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Comparative Analysis of Solar Irradiation and Photovoltaic Energy Output in Athens, Tokyo, UAE, and Beijing Using PVGIS

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Abstract

Implementation of solar system requires optimum solar irradiation and energy output. This paper conducts a comparative analysis of solar radiation and PV energy output for four different climatic locations Athens ,Tokyo, UAE, Beijing using PVGIS software . the UAE gets the highest solar radiation and energy output ,while Tokyo have lowest values due to more variation in seasons . Athens and Beijing gives average performance due to climatic conditions .

Keywords : Athens ,Tokyo, UAE, Beijing ,Solar irradiation , PV system ,PVGIS.

Introduction

Solar energy is one of the important renewable energy for sustainable energy generation in the world. For developing the solar energy systems we need optimum solar irradiation and solar energy output. The best tools and methods are necessary to calculate the availability of resources in different climatic zones throughout the world.PVGIS software is one of the them developed by European Commission's Joint Research Centre which gives solar radiation data and estimated data for PV system setup. In this research paper the monthly solar irradiation and monthly energy output (KWh) of PV system for four different cities Athens, Tokyo, United Arab Emirates (UAE), and Beijing has been calculated. all cities are present in different climatic zones .the outcome result is useful for stalk holders who planning to invest in PV solar system projects in world.

Literature Review

For good planning of photovoltaic (PV) systems, it's important to know how much solar energy is available in different parts of the world. The European Commission's Joint Research Centre made the Photovoltaic Geographical Information System (PVGIS), which is a very popular tool that gives free access to solar

irradiation and PV performance data from all over the world[1]. PVGIS combines several satellite-based and reanalysis databases, like SARAH2, NSRDB, and ERA5, to give hourly, monthly, and yearly data on global horizontal irradiation (GHI), direct normal irradiation (DNI), and diffuse horizontal irradiation (DHI) [2].

Comparative analyses have evaluated the accuracy of PVGIS in relation to alternative simulation tools. One study found that PVGIS and other tools like it tend to overestimate solar irradiation but underestimate the amount of electricity that real-world PV systems actually produce [3]. A different study that looked at PVGIS and PV system in Turkey found that PVGIS predicted about 30% less annual energy output than PV system for the same fixed-axis system [4]. These results indicate that although PVGIS is dependable for estimating irradiation, its energy output forecasts may necessitate calibration or supplementary data for improved precision. Research conducted in specific regions underscores PVGIS's versatility across various climates. A study conducted in Athens documented the monthly energy production from fixed-angle PV systems utilizing PVGIS, illustrating its applicability in Mediterranean environments [5]. Additionally, a comparative evaluation of solar irradiance models in urban settings revealed that PVGIS's plane-of-array irradiance estimates for Athens exhibited a commendable root mean square error (RMSE), underscoring its significance in urban solar analysis [6].

There isn't much literature that looks at Tokyo, the UAE, or Beijing directly using PVGIS, but there are some studies that are related that give some background. In the UAE, modeling and simulation of PV cell performance under different temperature and irradiance conditions have been done, but not with PVGIS. This shows that environmental factors have a big effect on solar potential [7]. Dust buildup, high temperatures, and urban microclimates are problems that affect PV output in cities in East Asia and the Middle East. These problems should be kept in mind when looking at PVGIS results.Cross-regional comparisons highlight the significance of localized analysis. Latitude, atmospheric conditions, and urbanization are some of the things that have a big effect on solar irradiation and PV performance [8]. Tools like PVGIS, which give standardized and location-specific data, are very useful for comparing different regions.

Methodology:

PVGIS is a robust and widely accepted tool for assessing solar irradiation and estimating PV energy output across varied geographic contexts. However, its energy output estimates may require validation or adjustment based on local conditions. This study builds on existing literature by applying PVGIS to four distinct cities—Athens, Tokyo, a representative location in the UAE, and Beijing—to compare solar potential across Mediterranean, East Asian, Middle Eastern, and North Chinese climates.

Solar irradiation data of Athens(Greece) at fixed yearly tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Fixed tilt angle	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.	30.6 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	9	15	9	0	0	0	0	0
6	0	0	2	30	65	71	55	35	15	1	0	
7	0	13	95	171	208	217	196	178	155	113	25	
8	112	164	263	342	374	386	364	356	335	282	214	116
9	252	322	429	506	526	541	522	533	512	446	377	247
10	382	459	569	636	650	658	641	670	652	572	499	360
11	470	557	664	715	718	729	706	751	729	643	571	427
12	512	604	695	739	742	742	730	774	743	638	583	444
13	493	586	667	709	692	706	685	718	677	575	545	420
14	415	514	577	622	608	624	621	635	583	476	441	345
15	300	393	444	485	482	502	513	510	448	341	292	232
16	159	243	287	324	336	361	365	351	284	185	127	98
17	3	70	127	161	181	204	208	185	118	32	0	0
18	0	0	6	26	48	68	70	44	6	0	0	0
19	0	0	0	0	4	15	13	2	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	3098	3925	4825	5466	5643	5839	5698	5742	5257	4304	3674	2689

Solar irradiation data of Athens(Greece) at optimum tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Optimum Tilt angle	40.6 Deg.	35.6 Deg.	30.6 Deg.	25.6 Deg.	20.6 Deg.	15.6 Deg.	20.6 Deg.	25.6 Deg.	30.6 Deg.	35.6 Deg.	40.6 Deg.	45.6 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	9	16	9	0	0	0	0	0
6	0	0	2	34	81	105	74	41	15	1	0	0
7	0	14	95	175	227	254	219	184	155	117	28	0
8	126	171	263	344	391	419	386	362	335	290	235	138

9	274	332	429	507	540	568	540	537	512	457	407	280
10	410	471	569	635	660	679	655	672	652	585	534	400
11	501	571	664	713	725	745	717	752	729	656	608	470
12	545	618	695	737	748	756	740	774	743	651	620	487
13	526	600	667	707	700	722	696	718	677	587	581	463
14	445	528	577	621	617	643	634	636	583	487	473	384
15	326	405	444	485	495	527	529	514	448	350	318	264
16	178	251	287	326	353	392	384	356	284	190	143	121
17	3	73	127	165	200	239	229	191	118	34	0	0
18	0	0	6	29	64	101	90	49	6	0	0	0
19	0	0	0	0	5	16	14	2	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	3334	4034	4825	5478	5815	6182	5916	5788	5257	4405	3947	3007

Solar irradiation data of Tokyo (Japan) at fixed yearly tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Fixed tilt angle	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.	29.6 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	2	0	0	0	0	0	0
5	0	0	0	14	36	37	30	18	5	0	0	0
6	0	4	28	76	145	120	111	82	45	24	8	0
7	27	104	226	274	295	234	231	261	228	195	154	30
8	332	338	402	436	444	347	358	414	373	338	326	326
9	502	499	544	569	564	454	466	553	495	456	462	474
10	630	613	647	653	649	526	547	644	571	532	548	578
11	680	663	684	692	677	562	586	681	595	541	573	617
12	655	634	657	666	656	541	575	675	580	506	536	581
13	572	562	584	594	588	492	510	602	502	425	443	492
14	437	447	478	476	473	402	417	484	392	316	316	357
15	282	316	338	340	336	301	312	352	269	198	173	166
16	15	88	168	180	187	179	187	193	125	28	4	1
17	0	0	14	34	59	71	74	55	12	0	0	0
18	0	0	0	0	6	15	14	3	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0

23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	4132	4268	4770	5004	5115	4283	4418	5017	4192	3559	3543	3622

Solar irradiation data of Tokyo (japan) at optimum tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Optimum Tilt angle	39.6 Deg.	34.6 Deg.	29.6 Deg.	24.6 Deg.	19.6 Deg.	14.6 Deg.	19.6 Deg.	24.6 Deg.	29.6 Deg.	34.6 Deg.	39.6 Deg.	44.6 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	3	0	0	0	0	0	0
5	0	0	0	15	38	46	32	18	5	0	0	0
6	0	3	28	79	160	139	123	86	45	24	7	0
7	26	107	226	277	311	255	245	267	228	199	166	27
8	364	349	402	438	458	368	372	419	373	344	348	373
9	543	512	544	570	577	473	479	557	495	463	490	530
10	676	628	647	653	660	543	559	648	571	541	579	639
11	726	679	684	692	687	579	598	684	595	550	604	679
12	700	649	657	667	667	558	587	678	580	514	566	641
13	614	575	584	595	600	510	522	606	502	432	470	547
14	473	459	478	478	487	422	431	489	392	322	339	405
15	313	326	338	344	352	324	327	358	269	203	190	194
16	14	91	168	184	203	203	202	199	125	28	4	1
17	0	0	14	36	72	90	87	59	12	0	0	0
18	0	0	0	0	6	16	15	3	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	4449	4378	4770	5028	5278	4529	4579	5071	4192	3620	3763	4036

Solar irradiation data of Dubai (UAE) at fixed yearly tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Fixed tilt angle	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.	23.8 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	7	40	67	65	51	39	33	21	0	0
7	82	107	158	226	255	229	202	202	210	222	187	123
8	287	332	387	456	477	433	401	418	444	471	428	344
9	508	571	623	675	683	629	597	628	669	701	648	562
10	700	771	810	839	838	781	753	793	841	872	812	743
11	825	909	933	939	929	875	853	897	942	963	900	848
12	872	957	973	964	949	899	884	926	963	972	905	870
13	835	919	930	912	894	852	841	877	900	896	829	815
14	724	806	809	788	770	737	729	754	759	743	683	686
15	548	622	622	605	589	567	563	575	559	529	478	492
16	322	389	394	380	375	367	366	363	326	280	236	256
17	82	146	156	157	162	169	173	158	110	55	3	4
18	0	0	2	15	26	39	39	23	2	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	5785	6529	6804	6996	7014	6642	6452	6653	6758	6725	6109	5743

Solar irradiation data of Dubai (UAE) at optimum tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Optimum Tilt angle	33.8 Deg.	28.8 Deg.	23.8 Deg.	18.8 Deg.	13.8 Deg.	8.8 Deg.	13.8 Deg.	18.8 Deg.	23.8 Deg.	28.8 Deg.	33.8 Deg.	38.8 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	7	45	86	93	64	43	33	22	0	0
7	98	113	158	233	284	274	227	211	210	229	209	156

8	315	343	387	463	509	485	432	428	444	481	462	395
9	545	586	623	682	714	681	629	638	669	714	689	625
10	744	788	810	845	867	831	785	803	841	886	856	815
11	872	928	933	944	958	922	885	906	942	978	946	923
12	921	976	973	969	977	946	915	935	963	986	950	946
13	884	938	930	917	923	900	872	886	900	910	874	890
14	771	824	809	794	800	787	761	764	759	756	725	759
15	591	638	622	611	620	620	595	585	559	541	516	558
16	356	402	394	388	406	419	397	373	326	288	263	306
17	98	154	156	164	188	213	198	166	110	57	3	4
18	0	0	2	15	24	51	46	22	2	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	6195	6690	6804	7070	7356	7222	6806	6760	6758	6848	6493	6377

Solar irradiation data of Beijing (China) at fixed yearly tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Fixed tilt angle	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.	31.5 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	3	21	28	16	0	0	0	0	0
6	0	0	10	62	100	98	72	55	39	8	0	0
7	0	57	165	225	260	235	188	181	188	153	69	2
8	225	284	385	422	444	397	332	343	377	356	277	224
9	456	512	607	615	615	549	463	501	553	542	471	447
10	643	698	783	765	741	663	568	619	691	681	615	617
11	760	816	888	852	808	729	635	690	764	751	690	714
12	796	856	909	863	807	737	651	695	769	749	691	730
13	747	813	854	801	748	684	616	650	706	672	614	663
14	616	681	720	667	627	564	520	561	575	533	468	515
15	421	497	541	499	476	436	413	431	421	358	277	309
16	188	272	322	306	306	291	279	280	245	165	83	80
17	0	46	114	129	148	154	149	133	81	12	0	0
18	0	0	1	19	40	51	47	26	2	0	0	0
19	0	0	0	0	0	9	7	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0

22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	4852	5532	6299	6228	6141	5625	4956	5165	5411	4980	4255	4301

Solar irradiation data of Beijing (China) at optimum tilt angle												
Hour	Jan W/m^2	Feb W/m^2	Mar W/m^2	Apr W/m^2	May W/m^2	Jun W/m^2	Jul W/m^2	Aug W/m^2	Sep W/m^2	Oct W/m^2	Nov W/m^2	Dec. W/m^2
Optimum Tilt angle	41.5 Deg.	36.5 Deg.	31.5 Deg.	26.5 Deg.	21.5 Deg.	16.5 Deg.	21.5 Deg.	26.5 Deg.	31.5 Deg.	36.5 Deg.	41.5 Deg.	46.5 Deg.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	3	23	30	17	3	0	0	0	0
6	0	0	10	66	116	123	85	51	39	8	0	0
7	0	60	165	229	278	264	204	176	188	158	77	2
8	255	296	385	424	461	425	347	337	377	366	303	266
9	502	531	607	615	627	572	477	495	553	556	509	513
10	699	721	783	762	750	680	579	614	691	698	660	698
11	822	841	888	848	815	744	644	685	764	769	738	802
12	860	882	909	798	813	751	660	691	769	767	739	818
13	809	838	854	666	755	700	626	645	706	688	659	748
14	672	703	720	500	637	583	532	556	575	546	505	588
15	466	515	541	309	489	459	427	425	421	368	303	361
16	215	284	322	133	322	318	294	273	245	170	94	100
17	0	48	114	19	164	179	164	127	81	13	0	0
18	0	0	1	0	45	67	58	25	2	0	0	0
19	0	0	0	0	0	10	7	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
Total	5300	5719	6299	5372	6295	5905	5121	5103	5411	5107	4587	4896

Result: Athens (Greece)

Global irradiation % increase due to optimum tilt of Athens (Greece)				
Month	Global Irradiation On fixed tilt 30.6 degree	Optimum tilt angle in degree	Global Irradiation For optimum tilt	% increase
Jan	3098	40.6	3334	7.62%
Feb	3925	35.6	4034	2.78%
Mar	4825	30.6	4825	0.00%
Apr	5466	25.6	5478	0.22%
May	5643	20.6	5815	3.05%
Jun	5839	15.6	6182	5.87%
Jul	5698	20.6	5916	3.83%
Aug	5742	25.6	5788	0.80%
Sep	5257	30.6	5257	0.00%
Oct	4304	35.6	4405	2.35%
Nov	3674	40.6	3947	7.43%
Dec	2689	45.6	3007	11.83%
Yearly	56160		57988	3.25%

Result: Tokyo (Japan)

Global irradiation % increase due to optimum tilt of Tokyo (Japan)				
Month	Global Irradiation On fixed tilt 29.6 degree	Optimum tilt angle in degree	Global Irradiation For optimum tilt	% increase
Jan	4132	39.6	4449	7.67%
Feb	4268	34.6	4378	2.58%
Mar	4770	29.6	4770	0.00%
Apr	5004	24.6	5028	0.48%
May	5115	19.6	5278	3.19%
Jun	4283	14.6	4529	5.74%
Jul	4418	19.6	4579	3.64%
Aug	5017	24.6	5071	1.08%
Sep	4192	29.6	4192	0.00%
Oct	3559	34.6	3620	1.71%
Nov	3543	39.6	3763	6.21%
Dec	3622	44.6	4036	11.43%
Yearly	51923		53693	3.41%

Result: Dubai (UAE)

Global irradiation % increase due to optimum tilt of Dubai (UAE)				
Month	Global Irradiation On fixed tilt 23.8 degree	Optimum tilt angle in degree	Global Irradiation For optimum tilt	% increase
Jan	5785	33.8	6195	7.09 %
Feb	6529	28.8	6690	2.47 %
Mar	6804	23.8	6804	0 %
Apr	6996	18.8	7070	1.06 %
May	7014	13.8	7356	4.88 %
Jun	6642	8.8	7222	8.73 %
Jul	6452	13.8	6806	5.49 %
Aug	6653	18.8	6760	1.61 %
Sep	6758	23.8	6758	0 %
Oct	6725	28.8	6848	1.83 %
Nov	6109	33.8	6493	6.29 %
Dec	5743	38.8	6377	11.04 %
Yearly	78210		81379	4.05 %

Result: Beijing (China)

Global irradiation % increase due to optimum tilt of Beijing (China)				
Month	Global Irradiation On fixed tilt 31.5 degree	Optimum tilt angle in degree	Global Irradiation For optimum tilt	% increase
Jan	4852	41.5	5300	9.23331 %
Feb	5532	36.5	5719	3.38033 %
Mar	6299	31.5	6299	0 %
Apr	6226	26.5	5372	-13.717 %
May	6141	21.5	6295	2.50773 %
Jun	5625	16.5	5905	4.97778 %
Jul	4956	21.5	5121	3.3293 %
Aug	5165	26.5	5103	-1.2004 %
Sep	5411	31.5	5411	0 %
Oct	4980	36.5	5107	2.5502 %
Nov	4255	41.5	4587	7.80259 %
Dec	4301	46.5	4896	13.834 %
Yearly	63745		65115	2.14919 %

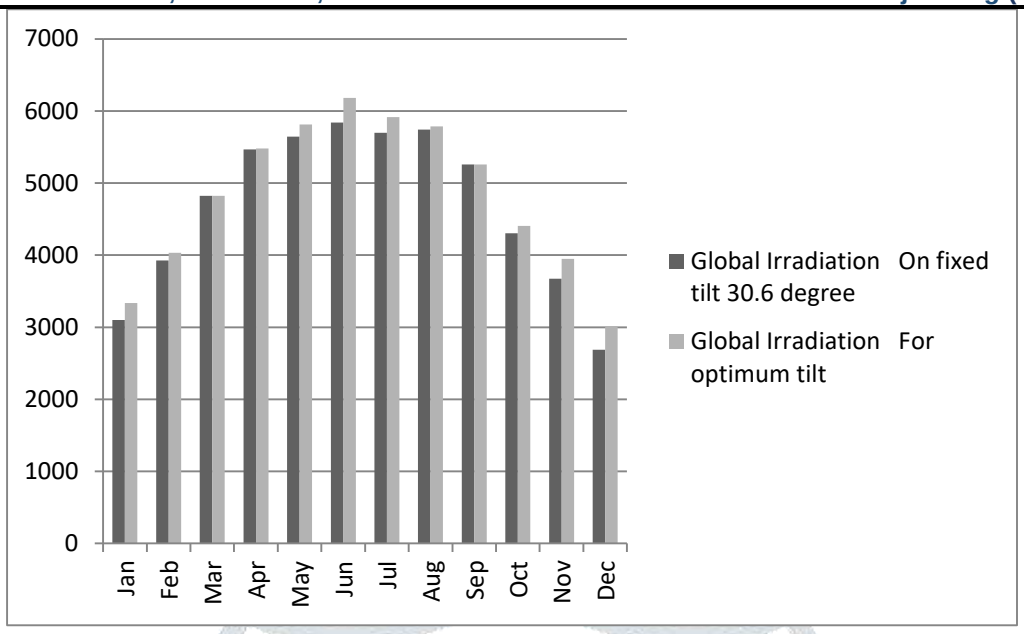


Fig. global irradiation difference at Athens(Greece)

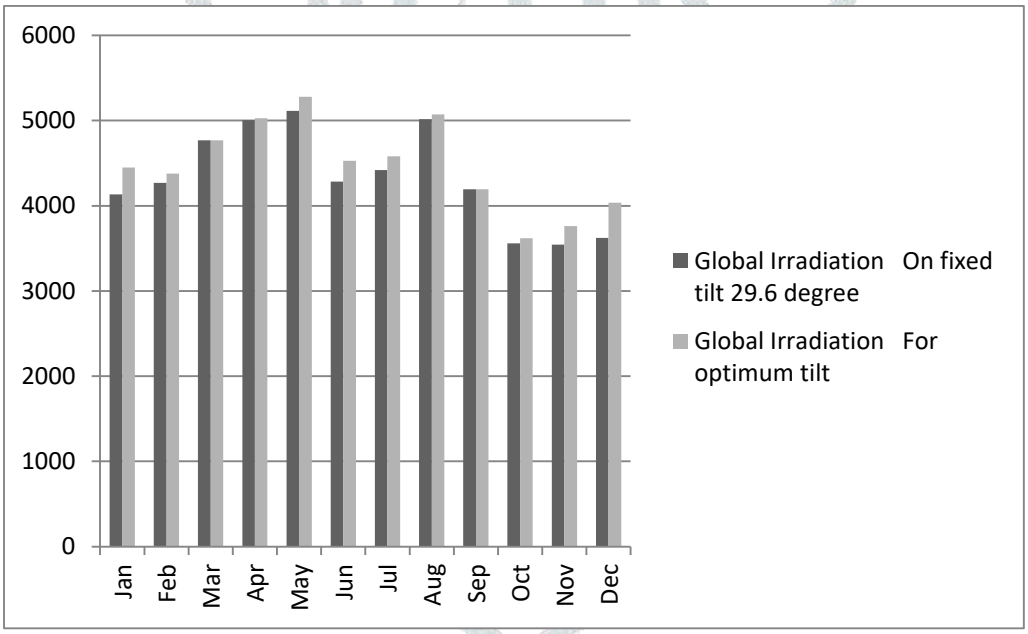


Fig. global irradiation difference at Tokyo(Japan)

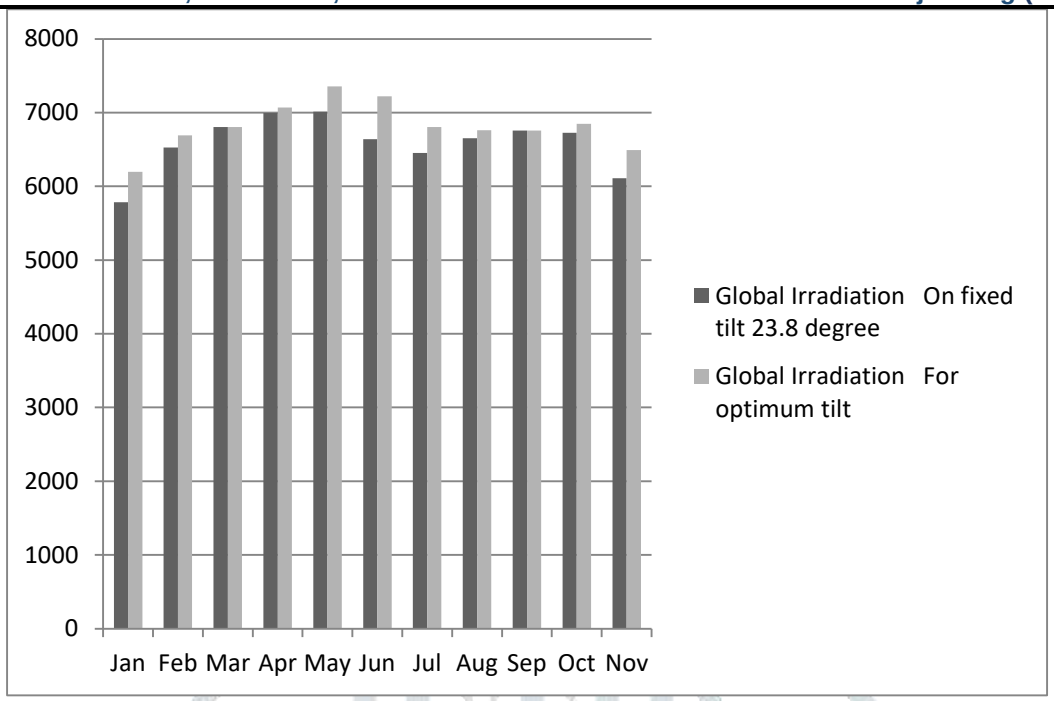


Fig. global irradiation difference at UAE (Dubai)

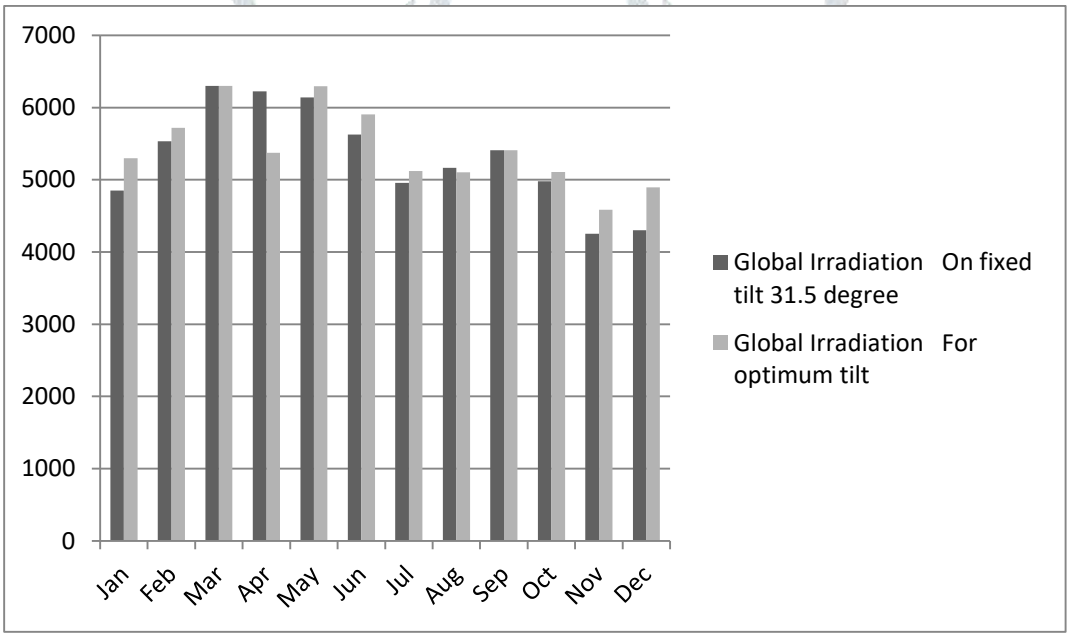


Fig. global irradiation difference at Beijing (China)

Performance of grid connected PV 10 kw with system loss 14 %

Monthly solar irradiation (KWh /m^2)Athens (Greece) with PVGIS ERA 5 at seasonal tilt			
Month	30.6 (Degree)	15.6 (Degree)	45.6 (Degree)
Jan.	96.1	80.8	106.0
Feb.	109.9	96.9	117.0
Mar.	149.5	139.4	151.7

Apr.	164.0	162.3	157.4
May.	174.9	181.4	160.0
Jun.	175.2	185.4	157.1
Jul.	176.7	185.2	160.0
Aug.	177.9	179.3	167.6
Sep.	157.7	150.0	156.8
Oct.	133.4	119.3	140.2
Nov.	110.2	92.9	121.3
Dec.	83.4	68.9	93.2
Yearly	1708.90	1641.80	1688.30

Monthly Energy output (KWh) of PV system Athens (Greece) with PVGIS ERA 5 software at seasonal tilt

Month	30.6 (Degree)	15.6 (Degree)	45.6 (Degree)
Jan.	821.6	684.0	908.0
Feb.	927.0	814.9	986.3
Mar.	1219.7	1138.2	1236.8
Apr.	1293.7	1282.4	1241.8
May.	1341.7	1394.0	1229.3
Jun.	1312.1	1393.1	1174.9
Jul.	1307.9	1374.5	1183.4
Aug.	1322.8	1335.2	1246.0
Sep.	1190.5	1134.5	1183.5
Oct.	1049.4	936.3	1102.7
Nov.	904.0	756.1	995.3
Dec.	699.7	569.9	784.2
Yearly	13390.10	12813.10	13272.2

Monthly solar irradiation (KWh /m^2)Athens (Greece) with PVGIS ERA 5 at optimum seasonal tilt

Month	30.6 (Degree)	15.6 (Degree)	45.6 (Degree)
Jan.	-	-	106.0
Feb.	-	-	117.0
Mar.	-	-	151.7
Apr.	164.0		-
May.	-	181.4	-
Jun.	-	185.4	-
Jul.	-	185.2	-
Aug.	-	179.3	-
Sep.	157.7	-	-
Oct.	-	-	140.2
Nov.	-	-	121.3
Dec.	-	-	93.2
Yearly	1782.40		

Monthly Energy output (KWh) of PV system Athens (Greece) with PVGIS PVGIS ERA 5 software at optimum seasonal tilt

Month	30.6 (Degree)	15.6 (Degree)	45.6 (Degree)
Jan.	-	-	908.0
Feb.	-	-	986.3
Mar.	-	-	1236.8
Apr.	1293.7	-	-
May.	-	1394.0	-
Jun.	-	1393.1	-
Jul.	-	1374.5	-
Aug.	-	1335.2	-
Sep.	1190.5	-	-
Oct.	-	-	1102.7
Nov.	-	-	995.3
Dec.	-	-	784.2
Yearly	13994.3		

Monthly solar irradiation (KWh /m^2) Tokyo (Japan) with PVGIS ERA 5 software at seasonal tilt

Month	29.6 (Degree)	14.6 (Degree)	44.6 (Degree)
Jan.	128.1	107.3	141.4
Feb.	119.5	105.8	126.5
Mar.	147.8	139.1	148.6
Apr.	150.2	149.6	143.1
May.	158.6	164.7	144.7
Jun.	128.5	135.8	115.7
Jul.	136.5	143.4	124.1
Aug.	155.6	157.8	145.4
Sep.	125.8	121.7	123.4
Oct.	110.3	101.0	113.9
Nov.	106.2	91.4	115.2
Dec.	112.3	93.1	125.1
Yearly	1579.4	1510.7	1567.1

Monthly Energy output (KWh) of PV system Tokyo (Japan) with PVGIS ERA 5 software at seasonal tilt

Month	29.6 (Degree)	14.6 (Degree)	44.6 (Degree)
Jan.	1081.7	901.0	1193.6
Feb.	1000.9	884.1	1059.9
Mar.	1211.4	1140.4	1217.7
Apr.	1201.0	1198.5	1142.8
May.	1235.5	1287.5	1124.1
Jun.	978.9	1038.0	876.7
Jul.	1028.5	1081.7	927.8
Aug.	1168.7	1188.4	1090.2
Sep.	961.9	931.1	943.5
Oct.	867.9	791.4	897.0
Nov.	860.3	734.1	934.5
Dec.	937.9	770.4	1044.8
Yearly	12534.6	11946.6	12452.6

Monthly solar irradiation (KWh /m^2) Tokyo (Japan) with PVGIS ERA 5 software at optimum seasonal tilt			
Month	29.6 (Degree)	14.6 (Degree)	39.6 (Degree)
Jan.	-	-	141.4
Feb.	-	-	126.5
Mar.	-	-	148.6
Apr.	150.2	-	-
May.	-	164.7	-
Jun.	-	135.8	-
Jul.	-	143.4	-
Aug.	-	157.8	-
Sep.	125.8	-	-
Oct.	-	-	113.9
Nov.	-	-	115.2
Dec.	-	-	125.1
Yearly			1648.40

Monthly Energy output (KWh) of PV system Tokyo (Japan) with PVGIS ERA 5 software at seasonal tilt			
Month	29.6 (Degree)	14.6 (Degree)	39.6 (Degree)
Jan.	-	-	1193.6
Feb.	-	-	1059.9
Mar.	-	-	1217.7
Apr.	1201.0	-	-
May.	-	1287.5	-
Jun.	-	1038.0	-
Jul.	-	1081.7	-
Aug.	-	1188.4	-
Sep.	961.9	-	-
Oct.	-	-	897.0
Nov.	-	-	934.5
Dec.	-	-	1044.8
Yearly	13106.00		

Monthly solar irradiation (KWh /m^2) Dubai (UAE) 12with PVGIS ERA 5 software at seasonal tilt			
Month	23.8 (Degree)	8.8 (Degree)	38.8 (Degree)
Jan.	183.3	155.5	200.7
Feb.	186.3	166.1	196.1
Mar.	215.0	204.3	213.9
Apr.	213.4	216.2	199.3
May.	220.3	234.5	194.7
Jun.	201.8	219.3	174.7
Jul.	202.5	217.3	178.1
Aug.	208.4	214.9	191.3
Sep.	205.7	200.2	200.2
Oct.	211.9	193.0	218.9
Nov.	187.3	161.0	202.9
Dec.	181.9	151.7	201.7
Yearly	2417.8	2334	2372.5

Monthly Energy output (KWh) of PV system Dubai (UAE) with PVGIS ERA 5 software at seasonal tilt			
Month	23.8 (Degree)	8.8 (Degree)	38.8 (Degree)
Jan.	1444.2	1222.1	1581.5
Feb.	1433.8	1278.4	1509.0
Mar.	1612.0	1535.1	1604.2
Apr.	1560.7	1584.5	1456.9
May.	1551.6	1657.3	1366.7
Jun.	1409.4	1536.4	1212.3
Jul.	1420.9	1528.0	1242.7
Aug.	1479.8	1529.0	1355.1
Sep.	1474.0	1438.4	1433.0
Oct.	1550.6	1415.5	1600.6
Nov.	1426.7	1225.0	1543.8
Dec.	1420.6	1180.2	1573.4
Yearly	17784.3	17129.9	17479.2

Monthly solar irradiation (KWh /m^2) Dubai (UAE) with PVGIS ERA 5 software at optimum seasonal tilt			
Month	23.8 (Degree)	8.8 (Degree)	38.8 (Degree)
Jan.	-	-	200.7
Feb.	-	-	196.1
Mar.	-	-	213.9
Apr.	213.4	-	-
May.	-	234.5	-
Jun.	-	219.3	-
Jul.	-	217.3	-
Aug.	-	214.9	-
Sep.	205.7	-	-
Oct.	-	-	218.9
Nov.	-	-	202.9
Dec.	-	-	201.7
Yearly	2539.3		

Monthly Energy output (KWh) of PV system Dubai (UAE) with PVGIS ERA 5 software at seasonal tilt			
Month	23.8 (Degree)	8.8 (Degree)	38.8 (Degree)
Jan.	-	-	1581.5
Feb.	-	-	1509.0
Mar.	-	-	1604.2
Apr.	1560.7	-	-
May.	-	1657.3	-
Jun.	-	1536.4	-
Jul.	-	1528.0	-
Aug.	-	1529.0	-
Sep.	1474.0	-	-
Oct.	-	-	1600.6
Nov.	-	-	1543.8
Dec.	-	-	1573.4
Yearly	18697.9		

Monthly solar irradiation (KWh /m^2) Beijing (China) with PVGIS ERA 5 software at seasonal tilt			
Month	31.5 (Degree)	16.5 (Degree)	46.5 (Degree)
Jan.	150.4	122.2	169.6
Feb.	154.9	133.4	167.4
Mar.	195.3	179.9	199.7
Apr.	186.9	183.8	180.1
May.	190.4	196.0	175.2
Jun.	168.8	177.2	152.5
Jul.	153.6	160.0	140.0
Aug.	160.3	161.1	151.4
Sep.	162.3	154.1	161.7
Oct.	154.4	137.1	162.9
Nov.	127.7	106.7	141.3
Dec.	133.3	107.0	151.8
Yearly	1938.3	1818.5	1953.6

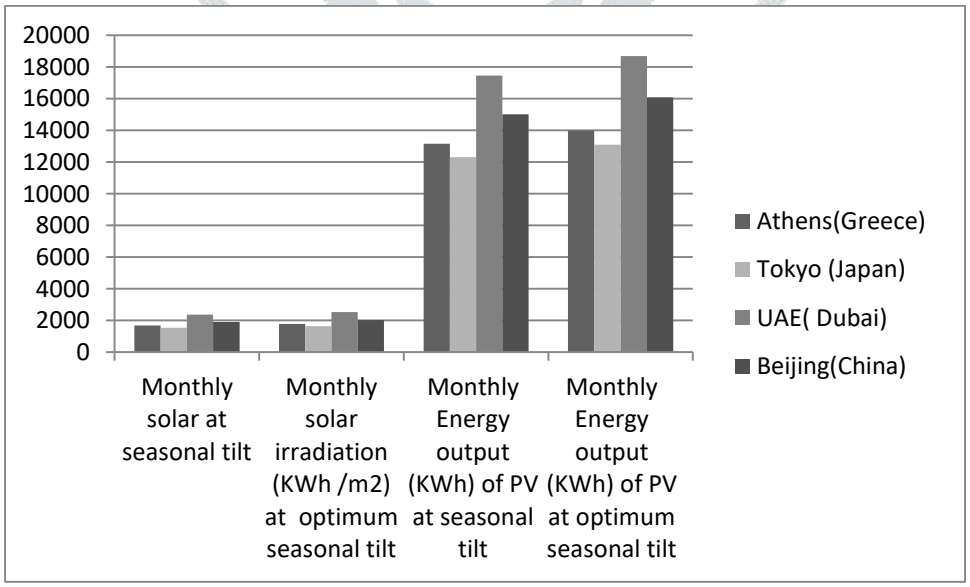
Monthly Energy output (KWh) of PV system Beijing (China) with PVGIS ERA 5 software at seasonal tilt			
Month	31.5 (Degree)	16.5 (Degree)	46.5 (Degree)
Jan.	1298.3	1049.2	1460.3
Feb.	1306.5	1125.0	1409.3
Mar.	1586.8	1464.9	1621.3
Apr.	1463.2	1442.9	1408.7
May.	1436.4	1482.8	1319.4
Jun.	1243.0	1308.2	1120.0
Jul.	1123.2	1173.3	1022.0
Aug.	1183.7	1192.2	1117.4
Sep.	1224.2	1164.9	1218.7
Oct.	1216.9	1080.7	1282.8
Nov.	1057.7	878.7	1169.8
Dec.	1151.0	914.4	1309.0
Yearly	15290.9	14277.2	15458.7

Monthly solar irradiation (KWh /m^2) Beijing (China) with PVGIS ERA 5 software at optimum seasonal tilt			
Month	31.5 (Degree)	16.5 (Degree)	46.5 (Degree)
Jan.	-	-	169.6
Feb.	-	-	167.4
Mar.	-	-	199.7
Apr.	186.9	-	-
May.	-	196.0	-
Jun.	-	177.2	-
Jul.	-	160.0	-
Aug.	-	161.1	-
Sep.	162.3	-	-
Oct.	-	-	162.9
Nov.	-	-	141.3
Dec.	-	-	151.8
Yearly	2036.2		

Monthly Energy output (KWh) of PV system Beijing (China) with PVGIS ERA 5 software at seasonal tilt			
Month	31.5 (Degree)	16.5 (Degree)	46.5 (Degree)
Jan.	-	-	1460.3
Feb.	-	-	1409.3
Mar.	-	-	1621.3
Apr.	1463.2	-	-
May.	-	1482.8	-
Jun.	-	1308.2	-
Jul.	-	1173.3	-
Aug.	-	1192.2	-
Sep.	1224.2	-	-
Oct.	-	-	1282.8
Nov.	-	-	1169.8
Dec.	-	-	1309.0
Yearly	16096.4		

Result:

City (country)	Monthly solar at seasonal tilt	Monthly solar irradiation (KWh /m^2) at optimum seasonal tilt	Monthly Energy output (KWh) of PV at seasonal tilt	Monthly Energy output (KWh) of PV at optimum seasonal tilt	% increase in energy output
Athens(Greece)	1679.66	1782.40	13158.46	13994.3	6.35
Tokyo (Japan)	1552.4	1648.40	12311.2	13106.00	6.45
UAE(Dubai)	2374.76	2539.3	17464.4	18697.9	7.06
Beijing(China)	1903.4	2036.2	15008.9	16096.4	7.24



Conclusion:

Monthly solar irradiation and energy output data for various cities shows Dubai leads in both metrics with 2374.76 KWh/m2 at seasonal tilt and an energy output of 17464.4 KWh, yielding a 7.06% increase compared to the optimum seasonal tilt output. Beijing follows closely, reporting 1903.4 KWh/m2 and 15008.9 KWh with a 7.24% increase. Athens and Tokyo have lower figures, with increases of 6.35% and 6.45%, respectively.

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