ASSESSMENT OF THE POTENTIAL OF GREEN FLOATING FILTERS FOR BIOENERGY PRODUCTION

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ABSTRACT: The purpose of this research is to use helophytes as floating filters in an artificial aqautic system for water treatment in Lake Cheimaditida and irrigation channels (Western Macedonia, 40 km southeast of Florina, Greece) and in irrigation channels and pods (broader region of Avila, province 150 km east of Madrid, Spain). By using these floating filters, the challenge of producing feedstock for bioenergy without using agricultural land will be achieved. There are several factors that should be considered in order to have successful results such as characteristics of the water body and its surroundings, planting density and distribution, etc. Also, there are some criteria that one site must meet for being suitable for GFF establishment. Some of them are the protection of the environment, the environmental conditions for helophytes growth, conditions on the area, etc. Hopefully, the findings of this study may be useful for both bioenergy production with no land use and for contaminated water treatment.
Keywords: bioenergy,bioethanol, biomass, CO2 reduction, climate change, filtration

1 INTRODUCTION

Green Floating Filters (GFF) are artificial aquatic systems made up of helophytes that are grown as floating mats for water treatment or aesthetic purposes. Growing helophytes as floating plants has been a relatively recent development; helophytes are perennial aquatic plants but, in nature, they are not floating plants but plants rooted to the mud or water body substrate, whose shoots largely emerge out the water. However, they can be grown as floating plants provided that water contains nutrients enough for their growth. The quality of water, which is frequently subjected to diffuse contamination from agriculture -as a result of indiscriminate use of mineral and organic fertilizers and residual water disposal- or to contamination by industries, is an issue of growing concern in Mediterranean environments. In controlled water bodies, like irrigation water carried through channels and industrial ponds, growing aquatic plants in a controlled way, could be a chance for removing contaminants. As a matter of fact, artificial wetlands have been promoted in rural areas for waste water treatment as well as for phytoremediation, since aquatic plants contribute to organic matter stabilization and take up nutrients causing water eutrophication and accumulate certain contaminating metals. Mixed systems that combine waste water treatment with biomass production have been proposed by the literature using different designs of artificial wetlands or lagoons vegetated with aquatic plants like cattails, which can be highly productive in auspicious environments. An interesting feature of cattails is the fact that they produce thick rhizomes rich in storage carbohydrates that can be potentially used for bioethanol production as well as leaves used for traditional applications. Nowadays the production of bioethanol is controversial since it is currently based on agricultural crops, often entailing impacts on land use (LUC, iLUC) and food supply. In fact the Renewable Energy Directive (RED) of the European Union was amended in 2015 in an attempt to mitigate such impacts. Europe needs next-generation-bioenergy-plants in order to reach its specific environmental targets, as outlined in the aforementioned EU directive and its follow-up, the upcoming RED II directive.

In order to tackle the challenge of producing feedstock for bioenergy without using agricultural land, an innovative concept based on GFF respectful of environment has been developed. In this article a review of GFF design, requirements for plant growth, nutrients uptake, yields, production of renewable energy and contribution to CO_2 capture is made in order to assess the potential of GFF for bioenergy production without using agricultural land.

The proof of concept is being undertaken under the EU LIFE+ Programme, in the framework of the just-started project 'Life Biomass C+', Project coordinated by the Centre for Research and Technology Hellas (CERTH, Greece) and participated by the Technical University of Madrid (UPM, Spain), the Irrigation Community of El Arenal (COMRA, Spain), Hellenic Petroleum S.A. (HELPE, Greece), BIOSTREAM (Netherlands) and Volterra Ecosystems SL (VOLTERRA, Spain).

The LIFE Biomass C+ gathers innovative concepts in cattails valorization: awareness of own biological resources (moving to a balanced perception of Typha spp., which can be a resource in some circumstances while in others can behave as a weed); seasonal crop (instead of perennial); controlled cultivation in eutrophic/polluted water bodies (instead of natural water bodies); integral use of biomass (above-water and under-water biomass, instead of only above-water biomass); bioenergy applications (solid and liquid biofuels) and biobased products; biomass production not dependent of agricultural land (LUC avoidance); biological 'device' for water quality improvement and CO_2 capture (C accumulation in the biomass).

2 LITERATURE REVIEW ON AQUATIC PLANT SYSTEMS

Literature on constructed (or artificial) wetlands and aquatic plant systems for waste water treatment (WWT) is extensive (see, for instance [1], [2], [3]). Thus, constructed wetlands have been promoted in small agglomerations (<1000 equivalent inhabitants) and rural areas since long time ago [4]. Although the overall objective of constructed wetlands (CW) and aquatic plant systems (AQ) is the same (WWT), they are significant differences between them; aquatic plant systems do not rely on a substrate bed (gravel bed, in CW), they are based on floating plant species (ground-rooted plants, in CW) and provide more friendly sight than CW (specially, in case of subsurface flow CW). Artificial aquatic plant systems have been used for water treatment for more than thirty years; they have been described as shallow ponds with floating or submerged aquatic plants that provide surfaces on which decomposing bacteria grow and media for filtration and adsorption of solids, and transfer gases to and from the submerged parts of the plant and uptake nutrients from water.

Helophytes, also known as 'emergent plants', are a type of aquatic plant species in the Magnoliophyta Division that, in nature are rooted to the ground while they have emerging shoots (leaves and stems) which means that a large fraction of their body emerges above the water. They exhibit interesting morphological and physiological adaptations to aquatic environments, such as a special parenchyma (aerenchyme) with large intercellular spaces filled with air and downwards oxygenation activity that helps to improve water quality. Helophytes are perennial plants with an annual development cycle that extends from spring to autumn in temperate climates. Shoots die off every autumn but the below-water plant parts remain alive; they have rhizomes rich in storage carbohydrates as perennating organs that enable spring re-growth.

Among the different species of helophytes, cattails stand out for their high biomass production potential; it can be said that they make the best use, in productivity terms, of the three growth medium components: soil and sediments (anchorage, nutrition), water (nutrition, biofilm surface) and air (gas exchange, photosynthesis, oxygen release). Due to that, in some aquatic environments of the World they can behave as invasive plants and have to be periodically removed to get rid of them. Literature data show that it is possible to take advantage of cattails growth for a number of applications when they are grown in a controlled way.

The common name 'cattail' refers to botanical species in the genus Typha (Family: Typhaceae, Class: Liliopsida). In nature, they grow in colonies next to the banks of water bodies (lakes, ponds, and swamps), channels and slow-moving rivers. Typically they grow in a range of 30-80 cm water depth. A summary of the botanical description of Typha spp. is next. Habit.- Perennial herbs, with erect shoots, 1.5->3 m high. Leave.- Very long leaves, plano-convex proximally to thinly plane distally. Stems.- Flowering stems with two separate inflorescences at the upper end, a brown pistillate inflorescence followed by a staminate inflorescence with earlier maturity. Root system.- Abundant thin roots and horizontal, unbranched rhizomes, about 70 cm long, thick starchy, firm andscaly. The widest spread species in Spain are T.latifolia and T.domingensis, being the latter more tolerant to water contamination than the former.[5][6]

Traditional and well-known applications of cattails are: roof thatching, handcrafted chairs, green forage (emergent plant parts), phytoremediation (metal accumulators), constructed wetlands (surface and subsurface flow wetlands, also named FWS & VSB), and gardening (ornamental ponds). Recently cattails have been proposed for aquatic treatment systems in which they have to be artificially grown like floating plants, and bioenergy, taking advantage of its high growth rate and biomass characteristics.

3 CRITERIA FOR GFF DEPLOYMENT

In this section, criteria for considering that a site could be suitable for GFF deployment are presented, withstanding that criteria are site-specific, i.e., each region or site should apply ad hoc criteria.

Special care should be taken to protect the environment and be respectful of natural areas so that the installation of GFF does not entail environmental impact costs. As a general rule, GFF should not be installed in natural areas; GFF is meant to be an artificial or constructed system for water quality improvement. Furthermore, the target site should be first surveyed for the presence of Typha in order to prevent introduction of allochthonous species.

In addition, due to the fact that GFF is a biological system, the environmental conditions (climate, water quality) should be characterized to determine if they are suitable for Typha growth. Plants require nutrients to grow, which is the basis of using GFF for water improvement. In terms of macronutrients, well-fed mature cattail shoots contain about 1.1-1.3% N, 0.15-0.36% P (equivalent to 2.6-0.82% P2O5) and 1.42-2.84% K (1.71-3.43 K2O); obviously, if cattails are grown as floaters, macronutrients must come from water. In case of high water quality, cattails are not expected to grow properly. Although there are differences between Typha species, the range of pH tolerated by cattails is approximately 3-8.5, the range of temperatures for plant growth, 6-30ºC [7].

In order to make a decision, the target area should be characterized for natural spaces, land use, climate, water resources, and water quality. Additionally, there are complementary data, such as agriculture and socio-economics in the site that can be useful to understand the social effects of GFF. Once GFF is established, their performance and environmental effects are recommended to be monitored.

Therefore, a baseline study is highly recommended that gathers data of the target site on the following aspects:
Characterization of the area:

- Geographic situation: country, region, coordinates (latitude, longitude), altitude, topography.
- Hydrology and water resources: river basin, rivers/streams.
- Climate: bioclimatic classification or Koppen climate category; means of temperature, rainfall, solar radiation (according to historical series of the closest meteorological station).
- Land use: land area (at the closest scale, e.g., municipality of county level), agricultural land, arable land, forest area, permanent cropland.

• Biodiversity-Ecosystems: natural protected areas, Natura 2000, categories (national park, LIC, ZEPA, etc); if any, give a brief description; vegetation, fauna.
• Agriculture: main crops, orchards, yields, current management practices, irrigation/dry crops data; if available for the area under study, provide data on agro-environmental indicators.
• Socio-economic data: population density, age pyramid, rural population, occupation, unemployment, rent, social and economic indicators, industries, etc.

4 DESCRIPTION OF THE DEMO SITES

4.1 Irrigation channels & ponds at El Arenal in Spain

This area comprises a series of irrigation channels and water storage ponds used to irrigate a surface of 3.000 Ha. The agricultural region of El Arenal is located in the Ávila province, approx. 150 km east of Madrid. The Comunidad de Regantes has 1,500 members, many small holders as in total 4,000 plots are registered for irrigation. The climate of the area responds to a dry Mediterranean climate with short winters and long dry summers, which determines that irrigation is a necessity. Even though that most of the water comes from mountains and is collected in a system of ponds, the quality of the water used in the irrigation system is variable, since it is often subject to diffuse pollution (from agricultural activities like livestock wastes and agro-chemicals). The main crops in the area are fruit trees (cherries, chestnut, figs and grapes), vegetables and some cereals, mainly for forage (alfalfa, barley and vetch). The water volume managed by this irrigation community is approx. 4,000 m3/ha/year.

4.2 Irrigation channel and lake Cheimaditida in Greece

It is located approx. 40 km southeast of Florina in Northwest Greece, Region of Western Macedonia. The lake is one of the few remaining freshwater lakes in Greece and is surrounded by extensive marshes with reeds (Phragmites sp). The wetland is rich in flora, fauna and habitat diversity. It supports six habitat types listed under Annex I of the EU Habitats Directive (92/43/EEC). The lake complex does not receive any industrial waste directly. However, it receives pollutants through precipitation due to coal incineration in the nearby power stations and run-off from the drainage area. Lake Cheimaditida also receives agriculture run-off through a connecting ditch with Zazari and wastewater from upstream communities. The main source of pollutants and nutrients for Lake Zazari is torrent Sklithros that collects waste waters of all upstream communities. The central drainage system of irrigation canal extends from the spillway of Lake Cheimaditida to the sluice gate near Rodona's village area. The canal is bordered on one side with croplands while on the other side extends the Amyntaio coal mine. The canal continues flowing about 110m up to the bridge at "Bramor" area and finally ends at Amyntas stream.

5 DESIGN OF GFF

In what concerns the design of GFF, the factors that should be considered, in order to reach to successful results are given below:

- Characteristics of the water body and its surroundings. The design may vary as a function of the type of water body intended for GFF (stream, lake, pond or channel), width, water depth, flow and accessibility. It is critical to choose a convenient place for GFF installation; it has to be accessible by foot and by vehicle so that operators are able to take to the banks all materials needed; preferably, banks should not have abrupt edges, i.e. GFF sites should be chosen with smooth slope banks and free of high/thick vegetation.
- Density and distribution. Planting density should be optimized to the site and the distribution of the plants balanced. In **Figure 1¡Error! No se encuentra el origen de la referencia.**, some models of planting density and plant distribution are shown. Every position (hole) in the sheet should not be planted; some empty positions around a planted position are needed to make room for new shoots and facilitate their emergence. For the GA-UPM conditions, the recommended planting density is 16-20 plants/m^2; lower planting density is cheaper (less plantlets, less labor) but it will take more time to form a thick plant mat.

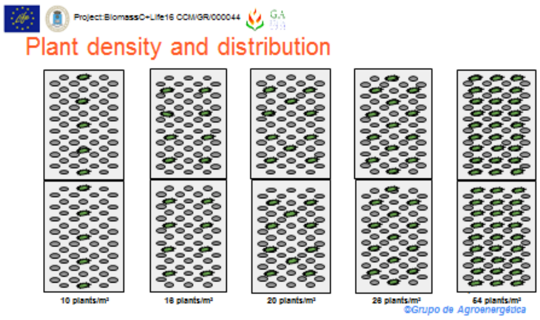

Figure 1: Planting density and models of plant distribution**.**

- Size, shape, layout and quantity. Size: area intended to be occupied by GFF; shape: rectangular or square shape (note that EPSS are rectangular); layout: sheet placement on the water body (close to the bank, or in the middle of the water body…); GFF units: number of independent GFF per water body. Some examples are given in **Figure 2**. The harvesting procedure and tools/machinery to be used should be taken into account as well, when making a decision on size, shape and layout.

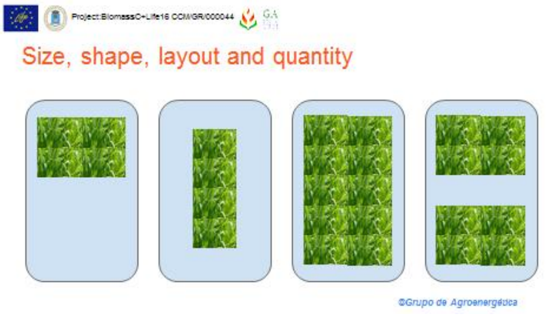

Figure 2: Examples of four different designs; green areas represent a GFF, whilst blue areas represent free water surface.

- Anchoring procedure

Two systems are proposed according to water body type.

In lagoons, ponds or lakes, anchorage to the bottom by means of ballast or weights **(Figure 3**).

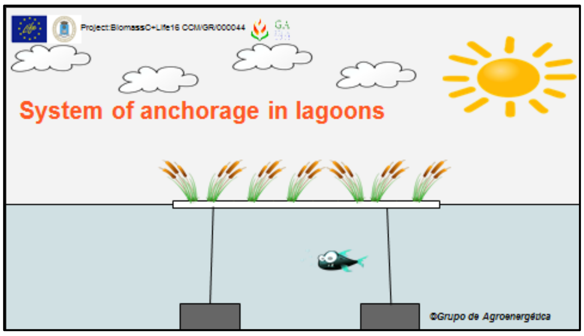

Figure 3: GFF anchorage to the bottom by means of ballasts.

In irrigation channels, rivers or streams, a lateral anchorage to the banks with the help of pegs/spikes/sturdy sticks, or to a tree trunk; an optional coil spring is recommended in case that water height varies over the seasons (**Figure 4**).

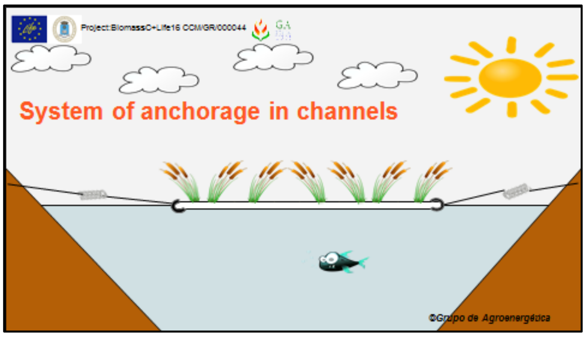

Figure 4: GFF anchorage to the banks.

6 EXPECTED RESULTS

The project seeks to achieve the following concrete results:

- Achieve a reduction of GHG emissions of approx. 250 tons of CO_2. This will be monitored through a detailed LCA STUDY which will measure the total CO_2 emitted in tons/ha for the production of macrophyte biomass compared to traditional fuel crops like wheat or corn. In addition, we expect to prove that market uptake of Biomass C+ can reduce significantly indirect Land-Use Change. This will be quantified through a comparative analysis of productivity ratios in ton/hectare.
- Demonstrate that the Biomass C+ concept can be implemented in any kind of large water body on an industrial scale. This project will prove that GFF can also be utilized in areas where climate, water flow and temperature cannot be controlled. A detailed manual of required adjustments will be produced, including an innovative floating tray system and sods, to establish the GFF efficiently at the beginning of each season.
- Demonstrate proof of concept both at lab and industrial scale that the sustainably produced biomass can be effectively converted into bioethanol and blended into biofuel. Yields of 15 tons of dry matter per hectare of GFF are expected to produce 2,600 liters of bioethanol that can be blended into at least 26,000 liters of biofuel, making this biomass source competitive against wheat.
- Demonstrate the efficacy of the macrophyte as a green filter and water quality improvement of at least 30% at the demonstration sites, both in biological terms (e.g. reduction in algae blooming) and in physical-chemical terms (reduction of pollutants). Improvement in local flora and fauna will also be monitored.
- Set up replication of results and market uptake during the project's lifetime. Partners will be in contact with potential replication agents since the beginning of the project and provide training and advice to third parties interested in developing the Biomass C+ system on a commercial scale.
- Develop an effective business plan, including cost-benefit analysis and modelling for industrial scale-up. EU production of bioethanol tripled between 2000 and 2014 and has reached a total of 6.7 billion liters, with a market value of nearly €8 billion, but EU dependence on biofuel imports (1.2 billion liters annually) is rising. A new, cost-effective and truly sustainable biomass source would be very interesting for the 60 major European bioethanol producers in Europe.

Till now, the first results prove that, in non-protected water bodies that contain nutrients for plant growth, it would be possible to capture 6.14 kg CO_2 per GFF installed m^2 (↔ 61 t CO_2 captured per GGF ha) and yield 5.73 MJ energy (bioethanol) per GFF m^2. A preliminary design for the bioreactor for the utilization of produced biomass will be performed. Finally, the basic requirements for the utilization of the produced bioethanol in existing refinery will be determined.

7 CONCLUSIONS

The Biomass C+ project contributes to the EU's climate change mitigation objective regarding Land-use, land-use change and forestry (LULUCF) by especially addressing the development and demonstration of an innovative biomass production system that can be replicated in several countries. One of the central challenges in this area is developing measures that ensure sustainable development and climate resilience in a manner that does not threaten food production. Attempts to do this always run against the challenge of both direct and indirect land-use change, which can cause water pollution from nitrogen run-off, potential biodiversity loss, air pollution and the release of GHG gases from fertilizer and machinery. Biomass C+ mitigates these negative effects through the exploration and facilitation of an advanced biofuel derived from biomass grown on water. This is in line with the Renewable Energy and Fuel Quality Directives, which set out the sustainability criteria for all biofuels produced or consumed in the EU so as to ensure that they are produced in a sustainable and environmentally friendly manner, and with the Directive to reduce indirect land-use change for biofuels and bioliquids (ILUC) which encourages research in new advanced biofuels that are not in competition with food crops, and highlights the importance of studying the impact of different crops on both direct and indirect land-use change. In addition, Biomass C+ will treat the water polluted by agricultural and/or industrial use. Typha can absorb heavy metals, eliminate eutrophicating elements and help to decompose organic matter reducing the solids in suspension and capturing organic waste. The project will thus have a double transformative impact which will contribute to the shift towards a low-carbon economy through a breakthrough renewable energy solution for transportation and fuels applicable to real industrial environments.

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9 LOGOS