Universidad Zaragoza
1542

ESTUDIO DE LA TECNOLOGÍA DE MÓDULOS FOTOVOLTAICOS FLOTANTES EN SUPERFICIES DE AGUA

STUDY OF FLOATING SOLAR PANELS IN WATER SURFACES TECHNOLOGY

Autor

Carlos Marín Peralta

Director/es

Director: Juan José Marcuello Pablo
Director en intercambio: Maciej Zajkowski

Escuela de Ingeniería y Arquitectura Universidad de Zaragoza

2015-2016

Escuela de Ingeniería y Arquitectura
Universidad Zaragoza

DECLARACIÓN DE AUTORÍA Y ORIGINALIDAD

(Este documento debe acompañar al Trabajo Fin de Grado (TFG)/Trabajo Fin de Máster (TFM) cuando sea depositado para su evaluación).

TRABAJOS DE FIN DE GRADO / FIN DE MÁSTER

D./Dª. CARLOS MARIN PERALTA,

con nº de DNI 73019934-V en aplicación de lo dispuesto en el art. 14 (Derechos de autor) del Acuerdo de 11 de septiembre de 2014, del Consejo de Gobierno, por el que se aprueba el Reglamento de los TFG y TFM de la Universidad de Zaragoza,

Declaro que el presente Trabajo de Fin de (Grado/Máster) GRADO, (Título del Trabajo) ESTUDIO DE LA TECNOLOGÍA DE MODULOS FOTOVOLTAICOS FLOTANTES EN SUPERFICIES DE AGUA

es de mi autoría y es original, no habiéndose utilizado fuente sin ser citada debidamente.

Zaragoza, ____________________

Fdo: [signature]

STUDY OF FLOATING PHOTOVOLTAIC PANELS IN WATER SURFACES TECHNOLOGY

Tutor: Zajkowski, Maciej

Student: Marín Peralta, Carlos

June 2016

RESUMEN

RESUMEN / MOTIVATION FOR THE PROJECT

Continuous development of and continuous increasing of the number of people in the world causes an increase in the total energy required. Every day we need more energy to supply but fossil fuels are finishing.

All of this and the fact that we need to protect environment to ensure a habitable future makes renewables energies very important in last times, and they will become even more in the future.

On these renewables sources of energy is solar energy. Nowadays it only represents a few percentage of the total energy production but scientists are investigating on it and they are arriving to promising findings.

One of these findings is the main topic of this report; the use of PV modules above water surfaces.
Doing that there is a cooling effect and properties of the PV panels get better
In this report there is going to be analyze all the benefits of this system, the way they are installed and best applications.

As a Spanish Erasmus student in Poland I will present the situation in both countries.

INDEX

INTRODUCTION

HISTORY OF THE SOLAR ENERGY

The sun is fundamental to understand the life in the earth. Now humans take advantage of it as energy form but since the beginning of our existence we use it, even animals and plants. This solar energy is also present in very important phenomena that occurs in our planet, the water cycle or photosynthesis in plants.

Now we use it to generate energy for all of the devices we have at home, in our companies, streets, malls… but it is not the beginning of its use by the humans.

Ancient civilizations venerated the sun as a god, conscious of its big importance in their lives. Aztecs created temples for the sun. Pyramids in Egypt are constructed in a way to use the power of the sun and several more examples.

It has been found inscriptions previous to 1000 b. C. that show ancient civilizations used to use solar power to heat objects or to illuminate spaces with advance methods. Archimedes thought in concave mirrors to get romans ships fired in Syracuse.

Romans were the first civilization that put glass in the windows to keep houses warmed.

It is reported that Edward Becquerel observed in 1839 a small voltage in one selenium electrolyte terminals. Despite this finding it took a time to find a use to it.

It is not before 1867 when Horace de Saussure made first solar collector. Between 1870 and 1880 several models of solar heating were presented in Paris. In 1883 first cylindrical collector was made by John Ericsson.

Around 1880 first solar cells of visible light were built. They had an efficiency of 1%, 2% maximum. In 50's, technology of silicon high pure glass production got a big progress and some cells got 4% efficiency first and 11% then. In 1958 a small satellite was powered by 1 Watt solar cell.

One important finding highly efficient was a solar warmer invented by Charles Greeley Aboot in 1936, it was very used in some states of USA. Due to low cost of natural gas after 50's industry of solar heating decreased until 70's. But also in this same time space investigations programs focused in PV development because of its really good features to this kind of application.

Figure 1. Solar panels in a satellite in 1960.

In 70's due to increase of fuel and gas price, investigation of solar energy got a revival. Gulf War in 1990 incited more interest on solar energy.

At this ages photovoltaic cells were so expensive to a commercial use, but they were a really interesting option for installations located far away to the electric public grid.

Figure 2. Solar installation isolated to public grid.

With the time, costs of PV panels production have been decreasing and performance of them have been increasing, making this technology more interesting and useful for other applications, reaching nowadays, when we can use it in many applications.

Nowadays, solar energy is used in two principal ways. It can be used at heating power to warm fluids or to impulse turbines or can be used to produce electricity directly (photovoltaic panels).

The important kind for this report is photovoltaic panels. And it is going to present one of the ideas of scientists to get a higher performance for PV panels but there are much more. Some other ideas like high concentration multi-junction solar cells achieve an efficiency of up to 46.0 % in labs, or concentrator technology, where module efficiencies of up to 38.9 % have been reached also in labs.

And it happens because we are finishing fossil fuels and we won't have sources of energy in the future. Also we are starting to think in our environment in last years and how to keep it well. Photovoltaic energy, with some other energies like Eolic or hydraulic are renewables and respect environment more than others.

For all of it, we must think in them as the future of the energy in our world, and we must realize the high importance they will have in energy system.

PV PANELS STATE

PV panels in the world

The technology of PV panels is suffering an exponential increasing on its production and installation since last 20 years. That increasing is also motivated by the promotion in some countries with economic incentives.

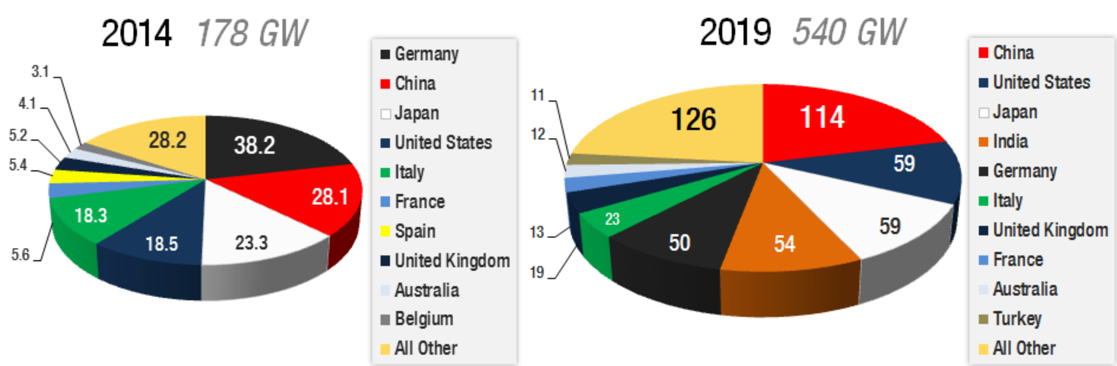
Until 1996 United States was the reference with an amount of 77 MWp of capacity. After that and until 2005 Japan was the new leader, in 2005 Germany started to be the country with the highest installation unitl these days, when China has become the new leader with 178 GWp, enough to supply 1% of global demand.

In 2010 cumulated power installed around the world was 40.000 MWp approximately. About 29.000 MWp (72%) were located in UE.

In 2014 an increase of 40 GWp was installed reaching the amount of 180 GWp.

Nowadays Asia is the continent which more is increasing its amount of capacity thanks to China, Japan and also India. After that America an Europe then are increasing in a similar way.

Figure 3. 2014 countries distribution and prevision for 2019 countries distribution



The prevision for this energy is to be the most important by 2050, reaching 26 % of total demand. That will be around 4.600 GWp. Most part of it will be installed in India and China.

PV panels in Poland

Renewables energies are growing in Poland. One reason for growing demand for renewable energy is the necessity of improving energy security of the country. Important if we take into account that polish industry is based on carbon.

The bet for renewables from polish government is important and it is estimated that in the period 2011-2020 the investment is going to be approx. 24 € billions and 3 more for biofuels.

In solar energy the investment is calculated as 8 € billions.

The public waste on renewable energy production is caused by the fact that the development of renewable energy is one of the priorities of Energy Policy of Poland until 2030.

Targets of these politics:

· 20-30 % gasses emission reduction.

· 20 % increase of sharing renewable energies use.

· 20 % increase in energy efficiency.

Figure 4. Prices for energy production in Poland

Power of an installation	Guaranteed repurchase price	Renewable energy source
up to 3 kW	PLN 0.75 (€ 0.19)	Water, wind and solar energy
3 kW – 10 kW	PLN 0.70 (€ 0.18)	Agricultural biogas
3 kW – 10 kW	PLN 0.65 (€ 0.16)	Water, wind and solar energy
3 kW – 10 kW	PLN 0.55 (€ 0.14)	Biogas from stockyards
3 kW – 10 kW	PLN 0.45 (€ 0.11)	Biogas from sewage treatment plants

The distribution of energy production in last years in Poland, for renewable energy sources is:

Figure 5. Distribution energies production

	Capacity (MWh)					
RES type	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Wind power	451.090	724.657	1180.272	1616.361	2496.748	2644.898
Hydropower	940.576	945.210	937.044	951.390	966.103	966.236
Biomass power	231.990	252.490	356.190	409.680	820.700	876.108
Biogas power	54.615	70.888	82.884	103.487	131.247	136.319
Solar power	0	0.001	0.033	1.125	1.290	1.290
Total	**1678.271**	**1993.246**	**2556.423**	**3082.043**	**4416.088**	**4624.851**
Growth y/y absolute values (MWh)	154.494	314.975	563.177	525.620	1334.045	208.763
Growth y/y in %	10.14%	18.77%	28.25%	20.56%	43.28%	4.73%

According to researchers, solar energy has not a high potential in Poland so the usage is not recommended for entire country needs, but rather for local applications.

A fact that confirms it is that ins winter insolation is 7 times less than in summer.

Despite all of this, this energy is growing, especially in polish households.

PV Panels in Spain

Spain is one of the most important countries in solar energy development, it is also one of the countries in Europe with more sunshine hours.

Few years ago, Spain was also one of the largest manufacturers in the world, even the largest in 2008, but economic crisis stopped this development and government cut its help for financing and feeds on tariff.

Figure 6. Insolation in Spain territory

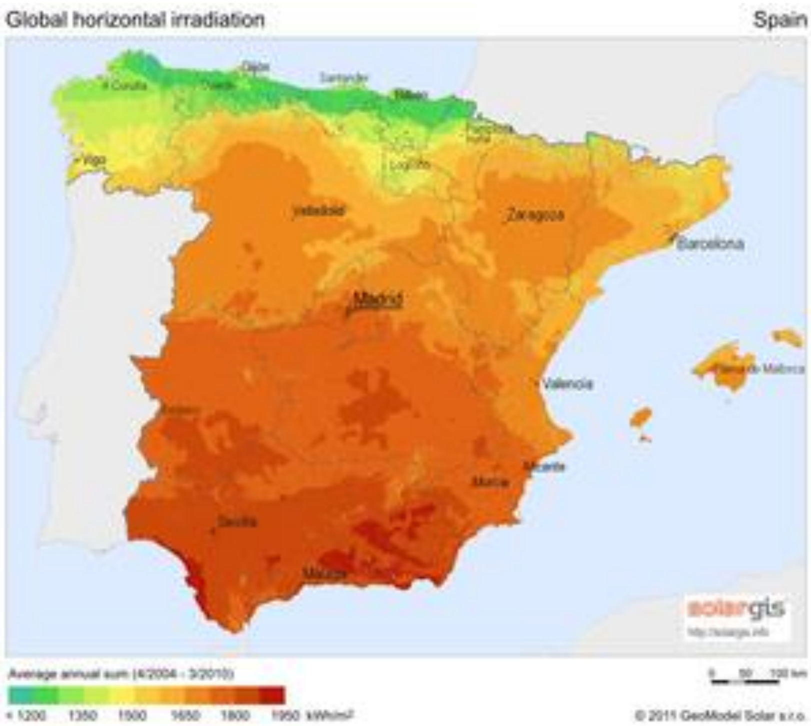
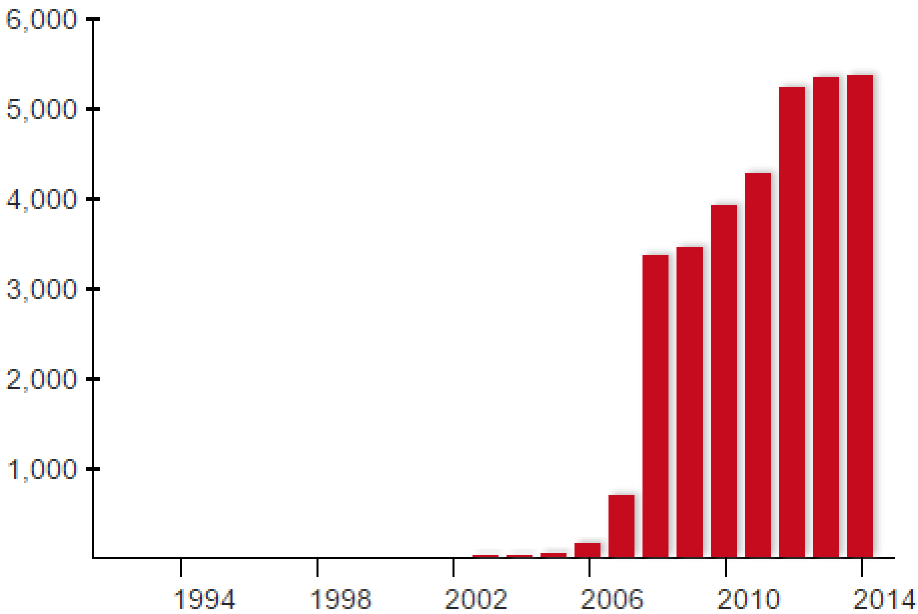


Figure 7. Increasing of photovoltaics in Spain



It is visible that in years when government put really good conditions there was a high increasing. Lot of people used this opportunity and started to speculate with that. When government realized, cut all this helps and development starter to grow slowly.

Intention now is to recover part of this increasing and the target of Spain reaching a percentage of 20 % of photovoltaic energy use by 2020.

CONSTRUCTION OF PV MODULE

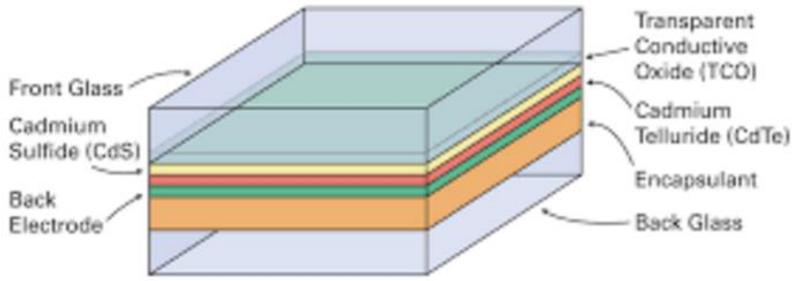
PV panels are composed by a number of solar cells which they are interconnected. These cells are set in a stable unit that brings them mechanical resistance and protection. In addition, cells are encapsulated to protect themselves against water or vapor, which ones could rust the connections.

In case of bulk silicon warranties are estimated in 90% of its rated output for 10 first years and 80% for next 15.

PV modules are covered by a transparent surface on the top, usually glass, that allows light approach to cells, an encapsulant that protect against humidity and hold cells and a rear layer made by tedlar.

Then a frame brings them mechanical protection and link every component.

Figure 8. Consttuction of PV cell

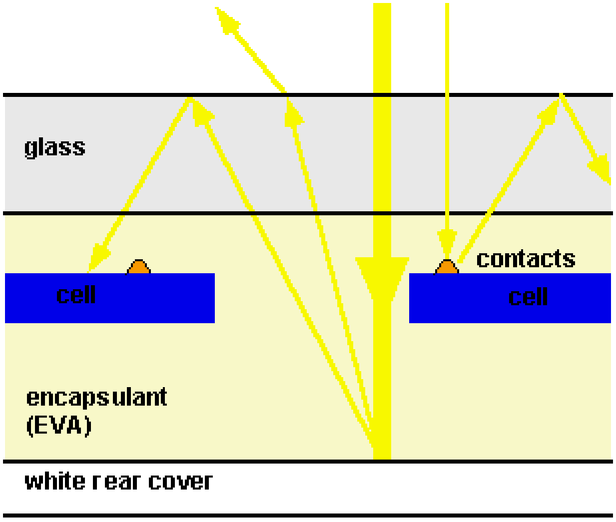


Glass must have good transmission in the wavelengths where cells work (range of 350 nm to 1200 nm). The reflection from the front surface must be low.

To get this reflection condition front surface texture can be treated to be rougher. That makes itself not to be self-cleaner.

Tempered, low iron-content glass is most commonly used as it is low cost, strong, stable, highly transparent, and impervious to water and gases, and has good “self-cleaning” properties.

Figure 9. Reflection in glass



EVA (ethyl vinyl acetate) is the most commonly used encapsulate material. It comes in thin sheets which are inserted between the solar cells and the top surface and the rear surface. Then, all of it is warmed to 150ºC to polymerize the EVA and link the module together.

There are some bi-face modules that are able to receive radiation from both sides. On these panels rear layer must be optically transparent to exploit the maximum energy.

The typical edge frame is made of aluminum.

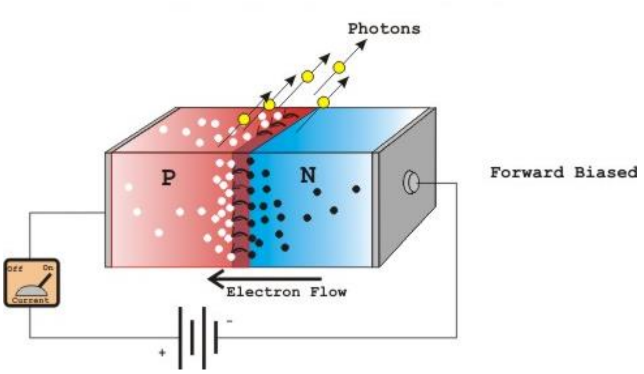
All these components must be resistant to conditions of high temperature and high UV radiation.

WORKING OF PHOTOVOLTAIC EFFECT AND TECHNOLOGY OF CELLS

Photovoltaic solar energy is the one that is taken thanks to the transformation of the solar energy that reaches from the sun into electric energy through the photovoltaic effect (photoelectric effect). This effect consists on the emission of electrons (electric current) that occurs when light insides on some surfaces.

Going further with this phenomena, we could say that it is the opposite way of a LED.

Figure 10. Working of a LED



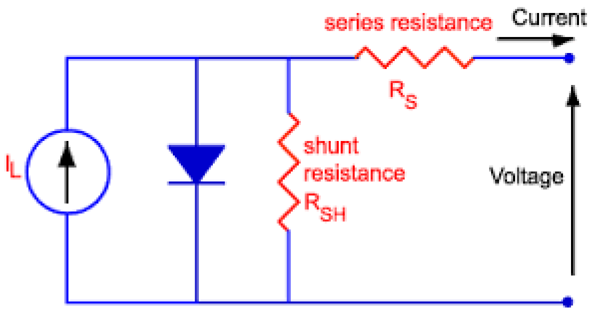
Photovoltaics cells are p-n electronic junctions. Atomically, appears two bands. One is valence band and the other one is conduction band.

When light arrive to the junction, energy in way of photons is able to stimulate electrons in the junction. When these electrons are stimulated, they can jump from one of the bands to the other. This movement of electrons incites a current in p-n junction. Cells construction take advantage of it and connect to a circuit. That is how cells work.

EFFECT OF TEMPERATURE IN PV MODULES

One photovoltaic cell is modeled like this following circuit

Figure 11. Equivalent circuit of cells



Source of current and diode represent ideal working of the cell. Series resistance represents resistance in wires and connections. Shunt resistance represents imperfections in junction p-n of diode.

Series resistance increase slowly in the range of usual temperature working of cells (25 to 70 ºC). That happens because conductivity decrease due to a decrease of load handles movility.

Gap energy (Eg) between conduction and valence bands decrease with temperature and more rays with a higher wavelength (and smaller energy level) are able to produce energy in cells. These new photons with small energy level and in a bigger quantity produce a decrease of energy, or voltage produced in cells, but with more quantity, what means higher current.

Typical values of these phenomena are:

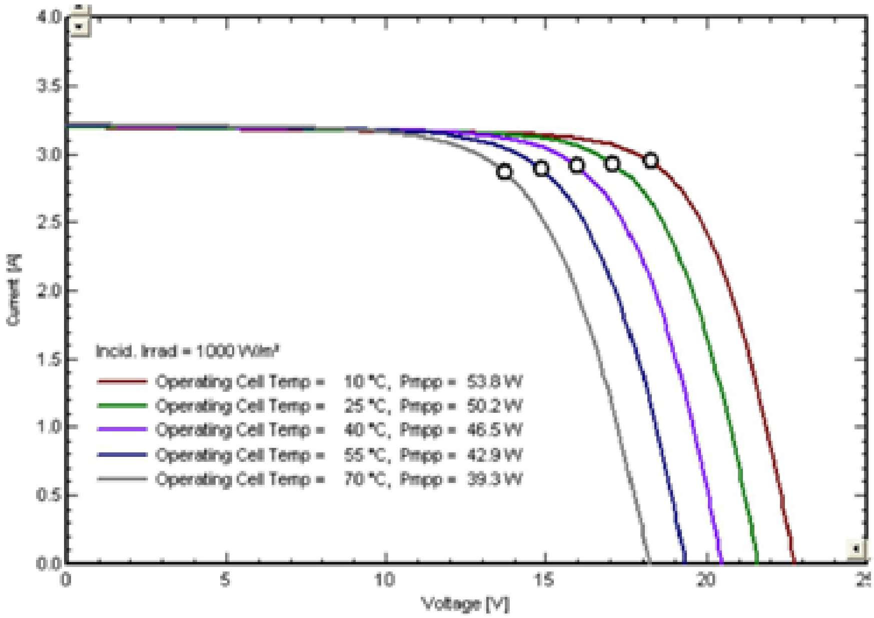
Coef Temperature I_{sc} (α) (% / C)	0,051
Coef Temperature V_{oc} (β) (% / C)	-0,31

Combining these values also decrease the value of the point with maximum power:

Coef Temperature P_{mpp} (β) (% / C)	-0,41

It is easily represented in V-I characteristic of PV panels, which are the diagrams that best describes the working:

Figure 12. Pmpp decreasing due to temperature



As temperature is increasing, the point of maximum power is going closer to origin. That means less power available in our modules.

FLOATING SOLAR MODULES TECHNOLOGY

Floating solar panels is a technology lead by the company Ciel et Tierre in collaboration with other partners. This technology consists on PV panel installation but installed in a water surface. They have developed a new system that brings solar panels stability and protection against disturbances that can appear on this kind of installation.

Figure 13. Hydrelio structure

The idea of this new technology in development is the use of the lower temperature of the water as a refrigerant. It is an easy system of cooling that not require special components for it, and it is increasing the performance of PV panels.

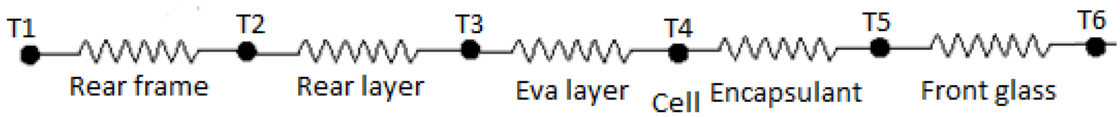
Typical method of heating transference is used in this study. There are two different temperatures in both sides of the PV module. On the water side, temperature is lower than in air side. Traditional systems only have air temperature.

With this system, what is happening is that temperature in cell, and, what really matters to our study, is in one point between temperature in water and air.

One of the characteristics of PV modules is losses due to effect temperature, and we are decreasing these losses with this Hydrelio's system.

Cold flows from the water and balance the high temperature from the air. Finally, in next chart, temperature of work in the cell is the temperature reached in T4. T1 is temperature in water side and T6 is temperature in air side.

Figure 14. Heating transference model



Other point of it is that it gives to electric companies the option of use them big water surfaces in dams.

As an environmental point of view, these systems reduce the evaporation in dams and it induce a higher level of water to use. One more environmental point is that it reduces the growth of water-plants, what is good for dam's fauna.

PRACTICAL ESTUDY OF THE TECHNOLOGY

It is followed the typical procedure of PV panels installation designing but keeping in mind that using water as a cooler component in our installation, temperature will decrease in cells and they will have a higher performance.

To find differences between the installation in different parts in the world, it has been taking this to places to make the study:

- Mikołajki (Poland).
- Caspe (Spain).

With the help of software RETScreen, one software created by environmental ministry of Canada we are able to find the environmental conditions from the places of study. Then, with other software like Solarius, the development of the project will be done.

Database of environmental conditions is from NASA, but data taken from there refers to the rate value of all day, not only hours with sun. A good approximation to compensate this problem and the one taken is to set a factor of 30% on the rate temperature of every day/month. It has been studied this factor in one random day in every month.

The production of these kind of installations depends on the place where they are mounted. In this case, we will be able to observe that in Spain production is higher due to the higher insolation. It is supposed that there are not obstacles that produce shadows in installations. One advantage of building it in lakes is that.

With all the conditions there will be set a group of losses indexes. To see the difference between a country like Spain with extremely hot temperatures in some periods and one colder country as Poland is, losses due to temperature will be considered.

Losses due to the effect of temperature will be set as 8 % and 6% in Mikołajki for traditional and hydrelio system respectively. I Caspe will be set as 14 % and 11% respectively.

$$\text{Total losses } [\%] = [1-(1-a-b) \times (1-c-d) \times (1-e) \times (1-f)] + g$$

a - Reflection losses.
b - Shading losses.
c - Mismatching losses
d - Losses due to the effects of temperature variations
e - Losses within DC circuits
f - Inverter losses.
g - Losses within AC circuits

1. *Description of installation*

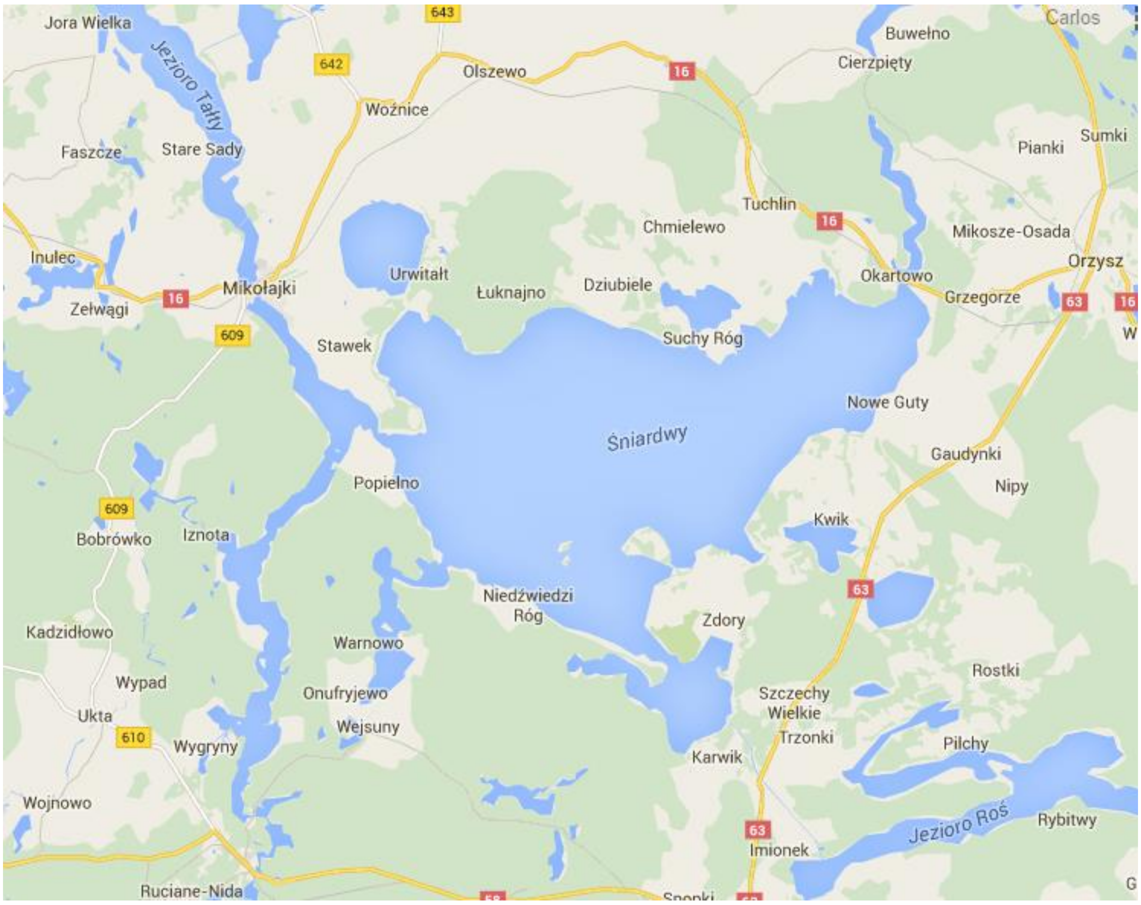
Installation is set in the new hydrelio system developed by the company Ciel et Terrie. The peak power of the installation is 200 kWp.

2. Emplacement of installations

1 – Mikołajki, Poland

		Latitude	Longitude	
Lake	Śniardwy	53,78 N	21,57 E	Degrees
City	Mikołajki			

Figure 15, 16 and 17. Picture and situation of lake Śniardwy


Jora Wielka
Jezioro Tałty
643
642
Olszewo
16
Buwełno
Cierzpięty
Carlos
Woźnice
Faszcze
Stare Sady
Pianki
Sumki
Tuchlin
Chmielewo
Mikosze-Osada
Inulec
Urwitałt
Łuknajno
Dziubiele
Okartowo
Orzysz
Mikołajki
Zełwągi
Grzegorze
63
609
Stawek
Suchy Róg
Nowe Guty
Śniardwy
Gaudynki
Popielno
Nipy
Bobrówko
Iznota
Kwik
Niedźwiedzi
Róg
Zdory
Kadzidłowo
Warnowo
Rostki
Wypad
Onufryjewo
Szczechy
Wielkie
Ukta
610
Wejsuny
Trzonki
Pilchy
Wygryny
Karwik
Wojnowo
Jezioro Roś
Rybitwy
Imionek
Ruciane-Nida

Those are the conditions measured in one year in Mikołajki lake:

Figure 18. Climate data Mikołajki

		Air temp rate (ºC)	Air temp min (ºC)	Air temp max (ºC)	Rel humidity	Solar radiation 0º	Atm pressure (kPa)	Wind speed (m/s)	Floor temp (ºC)	Solar radiatio
1	January	-5,75	-16,38	7,04	89,19%	0,57	99,93	4,61	-6,19	0,86
2	February	1,04	-6,02	9,22	89,52%	1,20	99,51	5,37	0,72	1,53
3	March	2,34	-5,07	13,18	82,69%	2,14	99,98	4,30	2,47	2,48
4	April	8,09	-0,45	17,67	72,05%	3,53	99,77	4,15	8,36	3,81
5	May	13,45	4,97	21,94	67,22%	4,82	100,10	3,86	13,95	5,07
6	June	16,40	6,9	26,86	64,57%	5,38	100,33	3,63	17,01	5,46
7	July	18,69	9,87	31,39	64,11%	4,83	99,96	4,15	19,04	4,93
8	August	21,17	8,79	33,18	55,23%	5,18	100,49	3,46	21,49	5,94
9	September	14,95	5,32	32,06	68,22%	2,78	100,34	4,03	15,10	3,13
10	October	6,26	-3,94	21,15	75,82%	1,69	100,82	4,07	6,19	2,13
11	November	3,84	-6,4	14,14	90,38%	0,40	99,92	4,99	3,63	0,61
12	December	2,03	-11,01	11	92,09%	0,41	100,92	5,38	1,64	0,67

The primary reason of this report is to analyze the good effect that cooling has in modules performance.

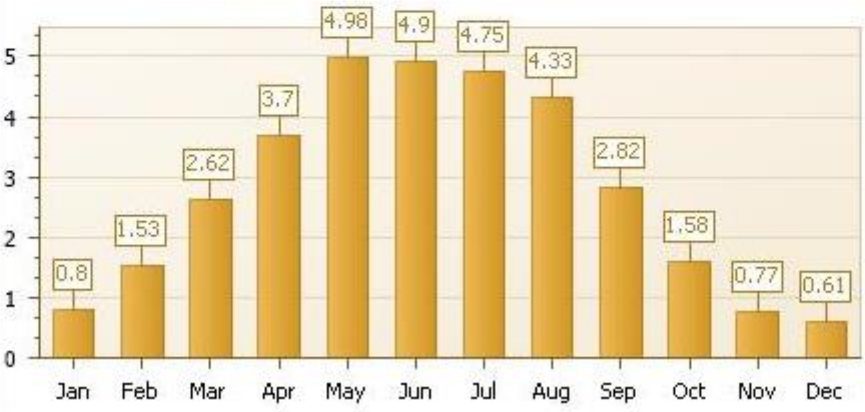
In the next chart, in last column appears the temperature of working in the cell, is quite lower than temperature along the day. This characteristic is set as 8 % in losses due to temperature effects in traditional systems and only 6 % in Hydrelio system. These percentages were developed in the section about losses.

Figure 19. Study of temperatures Mikołajki

	MIKOŁAJKI TEMPERATURES (ºC)			
Month	Rate emperature water	Rate Temperature air (day)	Rate temperature (all day)	Temperature of working
January	-3,02	-4,02	-5,75	-3,51
February	1,02	1,36	1,04	1,19
March	2,28	3,05	2,34	2,67
April	7,89	10,52	8,09	9,20
May	13,11	17,48	13,45	15,30
June	15,99	21,32	16,40	18,66
July	18,23	24,30	18,69	21,26
August	20,64	27,53	21,17	24,08
September	14,58	19,44	14,95	17,01
October	6,10	8,14	6,26	7,12
November	3,74	4,99	3,84	4,37
December	1,98	2,63	2,03	2,31

In this first case of study average solar radiation for an inclination of 12º south is:

Figure 20. Average dayly radiation per month (kWh/m2)



2 – Caspe, Spain

		Latitude	Longitude	
Lake	Mequinenza dam	41,05 N	0.1 O	Degrees
City	Caspe			

Figure 21, 22 and 23. Picture and situation of lake Mequinenza in Caspe


Massalcorei
LP-7
N-211
CATALUÑA
ARAGÓN
Mequinenza
N-211
A-1411
Tos
d'Alr
N-211
Playas de
Chacón
Chiprana
Caspe
A-1411
Fayón

Those are the climate conditions measured in one year in Caspe lake:

Figure 24. Climate conditions Caspe

		Air temp rate (ºC)	Air temp min (ºC)	Air temp max (ºC)	Rel humidity	Solar radiation 0º (kWh/m2/d)	Atm pressure (kPa)	Wind speed (m/s)	Floor temp (ºC)	Solar radiatio 12º (kWh/m2/
1	January	5,11	-2,83	17,36	71,97%	2,21	97,08	5,96	4,51	0,86
2	February	4,40	-4,7	16,1	73,62%	3,26	96,57	6,55	4,26	1,53
3	March	9,17	-1,4	21,74	69,44%	4,16	96,95	5,37	9,26	2,48
4	April	12,52	1,72	24,42	61,20%	6,04	96,87	4,18	13,02	3,81
5	May	17,61	5,23	32,1	53,22%	6,82	96,76	4,97	18,61	5,07
6	June	22,01	10,61	39,57	48,76%	7,56	96,77	3,61	23,56	5,46
7	July	26,74	13,25	41,78	39,54%	7,45	96,64	4,46	28,73	4,93
8	August	23,98	11,94	37,65	47,13%	6,67	96,59	3,79	25,59	5,94
9	September	18,28	8,82	31,11	52,50%	4,78	96,64	4,14	19,39	3,13
10	October	14,62	2,89	26,2	64,27%	3,38	96,55	4,06	14,90	2,13
11	November	10,91	-2,25	23,69	71,35%	2,21	97,31	4,74	10,31	0,61
12	December	8,85	1,53	19,15	70,44%	1,66	97,74	2,88	7,55	0,67

For the study of the benefits got thanks to the system, it is presented the temperature of workink for the cells in the case of Caspe.

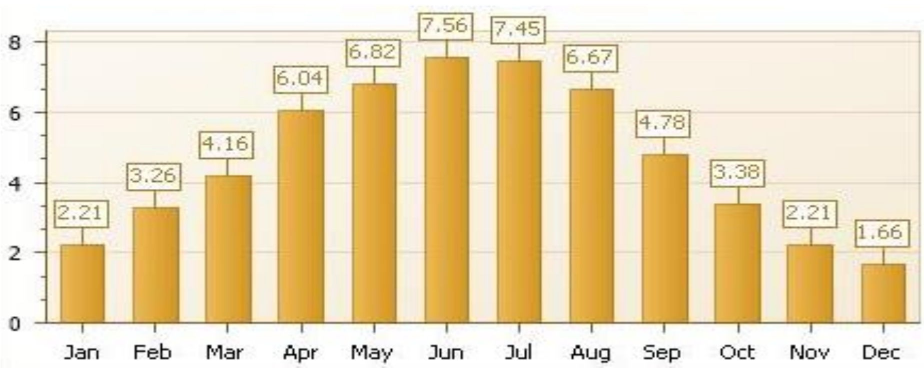
Percentages of losses due to temperature effect in Caspe are measured as 11 % for traditional systems and 15% for Hydrelio system. The temperatures are these ones:

Figure 25. Study of temperatures Caspe

	CASPE TEMPERATURES (ºC)			
Month	Rate emperature water	Rate Temperature air (day)	Rate temperature (all day)	Temperature of working
January	4,52	6,64	5,11	5,58
February	3,89	5,72	4,40	4,80
March	8,10	11,92	9,17	10,01
April	11,07	16,28	12,52	13,68
May	15,57	22,90	17,61	19,24
June	19,45	28,61	22,01	24,03
July	23,64	34,77	26,74	29,20
August	21,20	31,17	23,98	26,18
September	16,16	23,76	18,28	19,96
October	12,92	19,01	14,62	15,97
November	9,65	14,19	10,91	11,92
December	7,82	11,50	8,85	9,66

Here distribution of radiation is the following:

Figure 26. Average daily radiation per month (kWh/m²)



3. *Choice of photovoltaic panels*

Using 976 modules of a monocrystalline module technology, the rated power will be 200,080kW. That will cover 1246,35 m^2 in our lakes. Panel chosen is the following.

<u>Shangai Ja solar jam 5 (L) 72 205</u>

Figure 27. Datasheet of Shangai Ja solar jam (L) 72 205

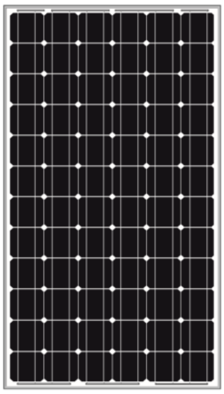
JAM5(L) 72/195-215

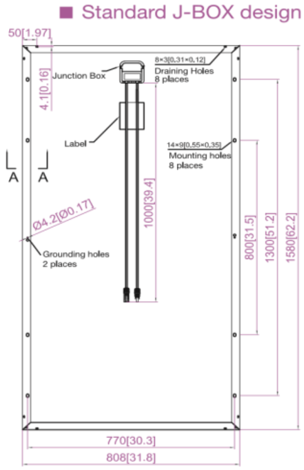
JA SOLAR

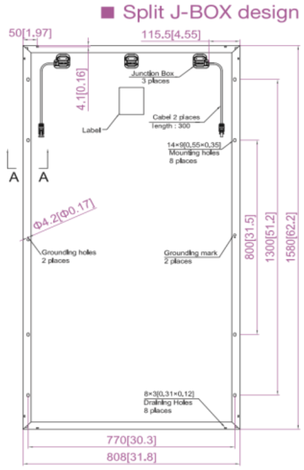
Engineering Drawings

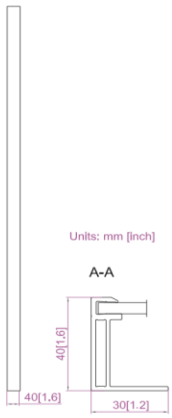
■ Standard J-BOX design

■ Split J-BOX design









■ customized cable length available upon request

MECHANICAL PARAMETERS

Cell (mm)	Mono 125×125 (L)
Weight (kg)	15.0 (approx)
Dimensions (L×W×H) (mm)	1580×808×40
Cable Cross Section Size (mm^2)	4
No. of Cells and Connections	72 (6×12)
Junction Box	IP67, 3 diodes
Connector	MC4 Compatible
Packaging Configuration	26 Per Pallet

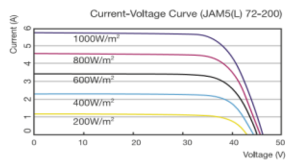
WORKING CONDITIONS

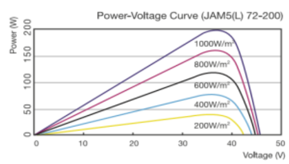
Maximum System Voltage	DC 1000V (IEC)
Operating Temperature	-40℃~+85℃
Maximum Series Fuse	10A
Maximum Static Load, Front (e.g., snow and wind) Maximum Static Load, Back (e.g., wind)	5400Pa (112 lb/ft^2) 2400Pa (50 lb/ft^2)
NOCT	45±2℃
Application Class	Class A

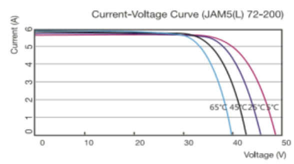
ELECTRICAL PARAMETERS

TYPE	JAM5(L) 72-195/SI	JAM5(L) 72-200/SI	JAM5(L) 72-205/SI	JAM5(L) 72-210/SI	JAM5(L) 72-215/SI
Rated Maximum Power at STC (W)	195	200	205	210	215
Open Circuit Voltage (Voc/V)	45.58	45.79	46.01	46.20	46.34
Maximum Power Voltage (Vmp/V)	36.87	37.12	37.42	37.65	37.86
Short Circuit Current (Isc/A)	5.62	5.70	5.79	5.88	5.96
Maximum Power Current (Imp/A)	5.29	5.39	5.48	5.58	5.68
Module Efficiency [%]	15.27	15.67	16.06	16.45	16.84
Power Tolerance (W)			-0~+5W		
Temperature Coefficient of Isc (αIsc)			+0.049%/℃		
Temperature Coefficient of Voc (βVoc)			-0.340%/℃		
Temperature Coefficient of Pmax (γPmp)			-0.410%/℃		
STC	Irradiance 1000W/m^2, Module Temperature 25℃, Air Mass 1.5				

I-V CURVE







NOCT

TYPE	JAM5(L) 72-195/SI	JAM5(L) 72-200/SI	JAM5(L) 72-205/SI	JAM5(L) 72-210/SI	JAM5(L) 72-215/SI
Max Power (Pmax) [W]	142.74	146.40	150.06	153.72	157.38
Open Circuit Voltage (Voc) [V]	42.13	42.24	42.45	42.61	42.68
Max Power Voltage (Vmp) [V]	33.20	33.58	33.80	34.08	34.44
Short Circuit Current (Isc) [A]	4.56	4.64	4.68	4.72	4.74
Max Power Current (Imp) [A]	4.30	4.36	4.44	4.51	4.57
Condition	Under Normal Operating Cell Temperature, Irradiance of 800 W/m^2, spectrum AM 1.5, ambient temperature 20℃, wind speed 1 m/s				

Electrical data in this catalog do not refer to a single module and they are not part of the offer. They only serve for comparison among different module types.

The inclination of the panels is set by hydrelio structure and it is 12º. Orientation is south. With the help of PVSIST.

Albedo value is set also as 0.2 for all installations

The distance between different rows of panels is set also by hydrelio structure and it is 1 meter.

4. Choice of inverter

This so big installation requires a really expensive and special inverter. To reduce the cost, the total number of panels will be divided in to 3, and every division will have its inverter. Those inverters will be compensating so there will not be any problem in electrical designing.

Siac Soleil 80:

Figure 28. Datasheet of Siac Soleil 80

Type	10	15	20	25	30	40	50	60	80	100	125	200	250	400	500
1. DC input side															
Recommended power of modules															
Minimum [KWp]	8	12	17,5	22	27	35	44	53	65	88	115	140	220	300	450
Rated [kWp]	10	15	20	25	30	40	50	60	80	100	125	200	250	400	500
Maximum [kWp]	11,6	17,2	22,8	28,4	34,1	45,2	56,5	67,6	90,0	111,9	138,9	247,4	309,2	494,7	618,4
mppt voltage [V]	330-700														
Max. Voltage at -10°C	780														
Min. Voltage (at +70°C)	330														
Modules max. I [A]	29	44	58	72	87	115	143	172	228	284	353	628	785	1256	1570
Nr. Of DC inputs	1					2		8				8			
No. Of MPPT	1													2	
2. AC output side															
Rated power [kW]	9	13,5	18	22,5	27	36	45	54	72	90	112,5	180	225	360	450
Maximum power [kW]	9	13,5	18	22,5	27	36	45	54	72	90	112,5	200	250	400	500
Connection	Trifase														
Rated voltage [V]	400														
Rated current [A]	13,0	19,5	26,0	32,5	39,0	52,0	65,0	77,9	103,9	129,9	162,4	259,8	324,8	519,6	649,5
Max current [A]	15,3	22,9	30,6	38,2	45,8	61,1	76,4	91,7	122,3	152,8	191,0	305,7	382,1	611,3	764,1
Min. Operating voltage [V]	Vn – 15%Vn														
Max. Operating voltage [V]	Vn + 15%Vn														
Operating frequency [Hz]	50														
Frequency tolerance [Hz]	+/- 0,3														
Max. Efficiency [%] (note 1)	93	93,8	94,2	94,4	94,5	95,1	95,1	95,3	95,5	96	96,7	96,5	96,5	96,5	96,5
Euro Efficiency [%] (note 1)	92	92,2	92,7	93	93,1	93,7	93,7	93,7	94,1	95,4	95,4	95,2	95,4	95,4	95,4
THD% I (@Pnom)	3														
Power Factor	1														
3. Additional values															
Ventilation system	Aria forzata														
Dissipated power at no-load [KW]	32	32	32	32	32	32	32	56	56	56	56	64	64	64	64
Control	Digitale														
Output wave form	Sinusoidale														
Operating temperature	0°C / +40°C a piena potenza														
Storage temperature	-20°C / +50°C														
Max. relative humidity	95% senza formazione di condensa														
4. Mechanical specifications															
Dba	60	60	60	60	60	60	60	64	64	64	64	68	68	68	68
Protection class	IP20														
Dimensions (mm)	550x850x1055					700x865x1415			1100x800x1950			1500x1000x2000		1500x1000x2000+ 1350x1000x2000	
Weight (kg)	230	280	300	330	390	560	580	600	700	900	980	1500	1600	2300	2700
Note 1: maximum efficiency is measured at a cell voltage of 400Vdc															

Every division will have 17 arrays and 15 modules per array for monocrystalline modules.

With that conditions and taking care of a sizing factor (108 % in this case) it is verified that the inverter responds for conditions under every temperature (-15ºC to 80ºC):

· Vm at 80ºC (372,8 V) is greater than Vmppt min (330 V).

· Vm at -15ºC (542,5 V) is lower than Vmppt max (700 V).

· Voc at -15ºC (647,5 V) is lower than maximum inverter voltage (780 V).

· Voc at -15ºC (647,5 V) is lower than maximum module voltage (780 V).

· Maximum generated current (151,9 V) is lower than maximum inverter current (288 A).

5. Connections and wires

Connections and wires are only considered for the budget with references from other budgets. They are not calculated

6. Budgets

In case of traditional first investment is smaller than using Hydrelio system:

· Traditional system

Figure 29. Budget for traditional systems

Product	Brand	Quantity	Price	Total
Mono Module	Shangai Ja solar jam 5 (L) 72 205	976	182,60 €	178.217,60 €
Inverter	Siac Soleil 80	3	6.510,00 €	19.530,00 €
Holder	Usual holder	976	92,00 €	89.792,00 €
Wire	General Cable	4000	0,37 €	1.480,00 €
Protections	Stimation	1	4.000,00 €	4.000,00 €
Equipments	Stimation	1	4.550,00 €	4.550,00 €
				297.569,60 €

· Hydrelio system

Figure 30. Budget for Hydrelio systems

Product	Brand	Quantity	Price	Total
Mono Module	Shangai Ja solar jam 5 (L) 72 205	976	182,60 €	178.217,60 €
Inverter	Siac Soleil 80	3	6.510,00 €	19.530,00 €
Water holder	Hydrelio (Ciel et terre)	976	178,00 €	173.728,00 €
Wire	General Cable	4000	0,54 €	2.160,00 €
Protections	Stimation	1	4.000,00 €	4.000,00 €
Equipments	Stimation	1	4.550,00 €	4.550,00 €
				382.185,60 €

RESULTS OF THE STUDY

ENERGY RESULTS

Presentation of results

· Case 1. Traditional system in Mikołajki.

Taking into account all losses, the efficiency of the system will be 77,71%, not including the efficiency of the modules.

Next chart shows the monthly energy production by the PV system:

Figure 31. Monthly energy produced by the system kWh

With the total production of 173132 kWh in one year, will be saved 38.09 tons of fuels. Much emissions will be avoided too, like 93380 kg of CO_2.

· Case 2. Hydrelio system in Mikołajki.

Hydrelio system brings to the installation a better performance, increasing to 79,54 %. Almost 2% more than usual systems.

It means that at least in first year, energy produced in this year will be 177213 kWh. It is 4081 kWh more than usual systems.

Monthly distribution of energy production is:

Figure 32. Monthly energy produced by the system kWh

With this production 39 tons of oil will be saved and 95581 kg of CO_2 emissions will be saved too.

· Case 3. Traditional system in Caspe.

On traditional system the production of energy in one year is 262581,94 kWh.

Because of the lack of elements that get colder the installation performance decrease to 71,30 %.

Monthly production of energy in this case is:

Figure 33. Monthly energy produced by the system kWh

When environment issues refers, 57,77 tons of oil equivalent are save, 141626 kg of CO_2. All of that in one year.

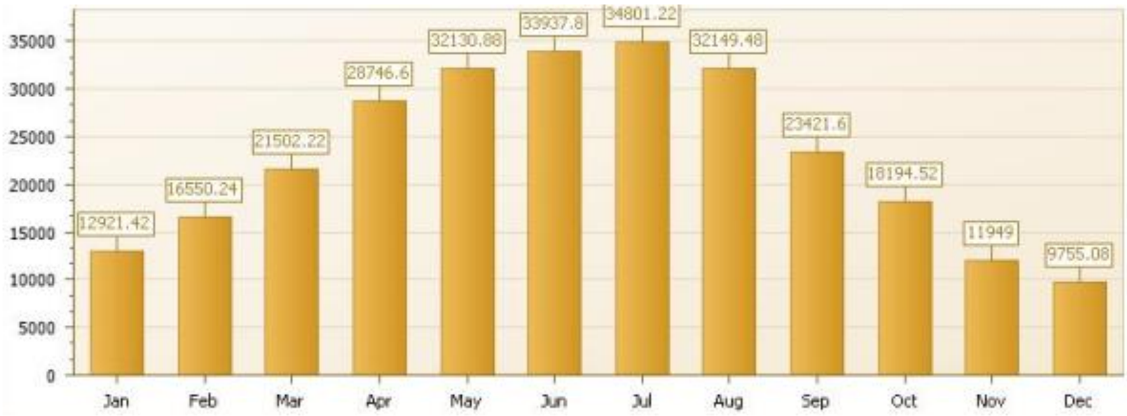
· Case 4. Hydrelio system in Caspe.

As in all cases, rated power is 200,080 kW thanks to 976 monocrystalline modules thath cover 1246,35 m2. In this case, annual energy production is 276060,06 kWh.

The performance in this case is 74,96 %. 4 points more than traditional systems due to cooling effect of water.

In this chart is showed next is the monthly distribution of energy produced:

Figure 31. Monthly energy produced by the system kWh



With this renawable source of energy we can say that 60,73 tons of oil would be save every year, 1365,13 in 25 years. Emissions to the atmosphere avoided are 148895,75 kg of CO_2 each year.

CONCLUSIONES

Conclusions

Figure 32. Energy results for Mikołajki and Caspe

Mikołajki				
	Traditional	Hydrelio	Difference	Diff (%)
Energy (kWh)	173132	177213	4081	2,36
Performance (%)	77,71	79,54	1,83	2,35
CO_2 avoided (kg)	93380	95581	2201	2,36

Caspe				
	Traditional	Hydrelio	Difference	Diff (%)
Energy (kWh)	262581	276060	13479	5,13
Performance (%)	71,3	74,96	3,66	5,13
CO_2 avoided (kg)	141626	148895	7269	5,13

These data show that this system is more effective in Caspe. That is because the difference between the water temperature and the temperature of the air is bigger in Caspe than in Mikołajki.

Other important aspect to keep in mind is that same installation in Caspe produce 51 % more energy. It was said in the introduction that conditions for this kind of energy in Poland are not the best.

ECONOMICAL RESULTS

Presentation of results

· Case 1. Traditional system in Mikołajki.

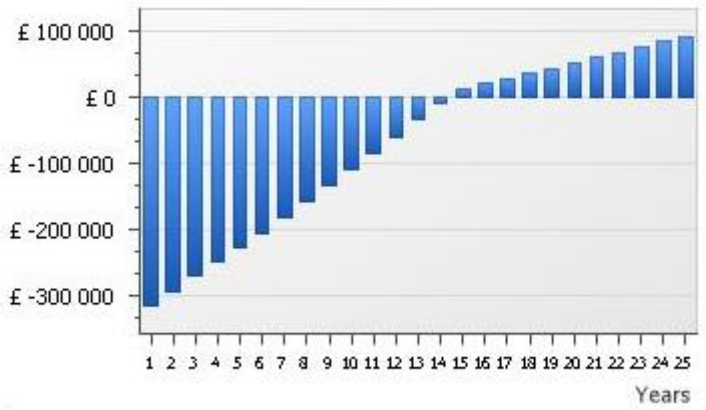
Total cost in this system is:

Figure 36. Costs estimation

Description	Amount
Construction costs – Materials and Labor (1 487.25 £/kW)	**£ 297 569.00**
Design fees (14.00 %)	**£ 41 659.66**
Other costs	**£ 0.00**
Total	**£ 339 228.66**

Expectancy to recover the investment is 15 years. After 25 years, appears a benefit of 91773,55 €.

Figure 37. Cumulative cash flow



· Case 2. Hydrelio system in Mikołajki.

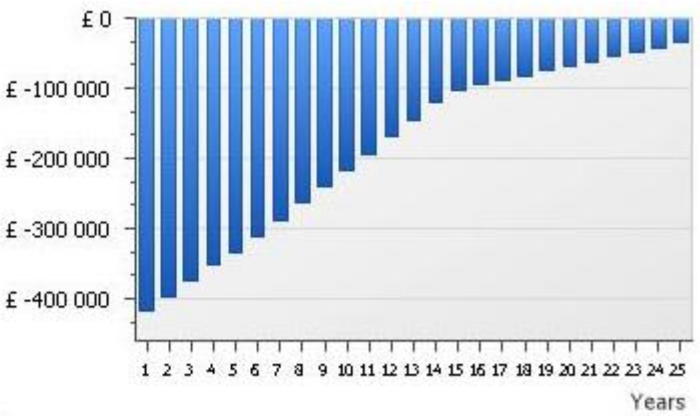
The final cost is:

Figure 39. Costs estimation

Description	Amount
Construction costs – Materials and Labor (1 910.16 £/kW)	**£ 382 185.56**
Design fees (15.00 %)	**£ 57 327.83**
Other costs	**£ 0.00**
Total	**£ 439 513.39**

To recover the initial inversion is needed more than 25 years, where the balance will be -35086,06 €.

Figure 40. Cumulative cash flow



· Case 3. Traditional system in Caspe.

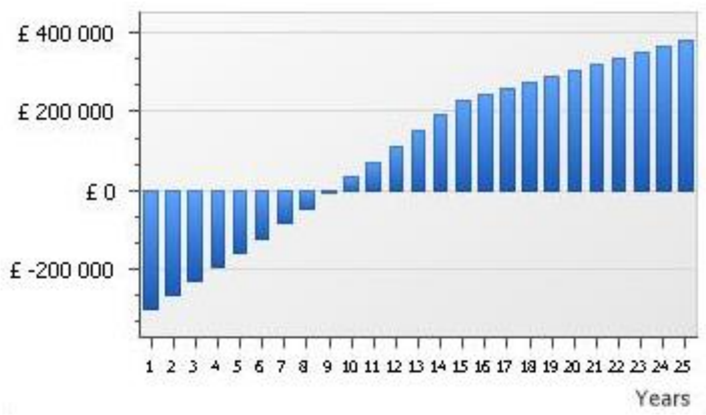
For a traditional system the cost is:

Figure 41. Costs estimation

Description	Amount
Construction costs – Materials and Labor (1 487.25 £/kW)	**£ 297 569.60**
Design fees (15.00 %)	**£ 44 635.44**
Other costs	**£ 0.00**
Total	**£ 342 205.04**

The time to get initial inversion back is 10 years and after 25 years the balance is 384003,40 €

Figure 42. Cumulative cash flow



· Case 4. Hydrelio system in Caspe.

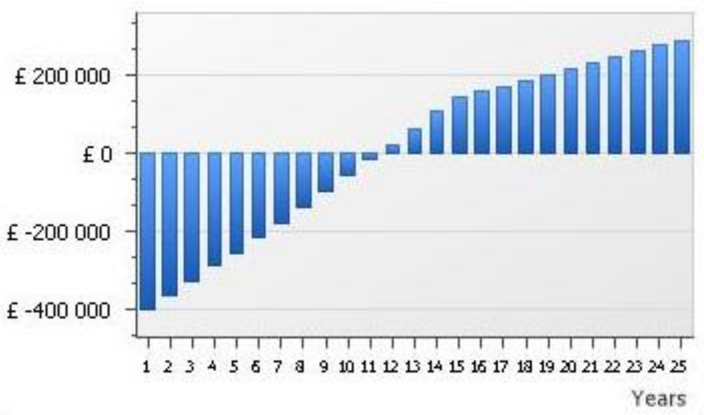
Investment on the installation is:

Figure 43. Costs estimation

Description	Amount
Construction costs – Materials and Labor (1 910.16 £/kW)	£ 382 185.60
Design fees (15.00 %)	£ 57 327.84
Other costs	£ 0.00
Total	**£ 439 513.44**

While the investment would be recover in 12 years, this system in this place, let earn a profits of 291210,47 € after 25 years.

Figure 41. Cumulative cash flow



CONCLUSIONES

Economical Conclusions

Figure 45. Economical results for Mikołajki and Caspe

Mikołajki				
	Traditional	Hydrelio	Difference	Diff (%)
Initial inversion	342205	439513,44	97308	28,44
Time of yield	15,00	*	*	*
Yield 25 years	91773,55	35086,06	-56687	-61,77

Caspe				
	Traditional	Hydrelio	Difference	Diff (%)
Initial inversion	342205	439513,44	97308	28,44
Time of yield	10	12	2,00	20,00
Yield 25 years	384003,4	291210,47	-92793	-24,16

As we can see, Hydrelio system is not very resendable economically, but as in technical analysis, there are a difference of its use between Mikołajki and Caspe.

The yield after 25 years, even being bad in some cases due to the higher price of introducing this technology, is rather better in Caspe than in Mikołajki.

Conclusions

To finish with a final conclusion about the application of this new technology it has been taking into account all studies and information presented before.

This technology is able to decrease the temperature of working in the cell, even 7º C. But that is only visible in the installation mounted in Caspe (Spain). Here, energy production increase in a good way, but the fact that Hydrelio installations are quite more expensive, from economical point of view, it is not rentable.

Same happens in Mikołajki (Poland). In this case, change of temperature is lower, so improvement of energy production is also lower. When economic analysis is made, we realized that is not rentable, due to the higher price of Hydrelio system installation.

Anyway, if the most important point is not the economical, or appear more wastes, this system reaches a better performance, so more energy production. It also has benefits for nature healthy on the lakes.

The most important advantage of it usage for me is the possibility of companies to install their installations in their own water surfaces, so they can save the spending of renting grounds to other owners. Keeping that in mind, maybe also economical point of view is also good in these cases

REFERENCES

RESEARCH ARTICLES REFERENCES

1. Jordi Prats. July 2015. Trabajos de seguimiento de la temperatura del agua en el cursol del río Ebro (España).
2. Fraunhofer Institute for Solar Energy Systems, ISE. 2016. Photovoltaic report. http://www.ise.fraunhofer.de/
3. Piotr Mrowiec, LL.M. 2015. Reference prices for the first round of bids for renewable energies in Poland.
4. Mike Shurtleff. 2014. The Continuing Exponential Growth of Global Solar PV Production & Installation

INTERNET REFERENCES

http://ainenergia.com/paneles-solares-flotantes/

http://celdassolares.net/

https://www.ujaen.es/investiga/solar/07cursosolar/home_main_frame/10_enlaces/10_links.htm

http://www.upv.es/materiales/Fcm/Fcm08/pfcm8_4_5.html

https://en.wikipedia.org/wiki/Growth_of_photovoltaics#Forecast

http://www.electricidad-gratuita.com/Unidad-de-control-en-sistemas-fotovoltaicos.html

http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/38/115/38115092.pdf

http://www.paiz.gov.pl/polish_law/renewable_energy#

http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_Poland_paper_2015_EN.pdf

http://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/766150805120639/766150805120639_4.pdf

http://www.keepontrack.eu/contents/publicationseutrackingroadmap/roadmap_finalversion3.pdf

http://www.sciencedirect.com/science/article/pii/S0038092X1000366X

https://ingelibreblog.wordpress.com/2014/11/09/influencia-de-la-irradiacion-y-temperatura-sobre-una-placa-fotovoltaica/

RetScreen Download address

http://www.nrcan.gc.ca/energy/software-tools/7465

Solarius PV software Download address

http://www.accasoftware.com/en/id55/solar-pv-system-design.html

PICTURE REFERENCES

Figure 1. Solar panels in a satellite in 1960.

http://www.nasa.gov/missions/science/f-satellites.html

Figure 2. Solar installation isolated to public grid.

https://www.google.pl/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=0ahUKEwiG1qy3qKbNAhUUTlIKHSV_DJQQjxwIAw&url=http%3A%2F%2Fsunpowerca.com%2Fportfolio_page%2Fground-mount-march-1-2014%2F&bvm=bv.124272578,d.aXo&psig=AFQjCNErAVfsN9D1RirVHd2zEjiFS6qL1g&ust=1465952399840244

Figure 3. 2014 countries distribution and prevision for 2019 countries distribution

http://fi-powerweb.com/Renewable-Energy.html

Figure 4. Prices for energy production in Poland

http://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/766150805120639/766150805120639_4.pdf

Figure 5. Distribution energies production in Poland

http://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/766150805120639/766150805120639_4.pdf

Figure 6. Insolation in Spain territory

https://en.wikipedia.org/wiki/Solar_power_in_Spain

Figure 7. Increasing of photovoltaics in Spain

http://www.energiasrenovablesinfo.com/solar/energia-solar-instalada-2/

Figure 8. Construction of PV modules

http://www.homepower.com/articles/solar-electricity/equipment-products/peek-inside-pv

Figure 9. Reflection in glass

https://www.ujaen.es/investiga/solar/07cursosolar/home_main_frame/10_enlaces/10_links.htm

Figure 10. Working of a LED

http://www.imagesco.com/articles/photovoltaic/photovoltaic-pg4.html

Figure 11. Equivalent circuit of cells

http://www.pveducation.org/pvcdrom

Figure 12. Pmpp decreasing due to temperature

https://firstgreenconsulting.wordpress.com/2013/05/04/effect-of-temperature-on-module-performance/

Figure 13. Hydrelio structure

http://www.ciel-et-terre.net/hydrelio-technology/

Figure 14. Heating transference model

https://neutrium.net/heat_transfer/thermal-resistance/

Figure 15, 16 and 17. Picture and situation of lake Śniardwy

https://maps.google.es/

Figure 18. Climate data Mikołajki

Nasa data. From RetScreen Software

Figure 19. Study of temperatures Mikołajki

Figure 20. Average dayly radiation per month (kWh/m2)

Solarius Software

Figure 21, 22 and 23. Picture and situation of lake Mequinenza in Caspe

https://maps.google.es/

Figure 24. Climate conditions Caspe

Nasa data. From RetScreen Software

Figure 25. Study of temperatures Caspe

Figure 26. Average daily radiation per month (kWh/m^2)

Solarius Software

Figure 27. Datasheet of Shangai Ja solar jam (L) 72 205

http://www.secondsol.de/index.php?page=ad_showup&ID_AD_UPLOAD=7154

Figure 28. Datasheet of Siac Soleil 80

http://www.servicepoolen.com/pdf/siac%20soleil%20inverter.pdf

Figure 29. Budget for traditional systems

Figure 30. Budget for Hydrelio systems

Figure 31. Monthly energy produced by the system kWh

Solarius Software

Figure 32. Monthly energy produced by the system kWh

Solarius Software

Figure 33. Monthly energy produced by the system kWh

Solarius Software

Figure 31. Monthly energy produced by the system kWh

Solarius Software

Figure 32. Energy results for Mikołajki and Caspe

Figure 36. Costs estimation

Figure 37. Cumulative cash flow

Solarius Software

Figure 39. Costs estimation

Figure 40. Cumulative cash flow

Solarius Software

Figure 41. Costs estimation

Figure 42. Cumulative cash flow

Solarius Software

Figure 43. Costs estimation

Figure 43. Cumulative cash flow

Solarius Software

Figure 45. Economical results for Mikołajki and Caspe