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Perspectives and challenges of small scale plant microalgae cultivation. Evidences from Southern Italy

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ABSTRACT

In recent years, the cultivation of algae has achieved attention of scientists and practicioniers due to the great variety of products that can be obtained, among which biofuels. The aim of this work is twofold. The first is to perform a profitability analysis of food and biofuel production from microalgae, in a small-scale setting. The second is to assess the economic impact of algae production systems on the dairy farms potentially interested in Southern Italy. The analysis was performed using financial and economic indicators and considering two system management scenarios, namely single and collective. Our results confirm that current microalgae production technology favors biofuel only as a co-product and that the production of high-value co-products improve profitability and net income in Southern Italian dairy farms, either in single or collective management. More specifically, the single management is more profitable, but the collective is more viable. The sensitivity analysis, based on the price uncertainty of algal biomass, confirms that the price of product is a critical parameter to ensure the investment feasibility in the agricultural context analyzed. Current study provides hints to entrepreneurs and managers operating in the agricultural sectors, interested in improving their firm's performance through the adoption of a diversification strategy of business activities.

1. Introduction

Microalgae represents a potentially great source of natural compounds that can be used both as functional ingredients [1] and as energy sources [2–6]. The use of microalgae, either directly as dietary supplements and/or for the extraction of biologically active molecules, is not a recent phenomenon. Since the fifties, Burlew [7] proposed their use as alternative protein sources to face the global food demand. Microalgae are demonstrated to be an important and sustainable source of high value molecules, pigments such as ß-carotene, Astaxathin and Phycocyanin, and Fatty acids, that are increasingly appreciated in the market, especially compared with other synthetic and traditional alternative molecules [8]. More recently, the use of microalgae has been proposed to produce biofuels, biodiesel in particular, thanks mostly to their high lipid content. Furthermore, unlike other crops, microalgae can be grown on marginal land or even in deserts [9]. They can grow in saline water and produce oil with high productivity per unit area and can make a positive contribution to energy balance and global warming reduction [10]. These advantages position microalgae among the main sources for the production of third generation biofuels and justify the massive interest of scholars, mainly due to high energy requirements and high cultivation and conversion process costs [6,11–14].

In 2014, worldwide production of algae, concentrated in 33 countries, was 27 million tons, especially used as food [15]. The microalgae market, 75% represented by dietary supplements [8], is relatively small. Opportunities for growth in this market, as pointed out by some authors ([16]; [17], [18,19]), are linked to market and economic factors. In particular, production of scale, company investments, regulation of novel food and access to credit represent the most relevant factors affecting the economic feasibility of the plants ([20]; [18,21]).

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For these reasons, in recent decades several studies have focused on the assessment of the economic feasibility of different microalgae production systems in relation to different food and non-food products. In large part, these works focus on hypothetical large-scale plants, based on pilot plant data. Most of these studies, which assess the results of high-value algal biomass productions on 100-hectare surfaces, are based on pilot plants not exceeding a few hundred square meters and then hypothetically upscaled [19,21,22]. For biofuel production, on the other hand, the hypothesized scale for the plants is greater, until it definitely surpasses the threshold of 1,000 hectares ([23]; [14]).

Algal biomass cultivation at scale has significant overlap with traditional agriculture [24], but the legal framework of this activity is not always clear. Trentacoste and colleagues [25] underline that algaculture has not yet been defined within the US federal legislation. However, some States (e.g. Arizona, Iowa and Ohio), have specifically amended their laws to define algaculture as part of agriculture. In Italy algae cultivation is considered as aquaculture activity. On this basis, algae cultivation could be a source of diversification and income for farms, due the potential production of compounds with a wide application and high added value [26]. The diversification of the agricultural business, through an innovative process such as algal biomass for the production of biodiesel and high added value products, could concretely contribute to the creation of a competitive advantage [27,28,29].

Despite a wide interest on this subject, there is a lack of references relating to the feasibility of such investments in the agricultural sector and almost no studies that considers small-scale plants. Building on the literature concerning the techno-economic analysis of microalgal biomass production, the goal of this paper is to examine the economic feasibility of a microalgae production system to obtain biodiesel and high value products in a small-scale plant, implementable by farms. In detail, starting from a pilot small-scale plant for food and biofuel production, we assess the economic impact of the plant on dairy farms considering three different scenarios followed by a sensitivity analysis based on price changes of microalgal food.

The remainder of the paper is structured as follows. Section two presents a review of the literature. The methodological approach used to address the research aim, organized in five sub-sections, is presented in the section three. In section four results are presented and discussed. The last section contains final considerations.

2. Literature review

Techno-economic aspects of microalgae cultivation have been widely studied over the last few years. These studies vary greatly in relation to the production system evaluated and the typology of products obtained. They focused on different production systems, open ponds (OPs) or photobioreactors (PBRs), analyzing the individual system or evaluating and comparing the economics of OPs versus PBRs, that produce both a single product, for example biofuel, and evaluating the economics of plant as a system able to obtain more than one type of product from microalgae. Despite a large number of studies conducted to date in this field, variability of the results makes necessary further investigations aimed at verifying the technical and economic feasibility of plants.

Several empirical analyses have focused on assessing the technical and economic feasibility of plants with different characteristics, but almost all based on pilot plants. Amer and colleagues [30], comparing five different biodiesel production processes from microalgae, found that OP systems represent the most cost-effective solution. A similar result is obtained by Richardson and colleagues [9] that used a financial feasibility study to compare an OP and a PBR in the South-West of the US. Authors found that PBR is less sustainable than an OP due to higher costs of the production of PBR. Even when dietary supplements or extraction of biologically active molecules are produced by microalgae, findings confirm a lower production cost in OP compared with PBR [31]. However, PBR offers several advantages. Among the most relevante, it works at higher cell concentration and reduces freshwater losses. The latter is important since it diminishes the risk of contamination and, as a consequence, avoids the loss of value of biomass that is especially important to produce human compounds and cosmetics [32,33].

As for the economics of the different production systems, literature seems to agree that are several the variables affecting economic returns. Santander and colleagues [34] found the selling price of biodiesel and the discount rate are the main factors affecting the economic viability of a microalgae production process. Brownbridge and colleagues [12], analyzing techno-economic aspects of algal-derived biodiesel under economic and technical uncertainties, concluded that the production cost of algal biodiesel, estimated between £0.8/kg and £1.6/kg, is affected mainly by algal oil content and annual productivity per unit area, which simultaneously influences the number and capacity of PBR and solar power plant capacity. Similar results were obtained by Sun and colleagues [11]. The influence of the yield of algae on the profitability of the plants is further confirmed by Thilakaratne and colleagues [35] who highlighted that, to improve techno-economics results, a 20% of increase in yields is necessary.

Several studies emphasize that, irrespective from the type of system adopted for biodiesel production, none of the alternatives (OPs and PBRs) was financially and economically competitive [14,36]. Empirical evidences seem to agree on the economic unsustainability of plants that exclusively produce biofuels from algal biomass, advancing more profitable solutions for plants that produce valuable compounds (pigments, fatty acids, etc.) [13,37,38]. In this vein, [39] found that biofuel production from microalgae does not have economic viability based on current capital costs per unit of fuel production. Therefore, integration of algal-fuels in a combined plant with simultaneous production of value added by-products, have a positive impact on the overall economic result [40]. The valorization of co-products is, in fact, particularly significant as it adds value and returns that makes the whole process economically viable [41]. In addition, Dutta and colleagues [41] emphasize that the economic feasibility of plants is also dependent by the geographical area. Consistent with this, Banerjee and Ramaswamy [42] found that microalgae production costs are highly sensitive to algal productivity potential associated to a given production area. The influence of the economic and social framework on the economic feasibility of the plants also arise in the study of Tredici and colleagues [33], that estimate the production cost of algal biomass devoted to feed, food ingredient, for probiotic production or for further extraction and purification of specific compounds (pigments, fatty acids, vitamins). They found that labor cost is the costliest, depending on plant location (in Italy represented 40% of the total cost, while 27% in Tunisia). Also in the case of biorefineries that produce biodiesel and co-products, a discriminating variable for plant profitability is represented by the price of finished products. Sari and colleagues [37] performed a techno-economic analysis comparing two alternative conditions for microalgal protein extraction (alkaline and enzymatic methods). They highlighted the high uncertainty of the results obtained due to the unavailability of a reliable industrial microalgae market price. The issue is also emphasized by Thomassen and colleagues [31], according to which the price of the end product, and in the specific case of ß-carotene, is the most critical parameter for economic process profitability. Indeed, as emphasized by Richardson and colleagues [9], it is essential to carefully assess the size of the market of each co-product in order to understand the level at which the market becomes saturated, influencing the profitability of the plants.

Gambelli and colleagues [43] evaluated the perspective of biofuel in Italy through a scenario analysis. Authors state that, in the best scenario, there is a 75% probability that biofuels from microalgae will exceed 20% of the biofuel market by 2030. This is conditional on the improvement and development of the technological changes and environmental policies, as well as of the markets for bioenergy and novel

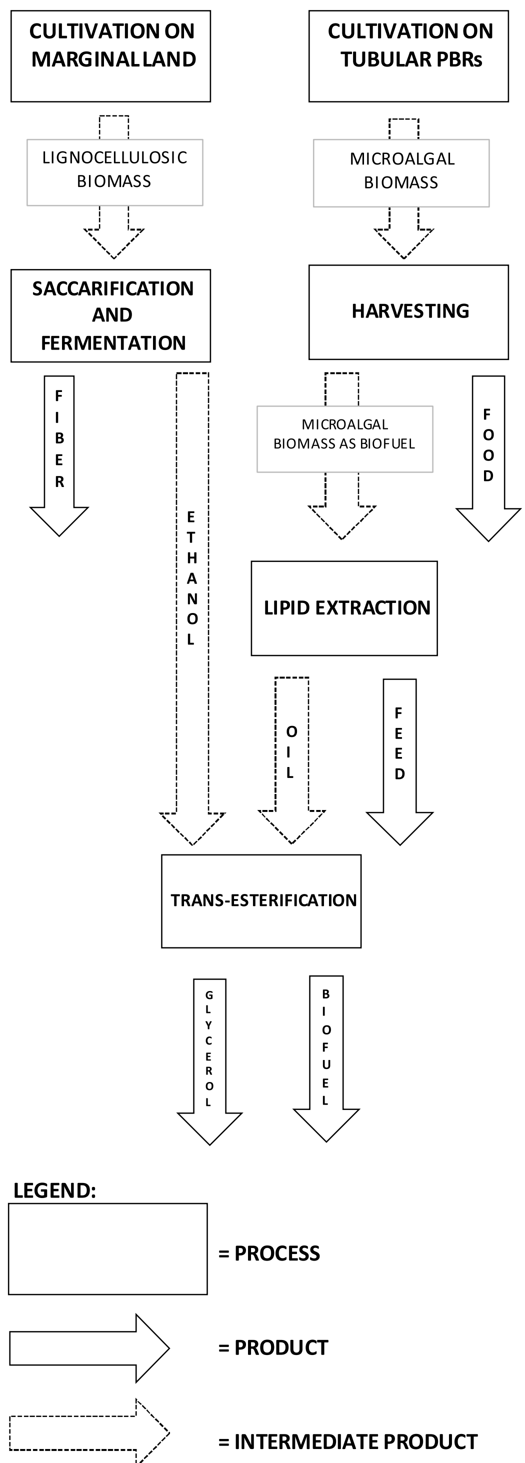

Fig. 1. Process flow diagram of the plant considered in the study.
Source: based on a study performed under BIO.FO.R.ME. project funded by the Italian Ministry of Agricultural, Food and Forestry Policy.

foods derived from microalgae [43].

This brief review focused on the main studies that have placed emphasis on the economic feasibility of different production systems, OPs and PBRs, for production of algal biomass for fuels and high-value co-products. It reveals a wide variety of production costs per unit of algal biomass produced due to different cultural systems studied, as well as to environmental and social conditions.

3. Methods

3.1. Technical features of the production facilities

Technical features are based on a study performed under BIO.FO.R.ME. project, funded by the Italian Ministry of Agricultural, Food and Forestry Policy, with the aim to assess the technical and economic feasibility of a plant approach for food and biofuel production from microalgae and lignocellulosic biomass. The process flow diagram and main outputs of the system are shown in Fig. 1. The integrated plant performs trans-esterification between bioethanol obtained from lignocellulosic biomass (e.g. Arundo donax or Hedysarum coronarium) and microalgal oil extracted from microalgae, in order to obtain biofuel and dietary supplements production.

As flow diagram shows (Fig. 1), algal biomass has two different destinies: food and biofuel (plus feed and glycerol). Comparison of economic results and the evaluation of viability to activate one or both the production lines, namely food compound and biofuel, was first investigated in the current study. The yield of algal biomass production in the PBR is one of the crucial aspects in our evaluation and one of the most debated issues in scientific literature. In the present study, the yield was equal to 30 g/m^2/day (78 g/ m^3 day), based on literature results [2,30,36]. The total annual production, obtained at operation time of 330 days, was approximately 14,400 kg of algal biomass. If all biomass were devoted to biofuel, annual production would be about 4,300 kg. In the current study, Chlorella has been chosen as algal species taking into consideration its versatility to be used either for food (good content of protein, fatty acids and pigments) and for biodiesel productions (good level of lipids) [44,45].

3.1.1. Microalgae production description

Microalgae cultivation takes place in tubular horizontal PBRs to obtain high nutritional content, high quality of biomass and the highest yield of microalgae biomass. This system ensures control and regulation of all parameters and reproducible cultivation conditions without contamination. The facility, positioned in a greenhouse, requires a working area of 1500 m^2 and is composed of glass tube arranged on close circulating mode. The choice of greenhouse is motivated by the need to ensure the optimal control of the environmental conditions for 11 months a year and a high productivity. The total area required by the plant was 2000 m^2. With reference to the literature (see Section 2), the hypothesized system can be considered small-scale. In particular, the plant was meant to be small-scale in order to be implemented in Italian agricultural context (see Sections 3.4,3.5), which represents one of the main peculiarities of this work. In this sense was important to considered the limits not only in terms of surfaces but above in terms of amount of capital and management skills of the farms involved. With reference to this topic, we note that, at the moment, only a few works have considered the economic performance of small-scale plants [21,22] but not tested in an agricultural context.

The proposed PBR consists in 112 modules, arranged as in Fig. 2. Every module it's composed by 288 tube with 65 mm outer diameter and 2.2 mm wall, 144 “U” bend and 108 coupling; supported by an metallic structure. Each modules it's equipped with a low pressure centrifugal pump, a recirculation tank for nutrients supply, a blower and 56 led tube for artificial lighting.

A volume of 560 m^3 of demineralized water is mixed with nutrients by a centrifugal pump located upstream on the solar receiver meanwhile continuous illumination is provided by both natural and artificial light. The PBR tube are cleaned as needed, using a pigging moved by water-sodium hypochlorite solution, using recirculation pumps. To ensure biofilm removal and sterility.

The microalgae grows in continuous mode and the microalgal biomass is completely harvested and separated from the liquid media with a dynamic settler, that can treat up to 2 cubic meter per hour. The output of the settler is a paste with 80% water content and the residual

Fig. 2. Tubular photobioreactor arrangement.
Source: the authors.

media, that is re-employed with a makeup volume of fresh water (10% of total liquid volume). The algae paste obtained from the settler is then delivered to dehydrators with a 40 kg capacity and air temperature ranging from 40 to 65 °C. The algae biomass is dried prior oil extraction, to increase extraction capacity of ethanol.

3.1.2. Bioethanol production description

Bioethanol production process occurs in a dedicated reactor. Pretreated lignocellulosic biomass is hydrolyzed by the action of acids or enzymes, which converts cellulose into sugar. Later, bacteria or yeasts carry out the fermentation of the sugar into bioethanol. The bioethanol produced is then distilled with a micro distillery, to reach ethanol purity greater than 96%.

3.1.3. Oil extraction from microalgae biomass

After the two-step purification made by distillation and dehydration, part of purified bioethanol (96% vol/vol) is used to treat microalgal biomass according to the method of Fajardo et al. [46] for oil extraction from microalgae.

The extraction process is made in two steps, in a stainless steel stirred reactor of 800 liters capacity at ambient temperature. The first steps, dried microalgae is joined with bioethanol with a ratio 10:1 (L/kg) Ethanol:biomass for 12 hours. The second step of extraction it's required to isolate saponifiable lipids. Water was added to ethanol/lipids solution to attain a water of 40% vol/vol, hexane was then added to the ratio 1:1 (vol/vol). After these steps the hexane phase contain roughly 91% of saponifiable lipids, that are collected and evaporated from hexane. The defatted biomass obtained from first step extraction, is collected and evaporated from bioethanol.

3.1.4. Biodiesel production

After evaporation of bioethanol, the saponifiable lipids are converted into biodiesel. The presence of bioethanol does not alter biofuel production because ethanol is involved in trans-esterification reaction. The synthesis of biodiesel is carried out in a stainless steel reactor with a capacity of 800 liters, according to [47]. The reactor is filled with the microalgae lipid and bioethanol, with a molar ratio lipid:bioethanol of 1:12 wt/vol. As catalyst is used the commercial preparation of lipase from Candida antarctica Novozym® 435 at 20% by weight with respect to the total weight of the reagents involved in the reaction. The reaction takes place at a temperature of 50 °C for a maximum period of 96 hours with a yield of about 98%.

3.2. Estimation of investment and operational costs

Production cost of the microalgae biomass obtained from the described plant was determined as follow. The total fixed capital was calculated after the major equipment cost is known, by multiplying the corresponding Lang factors, according to the nature of the item (Acién at al., 2011). The total investment costs for the pilot plant includes the interest on the capital anticipation. The cost of capital was 4% (Italian Government bond yields).

The operational costs were calculated as sum of depreciation, maintenance and direct costs using market prices obtained by interviewing key informants. Depreciation cost was estimated through a linear distribution. Maintenance cost was based on the installed equipment cost applying a 2% ratio [23,48]. Raw materials and utilities required were estimated based on the specific plant system requirements developed by the authors. In particular, the lignocellulosic biomass needed, was estimated based both on the empirical evidences obtained by the authors (University of Naples and University of Palermo) and the literature [49]. The total energy needed was 99,000 kW h of electricity and heat. In particular, most of energy were used for the cultivation process (60%) and the remaining part for algae harvesting (23%) and for the oil extraction process (17%). Thermal energy was produced using electricity, limiting the complexity of installations due to technical limitations of rural areas. Wages and consultancy were estimated considering the need to have four units globally to manage the plant (director, consultant and 2 workers), whose costs were estimated based on the Italian job market.

Scenarios about fiscal aspects might be affected by uncertainty, especially in PBR. In this work, taxation was based on rules applied to Italian farms. In Italy aquaculture and agriculture share the same tax system and algae cultivation is considered an aquaculture activity.

Table 1 describes the costs of the plant for obtaining biofuel and high value co-products from algal biomass, distinguished in investment and operational costs. The investment cost represents the capital required for the equipment installation, while operational cost is the sum of all the costs of the plant operation, which are important factors for the feasibility of the project. Concerning the total capital investment, the main items are the PBRs cost, about 1.11 million euros, 66.7% of the total investment, and the greenhouse total cost (14.7%). Other items have a lower influence on the total investment costs: start-up costs (5.6%), microalgae harvesting system and tanks (algae storage) (4.4%), trans-esterification and drying systems costs (3.5%).

Another important factor for the feasibility of the project is the operational cost that account for more than € 280,000. Wages and consultancy are the main items, 38.9% of the operational cost, followed by depreciation (28.1%) and plant maintenance costs (10.7%). The "energy" and the "water, nutrients and lignocellulosic biomass" represent respectively 6.7% and 5.0% of total cost operational. The estimates show that the lignocellulosic biomass does not represent a limit to the plant feasibility, both for the cost and for the area required by crops.

3.3. Cost-benefit analysis

Several economic analyses can be used in order to compare the benefits and costs of business decisions. Among these, Cost-Benefit Analysis (CBA) is one of the most widespread tool, since it is a rational and systematic decision-making support tool [50]. In this study, CBA has been used to estimate the economic feasibility of the proposed investment, adopting the following indicators: Net Present Value (NPV),

Table 1
Investment and operational costs of the plant.
Source: Investment and Operational cost calculated on the basis of commercial offers from commercial suppliers. Note: a) Lifetime = 20 years; b) Lifetime = 10 years.

Item	Value (€)	%
Investment cost		
PBR [a]		
n° 32.256 glass tube OD 65 mm, 5,5 m lenght	677,376	40.5
n° 16.128 "U" bends	185,572	11.1
n° 12.096 Coupling	78,624	4.7
Support structure	93,270	5.6
Pumps and piping	30,578	1.8
Lighting	8,200	0.5
Blower	15,000	0.9
Thermoregulation	24,300	1.5
Total PBR	1,112,820	66.5
Harvesting system [a]	60,000	3.6
Tanks [a]	13,000	0.8
Microalgae Oil extraction [b]	1,000	0.1
Biodiesel production [b]	8,000	0.5
Bioethanol production [b]	30,000	1.7
Drying system [b]	20,000	1.2
Industrial building [a] (200 m^2 * €30/m^2)	60,000	3.6
Greenhouse structure [a] (1500 m^2 * €150/m^2)	225,000	13.4
Greenhouse coverage [a] (1500 m^2 * €15/m^2)	22,500	1.3
Large square [b] (200 m^2 * €10/m^2)	2,000	0.1
Vehicle [b]	15,000	0.9
Land (2000 m^2 * €5/m^2)	10,000	0.6
Start-up costs	94,559	5.6
Total investment cost	1,673,879	100.0
Operational cost (per year)		
Depreciation	79,491	28.1
Plant Maintenance	30,306	10.7
Wages and consultancy	110,000	38.9
Energy (98,955 kW h * €0.19/kWh)	18,801	6.7
Circulation Pumps: 11900 kW h $year^{-1}$	2,261	
Blowers:4450 kWh $year^{-1}$	845.50	
Microalgae Harvesting: 24500 kW h $year^{-1}$	4,655	
Bioethanol production: 17800 kW h $year^{-1}$	3,382	
Microalgae oil extraction:13350 kWh $year^{-1}$	2,536.50	
Biodiesel production: 17100 kW h $year^{-1}$	3,249	
Other: 9855 kW h $year^{-1}$	1,872	
Water (2.200 m^3* €1/m^3)	2,200	0.8
Nutrient (0.8€/kg algal biomass)	11,880	4.1
Lignocellulosic biomass (15.99 t * €50/t)	799	0.3
Other items	15,000	5.3
Taxes	15,000	5.3
Total operational cost	282,678	100.0

Internal Rate of Return (IRR), Discounted payback period (DPP), Return On Equity (ROE) and Net Income (NI).

The NPV measures the performance of an investment over a time horizon, considering all expenditures and revenues at the time of their occurrence and assigning a time-value at the present time, using an appropriate discount rate. The basic formulation for computing NPV is shown as follow:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1 + r)^t}$$

where, CFt is the cash flow generated by the investment in year t obtained by subtracting to the total benefit of the t-th year, the total cost referred to the same period; r is the discount rate (%); n is the calculated duration of the investment in years. To estimate the economic benefits, it was necessary to establish the products price. For biofuel the corresponding price was estimated by using the average price for agriculture fuel used in Italy (2012-2014 period), equal to €1.12/kg[1] . The price of co-products (food, feed and glycerol) were taken from specialized literature, with particular reference to Egardt et al., [51], Quispe at al. [52], Spruijt et al. [22] and Ruiz et al. [19], integrated and confirmed with in depth interviews conducted with key informants, and taking into consideration the price of similar co-products currently adopted by several sellers in the on-line market where the product is available and it represent an average of the selling prices. In particular, prices were €35/kg for food, €5/kg for feed and €0.89/kg for glycerol. Total cost includes both investment and operational costs, described in detail in the section 3.2. Concerning the duration of the investment, it was considered an economic lifetime for PBR of 20 years according to the literature [53,54,55]. A value of NPV $>$ 0 means that the investment will result in a positive benefit; NPV = 0 means that the investment will just meet the expectation; and NPA $<$ 0 means that the benefits are lower than expected.

The IRR, represents the rate value when the NPV is zero. The investment is convenient if the IRR is higher than rate of capital. In the comparison between two or more investments, not necessarily at a greater NPV corresponds a higher IRR. In fact, while the NPV measures the creation of value, the IRR indicates the yield of the investment.

The DPP is the time (in years or fraction of years) required for a company to recover its original investment. It is a simple way to evaluate the risk associated with a proposed project. The main payback fault is the fact that does not consider the cash flows after they recovered the investment.

The ROE indicates the return on own capital and NI the difference between revenues and explicit costs (cost of external factors):

$$Return\ on\ Equity\ (ROE) = \frac{Net\ income}{Shareholder's\ Equity}$$

The use of a range of indicators was related to the possibility to evaluate different aspects of the investment.

3.4. Agricultural context

As mentioned above, one of the aims of this work was to assess the economic feasibility of a small-scale plant, for food and biofuel production from microalgae, in agriculture, being the microalgae a potential source of income and diversification for farms.

To identify a defined agricultural context, we considered the climatic conditions favorable to the cultivation of algal species in PBR and the balance sheet of farms, taking into consideration the high investment necessary and then the opportunity to obtaining credit from the banks.

As regards to the climatic conditions, Southern Italy has favorable conditions for microalgae cultivation, in terms of temperature and hours of sunlight, as it makes it possible to keep low the operational costs related to the temperature and luminosity control in the greenhouse. Southern Italy has characteristics similar to the South of Spain that, as emphasized by Ruiz et al. [19], is one of the best place to achieve biofuel and bio-products from microalgae.

The choice of the types of farm to assess the plant impact was done taking into account the Farm Accountancy Data Network (FADN), an European Commission tool to monitor the income and business activities of agricultural holdings and to evaluate the impacts of the common agricultural policy (CAP)[2], managed in Italy by CREA (Council for agricultural research and analysis in agricultural economics). Based on these data, the dairy farms were chosen because, compared to other agricultural sectors, they have an income sufficiently high to access to bank loan and, then, to carry out the investment. In particular, we focused on Campania and Sicily regions, where about half of the cattle and water buffaloes of Southern Italy is concentrated and almost 13.1%

[1] Bologna province Chamber of Commerce (vv.yy.). Listino prezzi, http://www.bo.camcom.gov.it, november 2016.

[2] European Commission. FADN website. http://ec.europa.eu/agriculture/rica/concept_en.cfm, february 2017.

SCENARIO	SUB-SCENARIO	FARM CORE	MICROALGAE PRODUCT	PLANT MANAGEMENT
A	A1	microalgae	biofuel and co-products	single
	A2	microalgae	food	single
B		dairy and microalgae	food	single
C		dairy and microalgae	food	collective

Fig. 3. Scenarios definition.
Source: the authors.

Table 2
Average UAA and net capital of dairy farms in Campania and Sicily (average 2012-2014)
Source: our elaborations by DB FADN (CREA, 2012-2014).

UAA	Campania – water buffalo farms			Sicily - cow farms		
Category	Average	Net	% Investment	Average	Net	% Investment
	UAA (ha)	capital (€)	Cost	UAA (ha)	capital (€)	Cost
< 5 ha	3.30	461,980	28	4.85	152,882	9
5-10 ha	7.33	629,904	38	-	-	-
10-20 ha	15.27	819,134	49	16.13	188,371	11
20-50 ha	32.68	1,848,511	110	34.59	546,630	33
> 50 ha	96.11	3,587,279	214	99.15	1,506,622	90

of Italy[3] . Furthermore, in Campania prevail the water buffaloes (74% of Italy), in Sicily the cattle. Starting from FADN data recorded during the 3-years (2012-2014), dairy cow farms in Sicily and dairy water buffalo farms in Campania were selected.

3.5. Scenarios definition and sensitivity analysis

The results of the small-scale plant for food and biodiesel production and its impact in the sample of dairy farms was assessed in three different scenarios (Fig. 3). In the first, the economic results of plant studied, comparing food and biofuel production, was evaluated (Scenario A). In fact, as stated before, the microalgae plant has two different ways, that potentially can coexist. In particular, the scenario compared two extreme solutions or sub-scenarios: only biofuel (A1) and only food production (A2). In the A2 sub-scenario, the cost related to the biorefinery was not considered. Consequently, in this case the total investment cost was slightly lower (1.63 vs. 1.67 million of euro). In the second and third scenarios the impacts of a plant were assessed, managed in a single farm (Scenario B) and with collective management (Scenario C). It should be noted that, as shown in Fig. 3, we assessed on farms only the best solution impact, based on the results of Scenario A (See Section 4). Therefore, the realization by the farms of only plants that produce food was supposed. Table 2 shows the dairy farms chosen as reference by FADN. The data show a high variability in net capital related to physical dimension (hectares of UAA - Utilized Agricultural Area) and higher capitalization of water buffaloes compared with cow farms.

Taking into consideration the high investment need, and then the opportunity for dairy farms to obtain bank loans, the impact was evaluated only on farms with a net capital/capital required ratio greater than 75%. There were only three categories with these requirements: two water buffalo farms category in Campania (20-50 ha; > 50 ha) and one cow farms category in Sicily (> 50 ha). The total number of balances examined was 98.

In the Scenario B the plant managed by a single farm was assessed. Scenario C considered the impact on farm of the plant with collective management. In particular, in this scenario the capital invested in the plant by the farms was based on a specific survey conducted on this issue by Schifani et al. [56]. In their work Schifani et al. [56] discussed contractual features to manage and coordinate a hypothetical microalgae plant and asked farmers to choose whether to participate or not in a collective investment regulated by contract schemes. The authors quantified the farmers' willingness to invest in that kind of activity. The average willingness to invest was €134,000 for farms with an UAA equal to 20-50 hectares and €313,000 for farms with UAA more than 50 hectares.

Finally, in the last part of the work a sensitivity analysis was developed. That analysis was developed to account for the significant fluctuations and the uncertainly in the market of microalgal food. In particular, the price ranged from € 35/kg (baseline price) to the price that made the NPV equal to zero (minimum price).

4. Results and discussion

In this section, we present results from the three scenarios, the first related only to the plant (A), the second (B) and third (C) related to the impact of the plant on farms, and then we show and discuss the sensitivity analysis, based on microalgal food price.

4.1. Scenarios analysis

Scenario A shows that producing food (A2) makes the production economically viable (Table 3). On the contrary, the biofuel production is not viable (A1), taking into account that all indicators, both economic and financial, are highly negative. This result is consistent with several empirical evidences that agree on the economic unsustainability of plants that exclusively produce biodiesel from microalgae [14,36]; Chandra et al., 2014 b). In particular, the NPV definitely does not recommend this investment. For this plant revenues were €57,000, with only 9% from biofuel, while almost 90% was related to feed and other co-products. The biofuel cost was very high, €70/kg with co-products, and €82/kg without co-products sale. This value was higher than the reference price (€1.12/kg) but also compared with the main literature references. With these assumptions about prices and costs, biofuel could obtain a positive NPV only with a microalgae yield of 314 $g/m^2/d$. This yield currently not only is far from the most optimistic forecasts but it is not possible on physical and biological perspective, as stated by Scott et al. [57] and Weyer et al. [58]. These results were also due to the choice to evaluate a small-scale plant. It is important to underline that this hypothesis was linked to decision to consider an investment in an agricultural context, achievable by farms for the differentiation of their investment, which is probably the main contribution of the present work in term of originality. Contrarily, the plant for food had better results, with revenues almost €500,000, a level of about 9 times higher

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Table 3
Scenario A: Plants results comparing biofuel and food.
Source: our elaborations. Note: a = marketable production, obtained net of a share of physiological losses (3%); n.a. = not available.

Item	UM	Sub-Scenario	
		Biofuel and co-products (A1)	Food (A2)
Algal biomass			
Total production	Kg	14,850	14,850
Net production	Kg	14,405	14,405
Revenues (Net production * price)			
- Food	€		504,158
- Feed	€	50,416	-
- Biofuel	€	4,840	-
Glycerol	€	1,536	-
Total		56,792	504,158
Results			
Net income	€	−231,366	221,479
Total operating cost	€	355,113	347,980
ROE	€	−13.8	13.6
NPV	€	−3,384,910	2,457,737
IRR	%	n,a.	17.7
Discounted pay-back	Years	n,a.	10

than the first plant, and a net income of more than €220,000. The NPV reached 2.5 million euro, highlighting the investment feasibility. The IRR stands at 17.7%, significantly higher than the capitalization rate assumed (4%), while discounted payback period was 10 years. Finally, ROE was 13.6%.

As underlined in Section 3.5, in the Scenarios B and C we analyzed the profitability of a plant for microalgal food production in Italian farms, respectively managed individually (B) or collectively (C).

Without plant, Sicilian Cow Farms (SCFs) had results closer to smaller Campania Buffalo Farms (CBFs1) in terms of net capital and revenues (Table 4). Also the net income was similar to CBFs1 but the ROE was similar to bigger Campania Buffalo Farms (CBFs2) (Fig. 4). The introduction in the individual farm of the microalgae plant (Scenario B) had an impact in terms of net income and profitability. More in detail, the increase in net income was from to 96% to 158%, the profitability of capital (ROE) showed an impact from +30% to +50%. For both the indicators, the increase was minimum for CBFs2 and maximum for CBFs1 (Fig. 4), emphasizing how the productive context affect significantly the profitability as revealed in several studies [42,33,59]. These results showed that the impact on the farms is stronger if initial capitalization and economic results are lower. Considering the net capital and revenues, the increase was at a minimum for CBFs2 and at a maximum for SCFs. In particular, the increase in term of net capital was from 46% to 108% and from 51% to 131% in term of revenues (Table 4). It is important to underline that ROE level was always more than double than the opportunity cost of capital (4%). Moreover, in this scenario plant investment cancels the gap between the water buffalo farm types in terms of ROE. This was due to the economic prevalence of algae production on the original livestock activity, especially for CBFs1. SCFs had a ROE slightly higher due to the highest initial ROE, compared to CBFs1 and the biggest impact of results, compared to CBFs2. It must be noted, that, anyhow, CBFs2 always

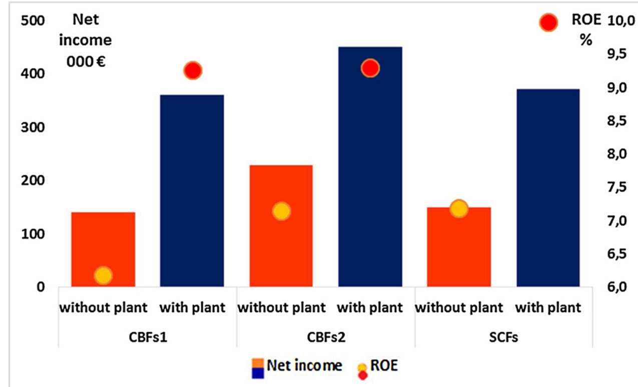

Fig. 4. Scenario B: Net income and ROE results with single management of plant.
Source: our elaborations by DB FADN (CREA, 2012-2014).

presented the best results in terms of net income, with values far to the other farms type (Fig. 4). It is worth underlying that the investment required in this management scenario was high and far greater than the willingness to invest assessed by Schifani et al. [56].

The results of collective management (Scenario C) were shown in Table 5 and Fig. 5. In this scenario the capital invested was based on the willingness to invest assessed by Schifani et al. [56]. On this basis, we estimated that to realize the plant it would be necessary for about 12 farms of class 20-50 hectares or about 5 of the class over 50 hectares. In general, the impact in this scenario was weaker than the Scenario B (Table 5 and Fig. 5). In particular, the introduction of a microalgae plant had a higher impact in the Sicilian cow farms. In fact, for all the variables studied, the highest growth rates were recorded in SCFs, conversely the lower increase was detected in the buffalo farms operating in Campania. As consequence, unlike the Scenario B, in the Scenario C the difference in term of ROE between the two buffalo farms type remained the same, increased slightly, while the SCFs had a few advantages compared to CBF2s (Fig. 5). These results depend on the ratio between capital required by investment and net capital of farms. As with the Scenario B, the CFBs2 had the best results in terms of revenues (Table 5) and net income (Fig. 5). The main farms advantage in collective management was especially the increase in net income more than in profitability (ROE). The main advantage of a strategies of cooperation is the centrality of the relational dimension among the different actors involved that encourages synergies not only in terms of scale, experience and scope economies, but also in terms of exploitation of other resources [60]. Furthermore, the comparison between the management scenarios (Scenario B vs. Scenario C) can be summarized as follow:

- Lower impact but more feasibility for the Scenario C compared to the Scenario B
- Reduction of distance among farms in terms of ROE in the Scenario B, increase in the Scenario C.

Table 4
Scenario B: Impact on dairy farms with single management of plant.
Source: our elaborations by DB FADN (CREA, 2012-2014).

	Campania - water buffalo farms						Sicily - cow farms		
Item	UAA 20- 50 ha (CBFs1)			UAA > 50 ha (CBFs2)			UAA > 50 ha (SCF)		
(Euro * 10^3)	Without plant	With plant	var-%	Without plant	With plant	var-%	Without plant	With plant	var-%
Microalgae plant investment	0	1,632		0	1,632		0	1,632	
Net capital	1,716	3,349	95	3,587	5,220	46	1,507	3,139	108
Revenues	495	999	102	989	1,491	51	384	889	131

Table 5
Scenario C: Impact on dairy farms with collective management of plant.
Source: our elaborations by DB FADN (CREA, 2012-2014).

	Campania - water buffalo farms						Sicily - cow farms		
Item	UAA 20- 50 ha (CBFs1)			UAA > 50 ha (CBFs2)			UAA > 50 ha (SCF)		
(Euro * 10^3)	Without plant	With plant	var-%	Without plant	With plant	var-%	Without plant	With plant	var-%
Microalgae plant investment	0	134		0	313		0	313	
Net capital	1,716	1,850	8	3,587	3,900	9	1,507	1,820	21
Revenues	495	536	8	989	1,083	10	384	481	25

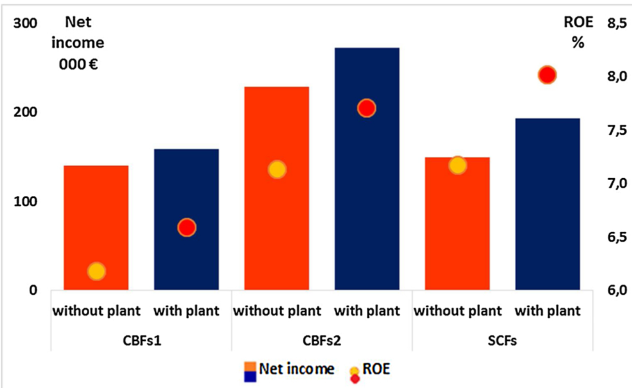

Fig. 5. Scenario C: Net income and ROE results with collective management of plant.
Source: our elaborations by DB FADN (CREA, 2012-2014).

4.2. Sensitivity analysis

The last part of the work was focused on the impact on farms results of algal biomass price as food. This analysis was justified by price uncertainty, which is one of the main result factors. The baseline price used in this study, €35/kg, was based on the scientific references [19], our personal interviews conducted in Italian context, and appears to be in line with the average price of similar products available in the market. It should be noted as other literature sources [51,17,61] and our personal interviews underline a very large price range, with the possibility to obtain a higher price. However, there are substantially situations of niche market. For this reason, now, it appears more prudent speculate on future scenarios with lower prices, due to an increase in microalgae production.

The range of price considered was from €35/kg (baseline price) to the price that makes the NPV of plant equal to zero. This price was estimated at €22.45/kg (price1), a value 36% lower than baseline. It is important to underline that in this case the plant profitability was lower than the dairy farms. Consequently, the investment was feasible but not convenient in the agricultural context analyzed. Instead, the IRR was equal to capital opportunity cost (4%). Furthermore, it was possible to estimate the minimum price levels to make the investment in microalgae implementable in the context studied. In fact, to make the investment convenient for the farms is necessary that the price reaches, at least, a level that gives a profitability equal to their ROE. We remember that the ROE of farms was from 6.18% (CBFs1) to 7.18% (SCFs), and that ROE of CBFs2 and SCFs was significantly similar (7.14% vs. 7.18%). The price that produce a ROE equal to 6.14% was estimated at €26.62/kg (price 2), 24% lower than the baseline and 19% higher than the price1. The price 2 shows the threshold price to make the investment convenient for the dairy farms with lower profitability. In this case, the plant results were NPV equal to €817,252 and IRR equal to 9.1%. However, this price level was not sufficient to make attractive the investment for farms over 50 hectares of UAA. In fact, for the biggest farms the threshold price was €27.77/kg (price3), 21% lower than the baseline, 24% higher than the first price but only 5% higher than the price 2. The NPV obtained was €1,042,378, while the IRR was 10.4%. It must be emphasized that to obtain the prices showed in all the cases it is necessary to produce high-value biomass.

5. Conclusions

Current study analyzed the cultivation of microalgae in PBR, through a small-scale plant, in an agricultural context, based on real balance sheets data. The findings showed that the production of valuable compounds (e.g. food) is more profitable than biofuel, which is economically unsustainable. In fact, current microalgae production technology favors biofuel only as a co-product, on the contrary, mid-scale algal cultivation for high-value product is possible with current, rapidly improving technology [61].

According to our results, the production of food could improve profitability and net income in Southern Italian dairy farms, in both single and in collective management. The single management was more profitable, but the collective was more viable. The sensitivity analysis confirms that the price of product is a critical parameter. Among the other elements to be evaluated there are also the possibility of public aids (e.g. RDP) and the legal framework uncertainties.

While acknowledging the main limitation of the work was related to the analysis based on a pilot plant, our study provides insights and hints to entrepreneurs and managers operating in the dairy industry, but also in other agricultural sectors, interested in improving their firm's performance through the adoption of a diversification strategy of the business activities. Nevertheless, it is necessary to develop structured supply chains able to give greater stability to the market and a higher degree of certainty to the stakeholders. It is also important to taking into account that the availability of the capital is one of the main problems for the realization of plant, as reported also by Vigani et al. [18]. In conditions of profitability levels, it is possible to assume the use of the banking system to receive a part of the resources necessary. The production of biofuels, under current conditions, appears not viable. We believe that the improvement in production technology should be supported in the context of an integrated system, such as the one proposed by the present work. The production of biodiesel from algal biomass could contribute to making production processes even more sustainable, guaranteeing environmental sustainability and economic sustainability of companies thanks to marketable co-products. Another element that could facilitate the implementation of microalgae plants and, more in general, the sector development, are the public aids. For example, in the European Union context a role could be played by the funds provided by the Rural Development Plan (RDP). In this sense, it should be emphasized that the results presented in this work have been estimated net of any form of public aid. Furthermore, a more precise legal framework is also necessary to eliminate the current uncertainties, i.e. the tax system.

In addition, taking into consideration the required investments and the necessary skills to manage the plants, should be envisaged horizontal coordination of dairy firms through collective action might encourage or accelerate the diffusion of these systems in the agricultural sector.

Future studies should be focused on a deep understanding of the propensity of operators in the agricultural sector, mainly consisting of family businesses, to diversify the business through the creation of PBRs for the cultivation of microalgae, also in a consortium. Furthermore, a sensitivity analysis based on the “costs side of thing” could further contribute to provide useful information to better understand the feasibility of the plants under different economic conditions.

Authors contribution

This manuscript is an original intellectual work of the authors. LM, formulated the research question, has written section 3.2 and contributed to the draft o of the section 4.2 with TDG. DT and LC wrote the section 3.3. AF and FS wrote the section 3.5. GA written the section 4.1 and contributed to the draft of the section 2 with LM. MM draft the section 3.1. AS write the section 3.4. MC, GS and GC wrote the section 1. Section 5 is the result of the joint effort of the Authors.

Statement of informed consent, human/animal rights

No conflicts, informed consent, human or animal rights applicable.

Declaration of Competing Interest

We declare that there are no potential financial or other interests that could be perceived to influence the outcomes of the research.

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