A New Perspective of Solar Renewable Energy for South Italy Using the Floating Photovoltaic System

Angelo Leggieri¹, Teodoro Semeraro²

¹Environmental consultant, via Firenze, 24, 74100 Taranto, Italy
²University of Salento, Department of Biological and Environmental Sciences and Technologies, Ecotekne, Prov. le Lecce Monteroni, 73100 Lecce, Italy
dott.angeloleggieri@gmail.com

Abstract. In recent years, renewable energy sources use has been growing rapidly worldwide. Solar energy is considered one of the most valid alternative energies thanks to its applicability worldwide. Furthermore, the solar energy is a continuous resource always available compared to other energy alternatives. The main technologies currently applied to the use of solar energy are photovoltaic systems. Recently, the installation of photovoltaic systems was carried out on the agricultural land creating a paradox, as it caused a conversion of land use and transformations in the agricultural landscape with negative impacts on the human well-being. Currently, a valid alternative for the exploitation of solar energy using photovoltaic systems is represented by floating photovoltaic systems. This type of system involves the positioning of photovoltaic systems on the free surface of the water of natural lakes or artificial water basins reducing the exploitation of the agricultural land resource. In particular, the photovoltaic floating system consists of a floating system, mooring system, photovoltaic system and cables that run in the water. Floating systems open-up new opportunities and scenarios to increase the production of solar energy, especially in countries with a high population density and where the natural and anthropic components are strongly interconnected and mutually conditioned. The purpose of this report is to briefly describe the design hypothesis of a floating photovoltaic system of the power between 90-100 MW, to be positioned on the free water surface of the Esaro Lake in the Municipality of Roggiano Gravina (CS). The socio-economic and environmental benefits of these types of plants will be examined on the basis of other plants already developed in the world. In addition, project indications will be provided with estimates of expected production and economic benefits. From the conducted analysis, it emerges that this type of Floating PV can allow for the reduction of soil consumption and increase the energy productivity considering the construction of photovoltaic systems on the ground with the same power. Therefore, the floating photovoltaic systems better meet the main objectives of sustainable development in the economic, social and ecological sphere compared to traditional ground PV plants.

1. Introduction

Solar energy is freely and enormously available all over the world and is an ever-present resource compared to other alternative energies. The most common application for the use of solar energy is through the use of photovoltaic (PV) systems. Photovoltaic (PV) modules are considered one of the most effective, sustainable and eco-friendly products in the field of renewable energy [1-3]. However, the installation of photovoltaic solar systems requires an intense need for land space, which is a basic natural resource for the production of food and therefore for the well-being of the population.
In the last few years, in the South of Italy, there has been competition in the use of the arable land between the agricultural and renewable energy production sector determined by the ever-increasing demands for the energy use of the country and by the need for decarbonizing the production [4].

Southern Italy has a great agricultural vocation, representing the important sustain of the Italian agri-food industry. Currently, many agricultural companies have rented or sold the land used for agricultural production to companies operating in photovoltaic energy because this ensures higher profitability. Many energy companies find large arable surface land in Southern Italy, because of intrinsic characteristics of the territory, such as morphology and high solar radiation favouring energy production. Therefore, European and national policies that push for an increase in renewable energy production have created a paradox. Policies to reduce greenhouse gas emissions and mitigate global warming can cause local land-use transformations with potential negative effects on climate change and human well-being both on a local and global scale [4-7].

The increase in energy needs due to technological advancement, also thanks to the promotion of electric mobility, could accentuate the problem of land consumption for the construction of ground photovoltaic systems. Therefore, it becomes essential to identify new forms of renewable energy plants that are able to develop in synergy international and national strategies and guidelines aimed at the conservation of natural resources, development of renewable energies, increase in the quality of life. Renewable energy plants should minimize environmental impacts and maximize the positive externalities connected with the use of renewable sources, like the arable land.

At an international level, projects are being developed that envisage the construction of photovoltaic systems in water basins (Floating Photovoltaic-FPV) as an alternative to those on the ground [8]. Mainly, FPV is characterized by a floating system, mooring system, photovoltaic system and cables that are in the water (Figure 1).

![Figure 1. Conceptual model of a floating photovoltaic system. Modified by Choi, 2014 [9]](image-url)

The social and economic advantage in FPV is determined by the use of obstacle-free surfaces that cannot be used in many cases for other purposes (tourism, production). In the case of the water basin, there is double exploitation of an area that continues to fulfil its main function like providing drinking water in combination with energy production. From an economic point of view, The FPV allows for the increase of energy productivity compared to the ground photovoltaic, because the photovoltaic panels can exploit the solar radiation reflected by the water’s surface (albedo). Furthermore, the presence of water reduces the panels’ overheating, which is one of the main causes of efficiency loss [10-12].

In Italy, in 2014, an experimental FPV project was launched on Lake Resia in Val Venosta (Bolzano), the largest lake in South Tyrol. The experiment showed that the energy productivity of the FPV in the mountains is greater because the sun's rays are stronger and lakes, by reflecting them, increase their
effectiveness. Thanks to this natural phenomenon amplified by the presence of water, ice and snow the FPVs are more productive. This type of installation seems to have the ability to increase energy production from 20% to 40% compared to a ground photovoltaic system [9].

Therefore, for the same installed surface, the FPV allows having a greater productivity of electric energy reducing to the minimum the exploitation of productive spaces like arable land and therefore the competition with agricultural activity [4].

Furthermore, the realization of the FPV, compared to the ground photovoltaic systems, reduces the risk of theft of the photovoltaic panels, eliminates the risk of damaging the system due to any fires of the vegetation that grows around the panels, and reduces the shading effect caused by the vegetation that must be systematically cut, increasing plant maintenance costs [4]. In addition, research conducted in Australia suggests that around 40% of the water in reservoirs can be lost by evapotranspiration. This value could be drastically reduced by about 30% through the installation of FPV systems [9].

In Europe, the FPV technology has been developed mainly for experimental purposes, while underdeveloped for production purposes compared to other countries and to that which involves the construction of systems integrated into the ground (Figure 2) [13].

| Country        | Total added capacity |
|----------------|----------------------|
| China          | 376.50 MW            |
| Japan          | 22.66 MW             |
| United Kingdom | 9.33 MW              |
| South Korea    | 6.00 MW              |
| Australia      | 4.00 MW              |
| Italy          | 0.77 MW              |
| United States  | 0.67 MW              |
| Spain          | 0.32 MW              |
| France         | 0.12 MW              |
| India          | 0.06 MW              |
| Singapore      | 0.005 MW             |
| Canada         | 0.0005 MW            |

Figure 2. FPV installati a livello mondiale [12]

The purpose of this study is to present a design idea of an FPV plant with a power of about 100 MW in the context of the Esaro river basin, Calabria region in Italy.

This plant aims to create a strong synergy between economic and institutional operators in the territories of Southern Italy.

This intervention, therefore, is not seen as a simple material work, but as a new political approach to territorial development that involves public actors and the business world through a convergence of purposes in order to guarantee the well-being of the population in combination with the economic interest of entrepreneurs who invest on national territory.

This plant would place Italy among the main states to use this technology and in particular would make Calabria, among the first regions in the world in the production of energy through FPV.

2. Study area
The proposed idea of FPV targets the free surface of the water of Lake Esaro located north of the city of Roggiano Gravina at a distance of about 2 km from the city centre. The reservoir has an area of approximately 270 ha (Figure 3).
The reservoir is currently owned by the Calabria Region and is managed by the Consortium for the Complete Reclamation of the Northern Basins of Cosentino. The reservoir was created by blocking the Esaro river with the aim of obtaining a water basin for human use, but also for the production of electricity.

**Figure 3.** Study area. The figure was developed using Base Map in QGIS software.

### 3. Project idea

The project involves the construction of a photovoltaic system of 100 MWp in the grid-connected configuration with the hypothesis of directly entering all the energy produced in the national electricity grid to sell it.

Floating modules will be used to position the photovoltaic panels on the surface of the water. Each can support 4 photovoltaic modules of the size of 2.06 m² with 405 Wp and an efficiency of 19% (Figure 4).

**Figure 4.** Single floating modules.

The modules will be positioned with a tilt angle of 10 degrees [14].
The floating photovoltaic system (FPV) will have the following main features (Figure 5):

- N. 246,914 photovoltaic modules for a total photovoltaic surface of 51 ha;
- N. 100 max DC power inverters 1 MW;
- N. 61,728 floating modules, for a total area of 61.7 ha

The configuration of the FPV can be twofold. First, the floating modules are arranged to form a square platform. Second, the floating modules form a platform that approximates the circular form (Figure 5). The second solution can be more pleasant for landscape vision and better optimize space.

![Figure 5. Potential configuration of the FPV. The figure was developed using Base Map in QGIS software.](image)

3.1. Energy analysis

Based on the geographical location of the plant, tilt angle of the PV, the value of the incident solar radiation on PV is equal to 1,868.8 kWh / m² [14], as can be seen from the database of radiation data present on the PVGIS [15] (Figure 6A). Therefore, the potential energy production is equal to 186,567,027.22 kW/year direct current (Incident Solar Radiation * PV surface * X PV efficiency). To determine the expected electricity production of the alternating current system, it is necessary to estimate the losses, which for this type of system is around 10.07% in optimal conditions. Therefore, the alternating current production for the first year is 167,779,728 kWh/year and specific energy production for the 1,677.8 kWh/kWp (Figure 6B).

The FPV can be equipped with a solar tracking system to increase energy production. Many studies state that the application of a tracking solar system can increase production by 30-40% (Durkovic et al., 2017), we assume conservatively and therefore an incidence of 25%. In addition, a self-consumption of energy value (0.5%) was applied for the operation of the tracking solar system, which affects the total losses [14]. In this condition, the potential energy production is equal to 233,208,784.02 kW/year direct current and to 208,558,615.55kW/year alternating current (Figure 6B).
3.2 Social and Economic income
The FPV will not involve any gaseous emissions into the atmosphere and therefore produce energy without CO2 emissions in the context in which it is inserted and the consumption of primary energy resources (Table 1)

Table 1. Index of environmental performance linked with the FPV realization

| Index of environmental performance | Hypothesis 1 | Hypothesis 2 |
|------------------------------------|-------------|-------------|
|                                    | Year        | 25 years    | Year        | 25 years    |
| kgCO2 emissions                    | 88,923,256  | 2,070,145,404 | 110,536,065 | 2,763,401,649 |
| Primary energy saved [TEP]         | 36,912      | 859,306     | 45,883      | 1,147,072   |
For the preparation of this project proposal, a double summary calculation of the expenditure was made considering two project hypotheses (Table 2):

- Hypothesis n.1: Fixed floating photovoltaic system;
- Hypothesis n.2: Floating solar tracking photovoltaic system.

The calculation of the expenditure necessary for the construction of the planned FPV was carried out by examining the average rates used by the major leading suppliers in the national and international sectors. Specifically, these generic “other cumulative costs” include supply service for 25 years for maintenance and management, for the disposal of the plant, the average tariff used by professionals in the sector for design, expenditure for the process authorization and potential royalties.

| Costs                      | Hypothesis 1 (€) | Hypothesis 2 (€) |
|----------------------------|------------------|------------------|
| Photovoltaic Panels        | 34,000,000       | 34,000,000       |
| Inverter                   | 10,000,000       | 10,000,000       |
| Others electric materials  | 10,000,000       | 10,000,000       |
| Floating modules           | 7,000,000        | 7,000,000        |
| Connection at National grid| 15,000,000       | 15,000,000       |
| Tracking Solar System      | 0                | 6,000,000        |
| Installations              | 6,000,000        | 7,000,000        |
| Other cumulative costs     | 15,600,000       | 16,700,000       |
| **Total**                  | **97,600,000**   | **105,700,000**  |

Assuming a life span of the photovoltaic system of 25 years, an annual degradation rate of 0.5% in energy productions, we will have a return on the initial investment of about 12 years, and a net profit of € 99,963,933.03 per hypothesis 1 and a return time of 11 years with a net profit of € 139,872,745.31 for the hypothesis 2.

The costs were calculated considering the prices from tariffs, it is expected that an economy of scale with a consistent order of the material and the various services, could decrease the FPV costs by at least 15% by decreasing the return time and increasing incomes Table 3, Figure 7.

| Economic balance       | Hypothesis 1                     | Hypothesis 2                     |
|------------------------|----------------------------------|----------------------------------|
| Total revenue          | 197 610 555.52 €                 | 245 639 830.71 €                 |
| Average annual revenue | 7 904 422.22 €                   | 9 825 593.23 €                   |
| Investment cost        | 97 646 622.50 €                  | 105 767 085.39 €                 |
| Return time [years]    | 12.4                             | 10.8                             |
| Income                 | **99 963 933.03 €**              | **139 872 745.31 €**             |
4. Conclusions
There are reservoirs available in various countries that can be used for FPV, saving arable land and reducing energy generation costs (Sahu et al., 2015). Therefore, the FPV systems can become a very logical alternative to produce solar energy that contributes to increasing the social-economic profitability and landscape resilience of solar projects (Sahu et al., 2016).

The construction of the FPV produces significant environmental advantages compared to traditional ground photovoltaic systems (Sahu et al., 2016; Farfana and Breyer, 2018):

Figure 7. A) energy production flow B) C) Economic income flow
• It avoids soil consumption, which is currently one of the main causes of climate change and landscape transformation;
• It reduces the evaporation of the water present in the basin, preserving the amount of water available for the needs of the population;
• availability of the water used for cleaning the PV panels is directly on-site, reducing waste.
• It allows for a100% recycle of the floating platforms;
• It reduces the proliferation of algae following the shading of the structure and reduces the penetration of light into the water, keeping the water body temperature low (K-water, 2011). As a result, the creation of the FPV can influence the quality of the water collected in the basin, thus reducing the purification costs to meet drinking water standards;
• It reduces the problem of the dust deposited on the photovoltaic panels compared to the plants built on the ground, which involve greater consumption of water for their routine cleaning;
• More resilient landscape due to the lower impact of ancillary works. FPVs do not require many of the construction site operations for site preparation which can be irreversible such as levelling the ground or laying foundations, which must be done for installations on the ground;
• Greater energy production with higher economic and social returns;
• It produces royalties to the community for the use of the lake surface. The economic advantage is not for individual landowners but for the whole community.

Therefore, in FPV, the main objectives of sustainable development in the economic, social and ecological sphere are satisfied to a greater degree than traditional ground systems, where panels replace agricultural crops, giving space to nitrophilic herbaceous vegetation with no ecological value.

Of course, the environmental impacts must be outlined on the basis of the reference context in which the FPV is made, the type of plant and the possible forms of mitigation and compensation that can be developed during the final design phase and consider also the stakeholders’ participation approach at different institutional levels [16].

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