UNIVERSITÀ degli STUDI di CATANIA

DIEEI

Green Power

PhD in Systems, Energy, Computer and Telecommunications Engineering XXXIII cycle A.A. 2018/2019

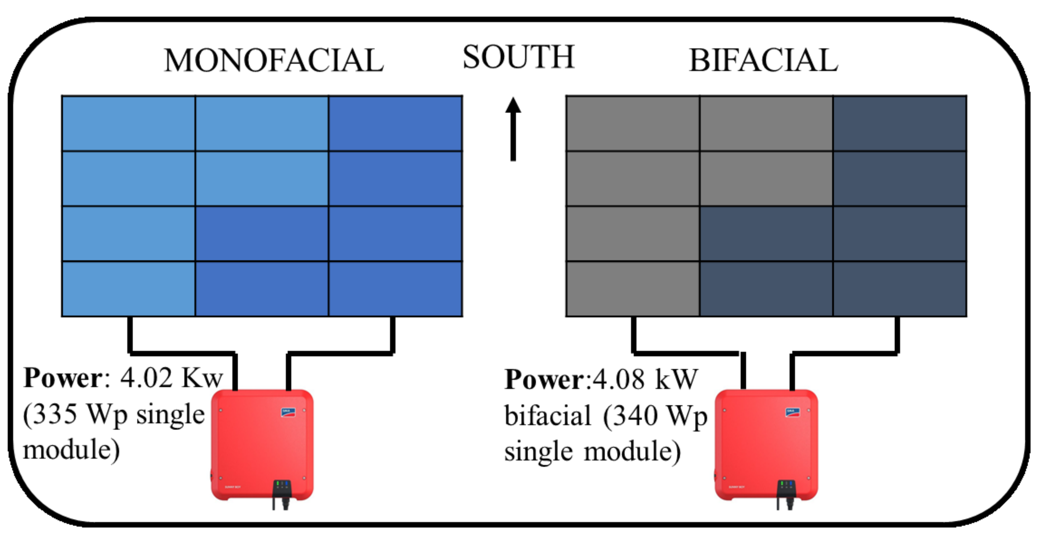
Modeling, experimental analysis and optimization of floating photovoltaic power plants

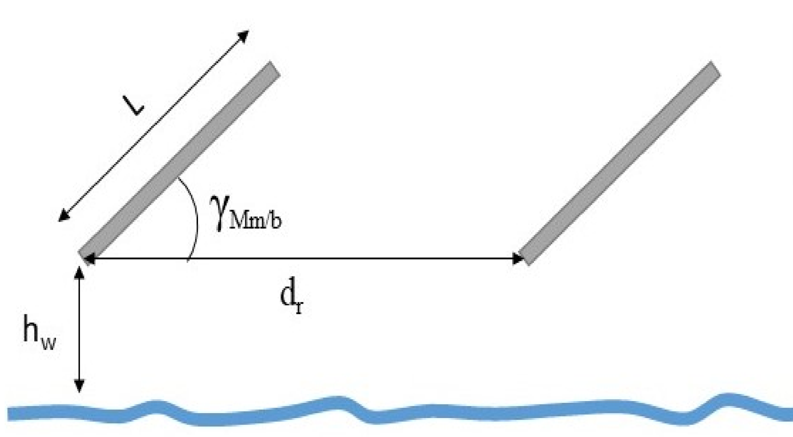
PhD Student: Fausto Bontempo S. **Tutor UniCT**: Prof. Giuseppe Marco Tina **Tutor EGP**: Ing. Leonardo Merlo **Tutor UniSplit**: Prof. Sandro Nizetic

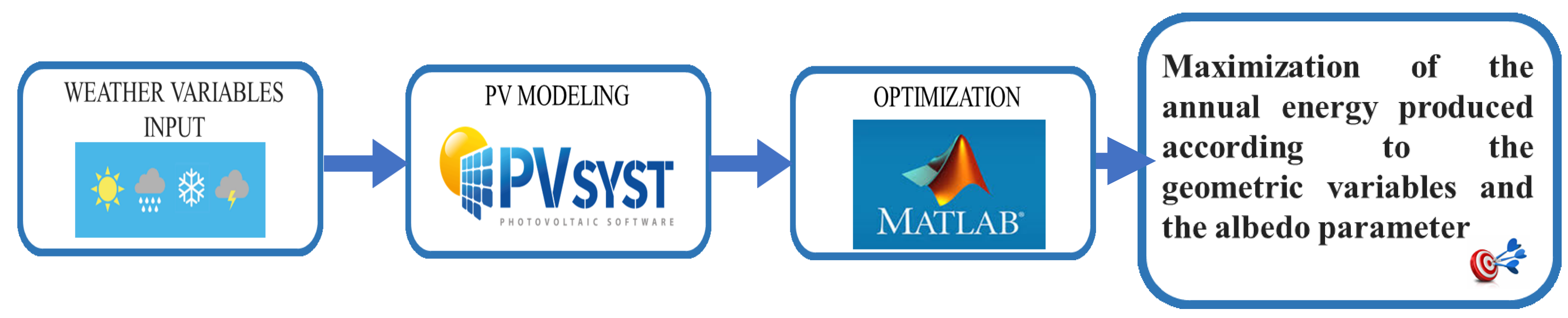
Context

The research work belongs to the general context of the renewable resources, specifically of the photovoltaic energy. The world's energy needs are always growing, so it is necessary to find clean and efficient energy sources. One technology that could meet these requirements is floating photovoltaic systems. In fact they have multiple advantages compared to the classic ground systems, including: Reduced evaporation from water reservoirs, improvements in water quality through decreased algae growth, easy integration into reservoirs of hydroelectric power plants and therefore easy to find water for cleaning and cooling. Furthermore, there is a considerable advantage in saving the land and an increase in efficiency compared to the classic ground systems as they work in favorable operating conditions.

Optimization of FPV

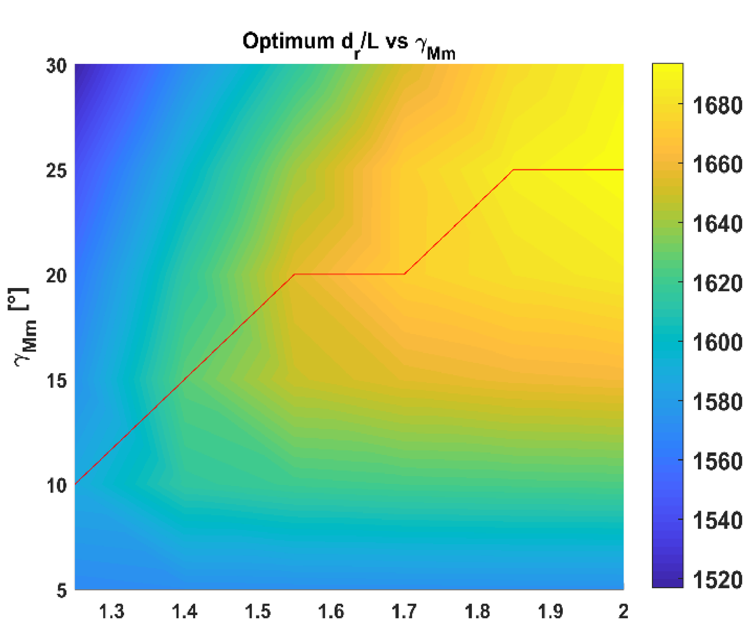




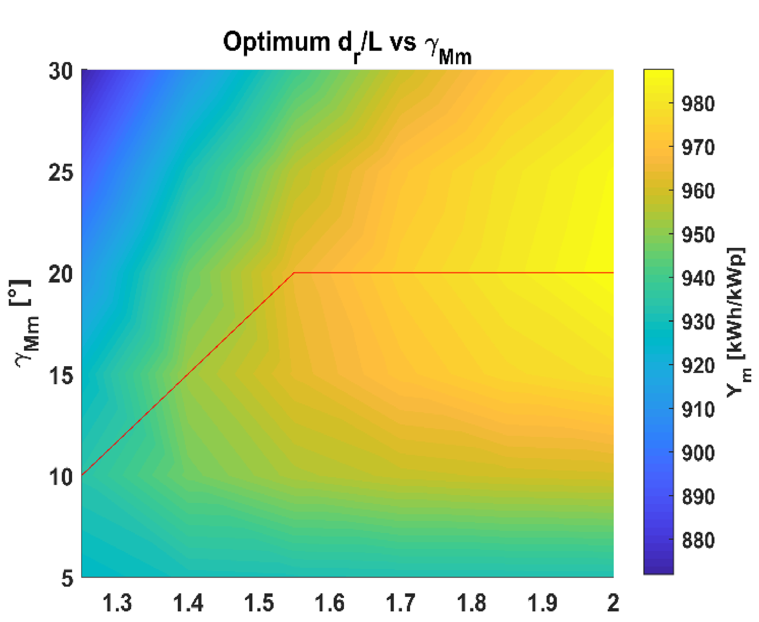


$$Y_{m/b} = \sum_{i=0}^{n} \frac{P_{mpp,m/b,i}\Delta t}{P_{p,m/b}} = \frac{Y'_{m/b}}{P_{p,m/b}} \qquad f_d = \frac{DHI}{GHI} \qquad BF = 100\frac{Y_b - Y_m}{Y_m}$$

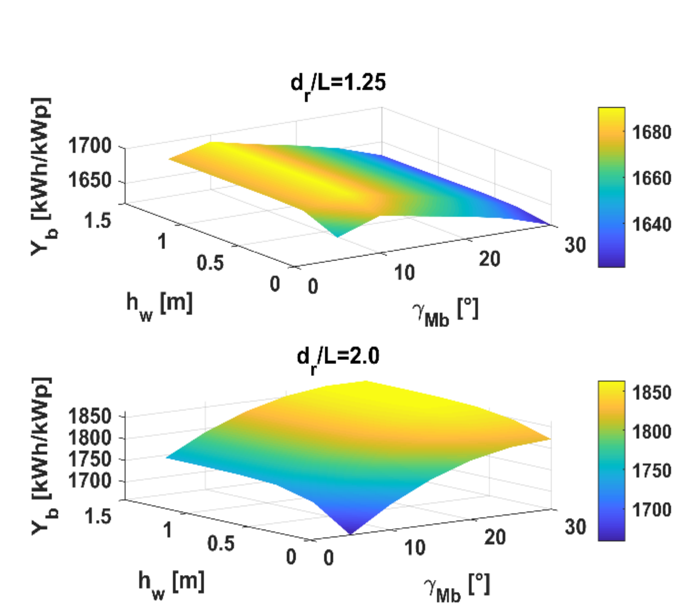
Through the PVsyst models the annual energy produced as a function of a geometric optimization implemented with Matlab was calculated



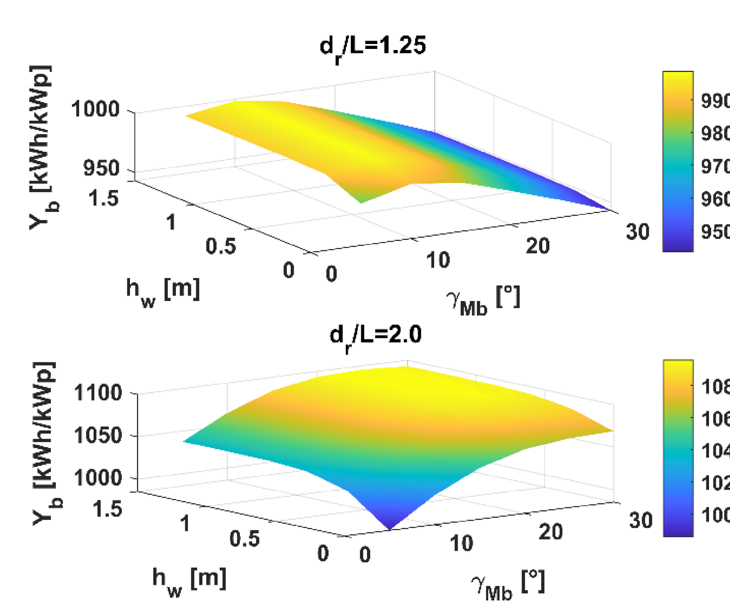
Monofacial pv system optimization for Catania



Monofacial pv system optimization for Frankfurt



Bifacial pv system optimization for Catania

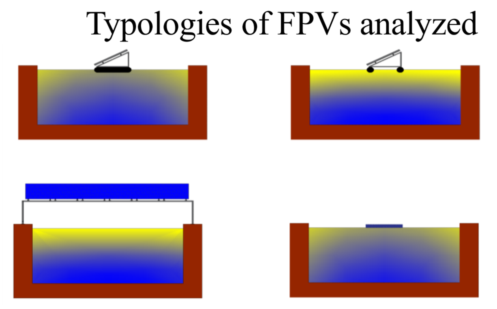


Bifacial pv system optimization for Frankfurt

The energy gain of bifaciality, for Catania, reaches 10% and for Frankfurt 11%. Monofacial systems, unlike the bifacial ones, have a lower sensitivity to albedo. The increase in energy ΔY in the bifacial compared to the monofacial with the same pitch is greater. The bifacial to be optimized, at the same pitch requires a tilt higher than the monofacial. For the analyzed configurations the trend of BF as a function of h_w is exponential and then it saturates at 0.9 m

Assessment of evaporation rate for FPV

Typologies of FPVs analyzed



Energy balance for floats that cover entirely the surface below the module

$$SW_{nFcover,a} = 0$$
$$LW_{nFcover,a} = \sigma T_w^4 (0.56 - 0.0092\sqrt{e_a})0.10$$
$$Q^* = Q^*_{free}(1-x) + Q^*_{Fcover}(x)$$
$$E_{FPVF,a/d\ Penman} = (1-x)E'_{free}$$
$$E_{Fcover,a\ lin.reg.} = a_0 + (1-x)a_1R_s + a_2T_a + a_3RH + a_4u_{10}$$
$$E_{FPVF,a/d\ lin.reg.} = E_{Fcover\ lin.reg.}(1-x)$$

Energy balance for flexible floats.

$$SW_{nFcover,d} = \alpha_{pv}(R_d + R_b)(1-\eta_{el})0.4$$
$$LW_{nFcover,d} = \sigma T_w^4 (0.56 - 0.0092\sqrt{e_a})0.10$$
$$Q^* = Q^*_{free}(1-x) + Q^*_{Fcover}(x)$$
$$E_{FPVF,a/d\ Penman} = (1-x)E'_{free}$$
$$E_{FPVF,a/d\ lin.reg.} = E_{Fcover\ lin.reg.}(1-x)$$
$$E_{Fcover,d\ lin.reg.} = a_0 + (1-0.95x)a_1R_s + a_2T_a + a_3RH + a_4u_{10}$$

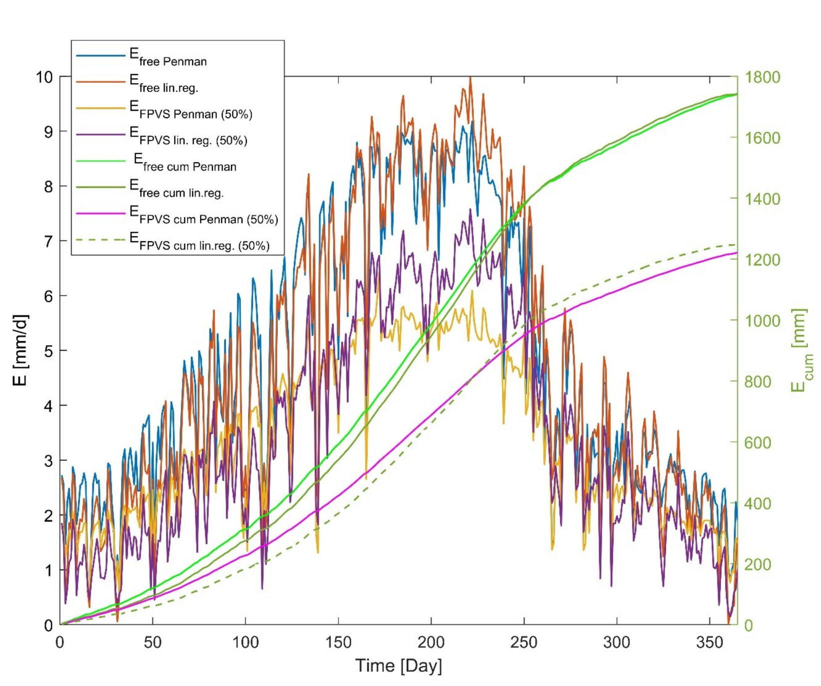
Energy balance for modules anchored to a tubular buoyancy systems and canal top

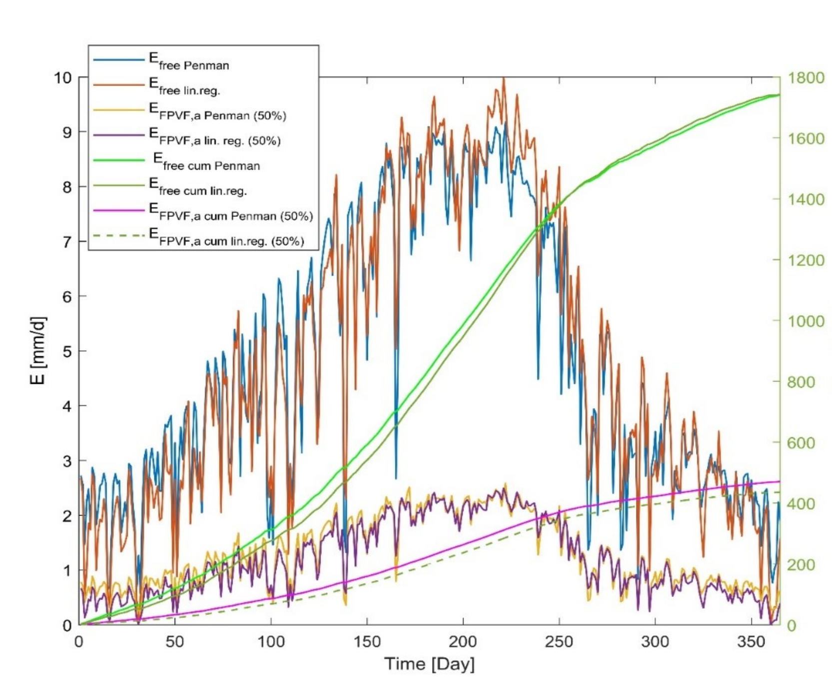
$$SW_{nScover} = (1-\alpha)R_d$$
$$LW_{nScover} = \sigma T_w^4 (0.56 - 0.0092\sqrt{e_a})(0.10 + 0.90 * 0.3)$$
$$E_{Scoverlin.reg.} = a_0 + 0.2a_1R_s + a_2T_a + a_3RH + a_4u_{10}$$
$$E_{FPVS} = (1-x)E_{free} + xE_{Scover}$$

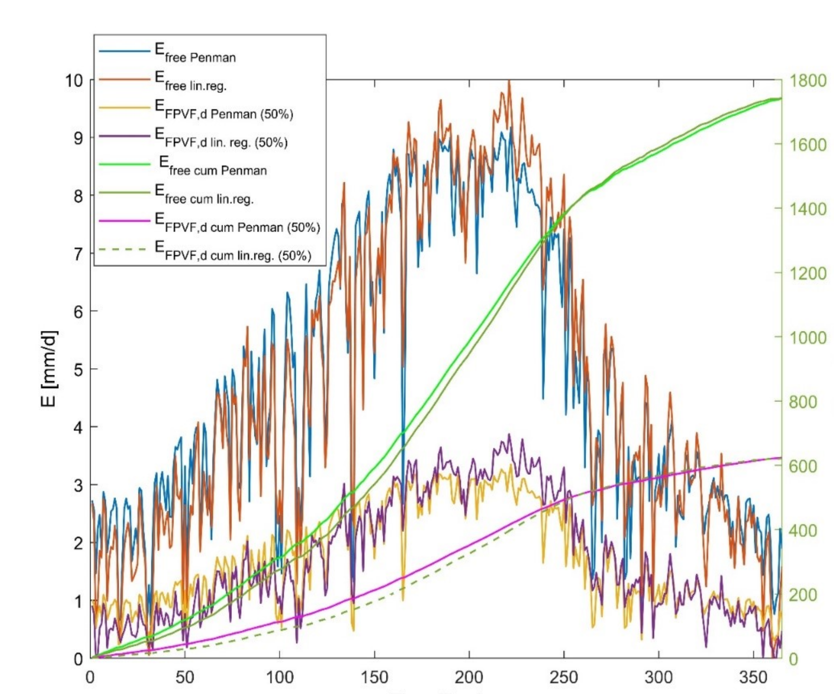
Yield indexes and model comparison

$$\Delta E_{FPV} = E_{free\ cum} - E_{FPV\ cum}$$
$$\eta = \frac{\Delta E_{FPV}}{E_{free\ cum}} * 100$$
$$\varepsilon_{FPV\ cum} = \frac{E_{FPV\ Penman\ cum} - E_{FPV\ lin.reg.cum}}{E_{FPV\ Penman\ cum}} * 100$$

The results of the developed analysis show the quantity of evaporated water depends not only on the percentage of surface covered, but also by the characteristics of floating systems. It has been shown that floating systems compared to suspended systems have a higher yield in terms of evaporation reduction. The floating systems that cover the entire surface below the modules, are the most efficient, followed by the flexible floats systems which have a lower efficiency since a part of the heat produced by the photovoltaic modules is exchanged with water.







Conclusion

Models have been developed that have allowed to obtain the optimal geometric configurations for the energy yield of floating photovoltaic systems, in particular for different technologies (monofacial and bifacial) and locations (Catania, Frankfurt). Furthermore, models have been developed that are able to predict the reduction of the evaporation rate due to the partial coverage of water surfaces, in relation to the characteristics of the floating systems. It has been shown that by covering 50% of the water surface it is possible to reduce from 30 to 73% of evaporated water.

References:

1. F. Bontempo, G. M. Tina, A. Gagliano, S. Nižetić, "Floating photovoltaic plants over water basins: Assessment of evaporation rate'', International Journal of Energy Research, 2019.
2. F. Bontempo, G.M. Tina, A. Gagliano, S. Nižetić, "Study of the evaporation reduction in water basins with floating photovoltaic plants", 4th International Conference on Smart and Sustainable Technologies (SpliTech), 2019.
3. F. Bontempo, G. Tina, A. Gagliano, " Comparison of evaporation models for free water basins surfaces, ", 4th International Conference on Smart and Sustainable Technologies (SpliTech), 2019.
4. G. M. Tina, F. Bontempo, L. Merlo, F. Bizzarri, "Comparative analysis of monofacial and bifacial PV modules for floating power plants", 14th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), 2019.