ELECTRICITY PRODUCTION COMPARISON OF PV SYSTEMS IN GREECE

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ABSTRACT: This paper presents the electricity production comparison of grid connected photovoltaic systems to the electrical power system of Greece. The geographical position of Greece provides very good conditions for the exploitation of solar radiation throughout the year. Throughout the country there is a considerable spread both of the available annual solar radiation (the annual global horizontal radiation ranges from 1.4 to 1.8 MWh/m2) and the ambient temperature. Nevertheless, the annual electricity production does not have such a high fluctuation due to the fact that PV systems in lower solar potential areas operate at lower temperatures compared to higher solar potential areas. Therefore, for fixed PV systems using crystalline silicon modules, the energy production range documented from various areas in Greece varies around 1560 kWh/kWp ± 140 kWh/kWp. The survey includes PV systems of all module technologies as well as fixed orientation, 1 and 2 axis tracking systems.

Keywords: System performance, Greece

1 INTRODUCTION

Before 2006 the installed PV systems in Greece were mainly privately owned autonomous systems in remote locations, while the grid connected market was relatively small (only few demonstration projects). Figure 1 presents the grid-connected PV capacity in Greece (annual and cumulative) from the year from 2006 and on. Looking at figure 1 it is clear that over than 95 percent of Greece's cumulative capacity was installed during the last 3 years due to laws 3468/2006 and 3851/2010 which introduced profitable feed-in tariffs and simplified the procedures for the introduction of PVs in Greece. It is worth mentioning that at the end of June 2012, when the most recent statistics were gathered, 391.2MW were added in the first half of 2012, value which is almost equal to the 425.9 MW of PV capacity connected in Greece during the year 2011 [1,2].

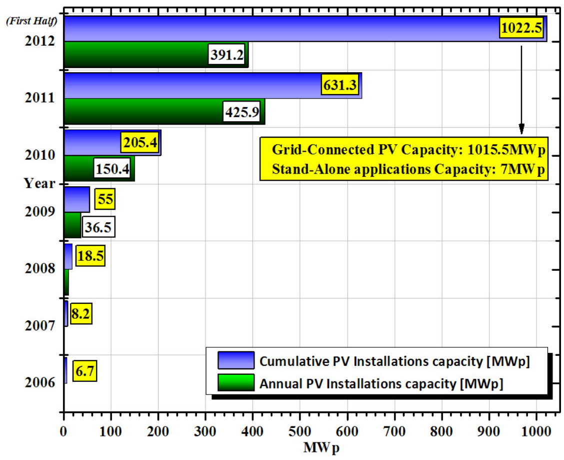

Figure 1: Greek PV market evolution, annual and cumulative PV Installations capacity from 2006 to 2012 first half.

Figure 2 presents the PV installations capacity per Region in Greece (for PV plants with installed power more that 20kWp) excluding the non-interconnected electrical islands to the mainland electrical grid. The top five regions in term of cumulative PV capacity are Peloponnese -9-, Central Greece -6-, Central Macedonia -2-, Western Greece -7- and Thessalia -5- , accounting for 75.5% of the national capacity. Moreover, figure 2 reports also the island of Crete -10- (without considering it at the PV installation capacity) as it is not interconnected with Greece's mainland electrical grid. The reason is that the Crete provides outstanding conditions for the exploitation of solar radiation throughout the year, a fact that it will be proved in the next paragraphs.

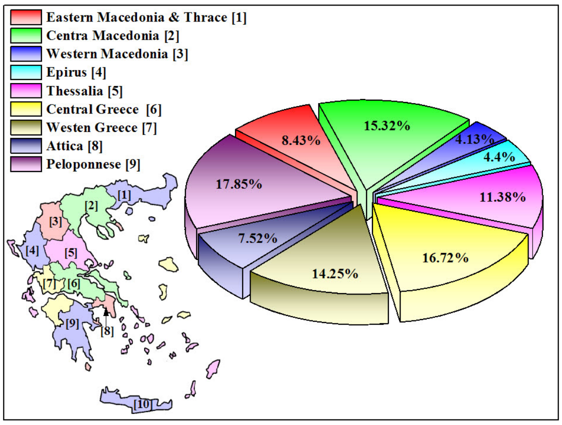

Figure 2: Grid-connected PV capacity by Region in Greece.

Considering that along the country there is a considerable spread both on the available annual solar radiation (the annual global horizontal radiation ranges from 1,4 to 1,8 MWh/m^2) and the ambient temperature (the annual 24 hour average temperature ranges from 10-19^{o}C), it is very interesting to compare the electricity production from various PV plants along Greece.

2 DATA COLLECTION

A survey was carried out in order to compare PV plants with similar technical characteristics in different locations, PV plants with different technical characteristics in locations with similar meteorological data as well as to compare the energy production between fixed orientation PV systems and 1 and 2 axis tracking PV systems.

The source of data was a publicly available monitoring website of an inverter manufacturer [3]. Among the several hundreds PV systems that are presented from Greece, only those that provided publically available and complete set of information were used. The data that were collected form the monitoring website were the location, the starting operation date, the array orientation and inclination, the PV module technology and the installed capacity. Finally, the monthly total energy productions in MWh for the calendar year 2010 and 2011 were collected. In all PV plants with fixed orientation, the PV modules are installed at a tilt angle close to latitude optimum, facing south.

In order to compare the electricity production (in terms of MWh/kWp) in various locations in Greece separate tables were created categorizing the PV plants regarding the PV module technologies (i.e. poly-Si, mono-Si, thin film) and tracking options (i.e. fixed orientation, 1 and 2 axis tracking).

Figure 3 illustrates the location and solar resource, where the PV systems reported are installed [4]. By studying figure 3, it is obvious that the location of each area plays an important role in the solar resource and performance of the PV plants, affecting the irradiation values. The aforementioned meteorological data are used in order to study their influence to the electricity production of PV systems in different region in Greece. Considering that it was impossible to collect the meteorological data from each PV system (since many publically available monitored PV systems do not have a meteorological station), the data was retrieved from the European Commission Joint Research Centre using the Photovoltaic Geographical Information System (PVGIS) [4].

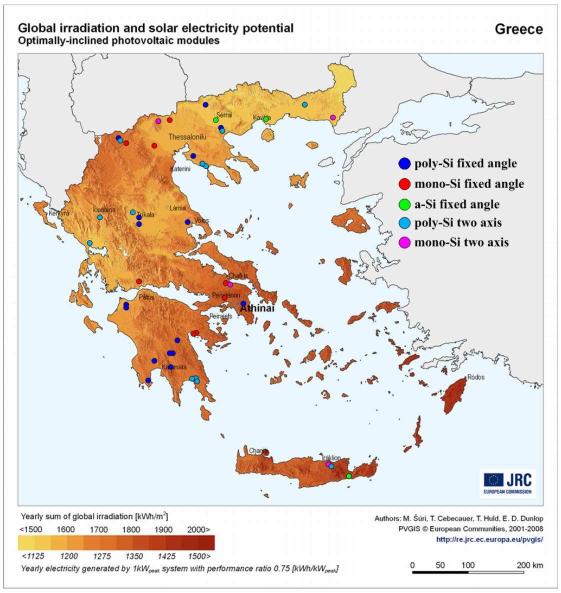

Figure 3 Global irradiation at optimum inclination [4]. Marked locations of investigated PV systems installation area.

Tables I, II and III present the region and the province where the investigated fixed orientation PV systems are installed, as well as the average daily irradiation value on optimally inclined plane (H_{opt}) [kWh/m^2/day]) and the average annual 24 hour ambient temperature (24h Temp) [^{o}C].

Table I: Hopt. and annual average 24 hour ambient temperature for poly -Si fixed orientation PV systems

PV Station Name	Region/ Province	Hopt kWh/m^2/day	24h AVG Temp. [^{o}C]
01-pSi	[2] Xalkidiki	5,32	15,4
02-pSi	[3] Florina	4,62	12,0
03-pSi	[2] Serres	5,13	14,6
04-pSi	[2] Serres	5,11	14,8
05-pSi	[5] Karditsa	5,18	15,8
06-pSi	[5] Karditsa	5,18	15,8
07-pSi	[5] Magnisia	5,23	15,8
08-pSi	[8] E. Attica	5,60	17,4
09-pSi	[9] Arkadia	5,24	13,3
10-pSi	[9] Arkadia	5,24	13,3
11-pSi	[9] Arkadia	5,25	14,4
12-pSi	[9] Mesinia	5,46	17,0
13-pSi	[9] Mesinia	5,52	17,1
14 pSi	[9] Achaia	5,74	16,8
15-pSi	[9] Achaia	5,77	16,6
16-pSi	[9] Laconia	5,41	16,9
17-pSi	[6] Viotia	5,36	17,1
AVG		**5,32**	**15,5**
MIN		**4,62**	**12,0**
MAX		**5,77**	**17,4**

Table II: Hopt. and annual average 24 hour ambient temperature for mono-Si fixed orientation PV systems

PV Station Name	Region/ Province	Hopt kWh/m^2/day	24h AVG Temp. [^{o}C]
01-mSi	[6] Viotia	5,36	17,1
02-mSi	[7] Et/Akarn	5,38	16,8
03-mSi	[8] W. Attica	5,54	17,3
04-mSi	[9] Argolis	5,47	17,2
05-mSi	[9] Argolis	5,47	17,2
06-mSi	[2] kilkis	5,15	14,8
07-mSi	[2] Imathia	4,70	13,6
08-mSi	[6] Viotia	5,36	17,1
AVG		**5,30**	**16,4**
MIN		**4,70**	**13,6**
MAX		**5,54**	**17,3**

Table III: Hopt. and annual average 24 hour ambient temperature for a-Si fixed orientation PV systems

PV Station Name	Region/ Province	Hopt kWh/m^2/day	24h AVG Temp. [^{o}C]
01-aSi	[1] Kabala	5,27	14,6
02-aSi	[2] Serres	5,12	14,8
03-Cdte	[10] Lasithi	6,16	17,3

AVG	**5,36**	**15,6**

Tables IV and V present the same information for the investigated two axis tracking (T_2) PV systems. Moreover, all tables give information about the average (AVG) values of H_{opt} and 24h Temp for all locations.

Table IV: Hopt. and annual average 24 hour ambient temperature for poly-Si two axis tracking PV systems

PV Station Name	Region/ Province	Hopt kWh/m^2/day	24h AVG Temp. [^{o}C]
01-pSi- T_2	[2] Serres	6,76	14,8
02-pSi- T_2	[1] Rodopi	6,60	14,3
03-pSi- T_2	[5] Trikala	6,73	15,7
04-pSi- T_2	[3] Florina	6,07	12,0
05-pSi- T_2	[4] Ioannina	6,14	12,7
06-pSi- T_2	[2] Xalkidiki	7,05	15,5
07-pSi- T_2	[2] Xalkidiki	7,05	15,5
08-pSi- T_2	[4] Preveza	7,21	16,7
09-pSi- T_2	[9] Laconia	7,89	16,6
10-pSi- T_2	[9] Laconia	7,89	16,6
11-pSi- T_2	[9] Laconia	7,89	16,6
12-pSi- T_2	[10] Iraklio	7,97	17,3
AVG		**7,10**	**15,4**
MIN		**7,97**	**17,3**
MAX		**6,07**	**12,0**

Table V: Hopt. and annual average 24 hour ambient temperature for mono-Si two axis PV systems

PV Station Name	Region/ Province	Hopt kWh/m^2/day	24h AVG Temp. [^{o}C]
01-mSi-T_2	[1] Feres	6,75	14,5
02-mSi-T_2	[2] Edessa	6,55	13,8
03-mSi-T_2	[6] Viotia	7,11	17,1
04-mSi-T_2	[10] Iraklio	7,97	17,3
AVG		**7,10**	**15,7**
MIN		**6,55**	**13,8**
MAX		**7,97**	**17,3**

Finally, tables I to III classify the fixed angle PV systems according to the PV module technology. Thus Tables I, II and III catalog fixed orientation poly-crystalline (pSi), mono-crystalline (mSi) and thin film (aSi and CdTe) PV systems respectively, while Tables IV and V classify two axis tracking PV systems. Table IV contains poly-crystalline (pS-T_2) and Table V mono-crystalline (mS-T_2) PV systems.

3 DATA PROCESSING

Figures 4 and 5 illustrate the meteorological data of the fixed orientation PV systems and two axis tracking PV systems respectively. In Tables VI and VII the annual electricity production for fixed orientation PV systems and two axis PV systems are presented for the various locations and PV module technologies. In figure 6, the annual energy production range and comparison between the investigated fixed orientation and 2-axis tracking crystalline Si PV systems are presented.

It is worth mentioning that the range for fixed orientation c-Si PV systems, independently of the location varies between 1,702 and 1,430 MWh/kWp, while the range of the investigated c-Si 2-axis PV systems varied between 1,927 and 2,127 MWh/kWp.

Therefore, it is noted that on average the 2-axis tracking c-Si PV systems in Greece produce about 28% per year than the fixed orientation ones.

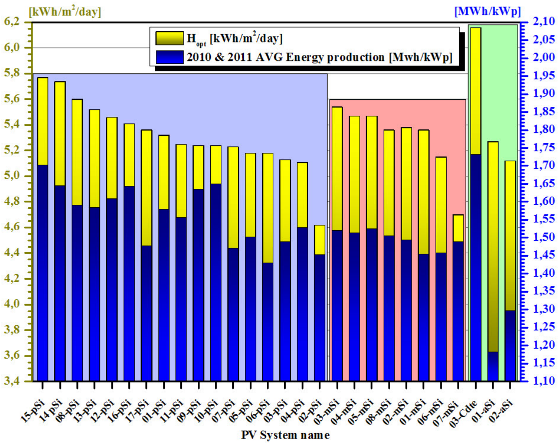

Figure 4: Fixed orientation PV systems meteorological data

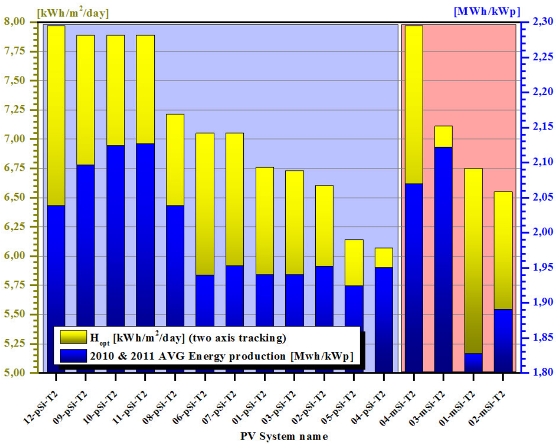

Figure 5: Two axis tracking PV systems meteorological data

Table VI: Annual electricity production for fixed orientation PV systems

PV Station Name	Electricity Production (MWh/kWp)	PV Station Name	Electricity Production (MWh/kWp)
01-pSi	1,580	01-mSi	1,455
02-pSi	1,453	02-mSi	1,495
03-pSi	1,490	03-mSi	1,521
04-pSi	1,529	04-mSi	1,514
05-pSi	1,503	05-mSi	1,526
06-pSi	1,430	06-mSi	1,458
07-pSi	1,471	07-mSi	1,490
08-pSi	1,591	08-mSi	1,506
09-pSi	1,636	**AVG**	**1,496**
10-pSi	1,650	**MIN**	**1,455**
11-pSi	1,557	**MAX**	**1,526**

12-pSi	1,610		
13-pSi	1,585	PV Station Name	Electricity Production (MWh/kWp))
14 pSi	1,646		
15-pSi	1,702	01-aSi	1,732
16-pSi	1,644	02-aSi	1,182
17-pSi	1,478	03-Cdte	1,298
AVG	**1,562**	**AVG**	**1,404**
MIN	**1,430**		
MAX	**1,702**		

Table VII: Annual electricity production for two axis PV systems

PV Station Name	Electricity Production (MWh/kWp)	PV Station Name	Electricity Production (MWh/kWp)
01-pSi- T_2	1,940	01-mSi-T_2	1,827
02-pSi- T_2	1,952	02-mSi-T_2	1,891
03-pSi- T_2	1,940	03-mSi-T_2	2,122
04-pSi- T_2	1,951	04-mSi-T_2	2,070
05-pSi- T_2	1,924	**AVG**	1,977
06-pSi- T_2	1,940	**MIN**	1,827
07-pSi- T_2	1,953	**MAX**	2,122
08-pSi- T_2	2,039		
09-pSi- T_2	2,096		
10-pSi- T_2	2,124		
11-pSi- T_2	2,127		
12-pSi- T_2	2,038		
AVG	2,002		
MIN	1,924		
MAX	2,127		

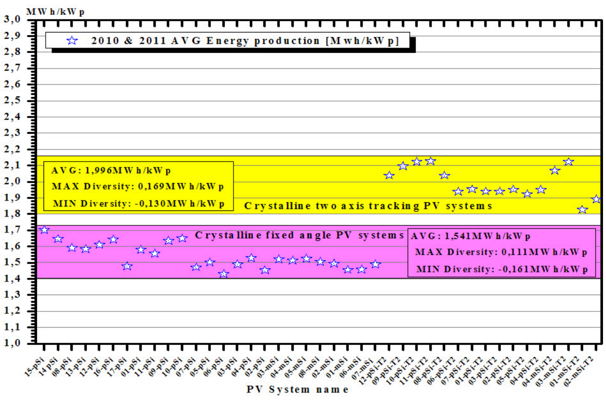

Figure 6: Annual energy production range and comparison between fixed orientation and 2-axis tracking crystalline Si, PV systems.

4 CONCLUSION

The annual energy yield for PV systems all over Greece, for several PV module technologies for fixed oriented, 1 and 2 axis tracking were presented. Although throughout Greece there is a considerable spread both of the available annual solar radiation (the annual global horizontal radiation ranges from 1.4 to 1.8 MWh/m2) and the ambient temperature, nevertheless, the annual PV system electricity production does not have such a high variance due to the fact that PV systems in lower solar potential areas operate at lower temperatures compared to higher solar potential areas. The sample of PV systems examined was that available publically for Greece at a major inverter manufacturer monitoring website and the data collected were complete for the years considered (2010 and 2011).

It is concluded that due to the small number of thin film PV systems it is not possible to make conclusive remarks on their performance but it is considered that for the c-Si PV systems the results are representative of the performance for most of the operating systems. The energy production range documented from various areas in Greece for c-Si PV systems varies in the range of 1560 kWh/kWp ± 140 kWh/kWp.

5 REFERENCES

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