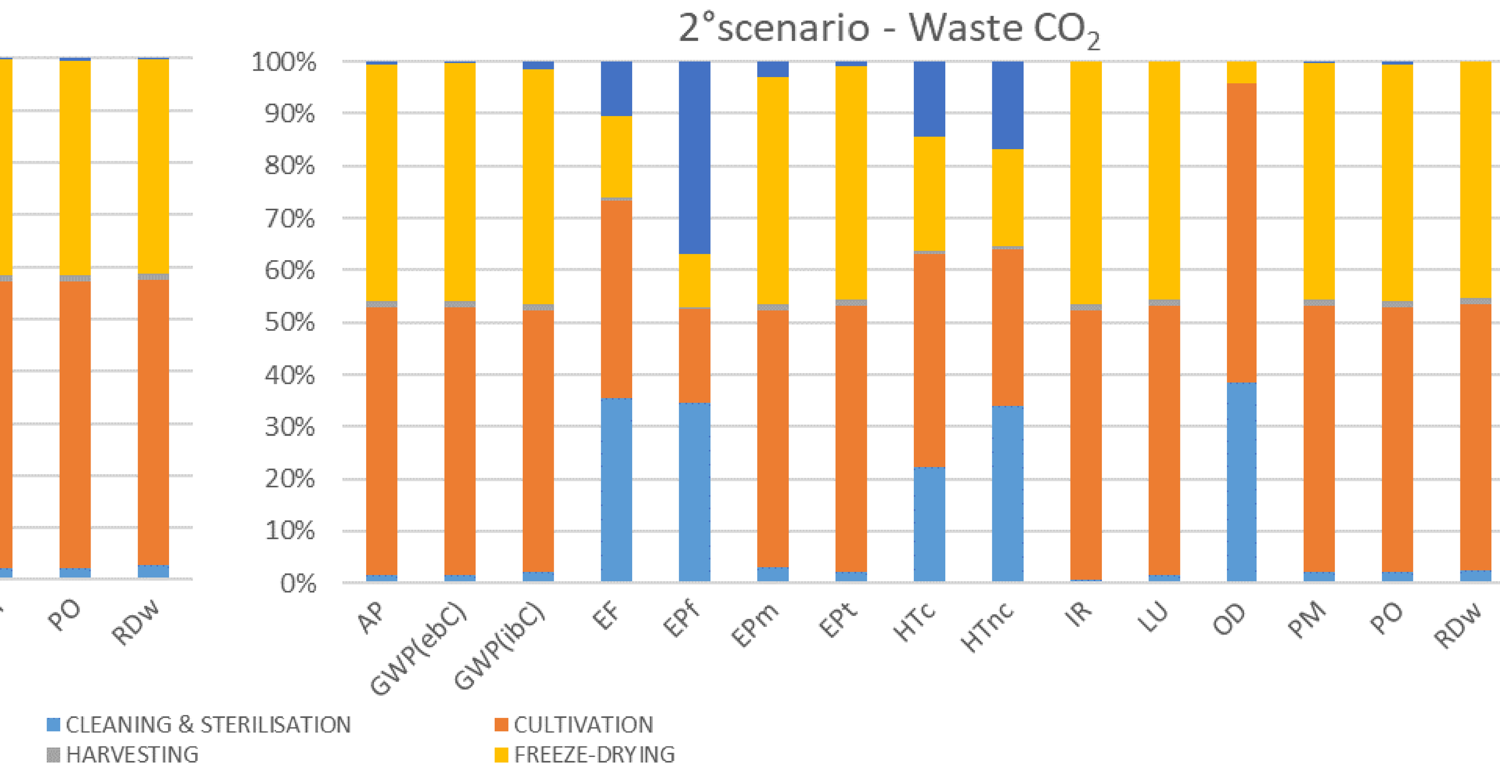
For most of the impact categories the main contribution derives from cultivation and freeze-drying stages, being the most energy-consuming ones. At the same time, harvesting step presents in all cases a negligible impact, since it only requires a relatively small amount of electricity for centrifuge operation. Exceptions can be observed for the ozone depletion (OD) impact category, in which an important contribution of the sterilisation process emerges, due to cleaning agent production processes, as well as for the human toxicity and ecotoxicity (EF) impact categories, where a significant contribution of waste water treatment process is also evident. Conversely, main contribution to freshwater eutrophication (EPf) is produced by sterilisation and waste water treatment, due to discharging of nutrient-rich water in freshwater bodies. However, these last results originate from the assumption that all wastewater is equivalent to the average municipal sewage: this assumption is very severe compared to the actual situation, so further investigation is needed to quantify the real contribution.

Impact category	Unit	Acronym	Syntethic CO_2	Waste CO_2
Acidification	Mole of H+ eq	AP	1.1E+00	1.0E+00
Climate change, excl biogenic carbon	kg CO_2 eq	GWP(ebC)	3.8E+02	3.2E+02
Climate change, incl biogenic carbon	kg CO_2 eq	GWP(ibC)	3.9E+02	3.2E+02
Ecotoxicity freshwater	CTUe	EF	3.0E+01	2.8E+01
Eutrophication freshwater	kg P eq	EPf	3.7E-03	3.4E-03
Eutrophication marine	kg N eq	EPm	2.3E-01	2.1E-01
Eutrophication terrestrial	Mole of N eq	EPt	2.3E+00	2.1E+00
Human toxicity, cancer effects	CTUh	HTc	5.7E-07	5.2E-07
Human toxicity, non-cancer effects	CTUh	HTnc	2.7E-06	2.5E-06
Ionizing radiation, human health	kBq U^{235} eq	IR	1.5E+02	1.4E+02
Land use	kg C deficit eq	LU	2.1E+02	2.0E+02
Ozone depletion	kg CFC-11 eq	OD	1.7E-07	1.6E-07
Particulate matter/Respiratory inorganics	kg PM2.5 eq	PM	5.2E-02	4.8E-02
Photochemical ozone formation, human health	kg NMVOC	PO	5.9E-01	5.4E-01
Resource depletion water, midpoint	m³ eq	RDw	2.3E+01	2.1E+01
Resource depl., mineral, fossils and renewables	kg Sb eq	RDm	1.3E-03	1.2E-03

LCIA results (Functional Unit = 1 kg_{DW} biomass)







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