SOLAR RESOURCE AND PHOTOVOLTAIC ELECTRICITY POTENTIAL IN EU-MENA REGION

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ABSTRACT:
The study offers updated and more accurate information about long-term annual solar resource in the most countries of Europe, Middle East and North Africa (EU-MENA) and evaluates PV power production potential. The underlying solar radiation and PV electricity output values are calculated form the solar and meteo database SolarGIS, which covers a history of recent 18 years. Direct Normal Irradiation data are presented to indicate potential of Concentrated PV in the region. PV electricity output is calculated for c-Si module options, using the recent numerical models. The analysis is focused on the urbanized and industrial areas and their hinterland. Attention is focused also to the quantification of uncertainty. Based on the GIS analysis, the solar resource potential of each country is rated.
Keywords: solar resource data, photovoltaic potential, EU-MENA region, GIS analysis, SolarGIS

1 INTRODUCTION

Various stakeholders, looking at PV development pathways in the post feed-in-tariff era, raise the requests for updated information of solar resource and PV potential in various regions of the world. This study builds on the previous works by [1,2,3,4] and provides an updated overview on the solar resource and photovoltaic power generation potential. Recent development of SolarGIS database, with high-resolution solar radiation and meteorological data with global coverage provides basis for more accurate regional analysis.

In this study we focus on EU-MENA region including most countries of Europe, Middle East and North Africa.

2 METHODS

The assessment focused on evaluation of Global Horizontal Irradiation (GHI) as the main data input in the calculation of photovoltaic (PV) power production and Direct Normal Irradiation (DNI) as the most important parameter for Concentrated PV (CPV). The analysis was performed only in the urbanized areas, industrial zones and their hinterland at the level of each country in Europe, Middle East and North Africa (EU-MENA region). The method is based on GIS analysis.

Firstly, a mask for analysis was created. Mask includes cities over 5000 inhabitants, derived from the world gazetteer [5]. Based on the population size, the hinterland for each city was defined in a range of 5 to 100 km in diameter. On top of this, the missing cities and large industrial areas were identified from the orthophoto maps and other sources. Based on this mask and country borders, zonal statistics was calculated on gridded GHI and DNI data. Based on the results from this analysis ranks of the countries were created.

Finally, we show the adaptation of this approach on PV power production, calculated by SolarGIS data and software.

3 DATA SOURCES

Annual averages of GHI and DNI are derived from satellite-based solar radiation database (SolarGIS). These values represent a period 1994-2010 (18 years) in 15-minute time-step with a spatial resolution 9 arc-sec (approx. 250 m) [6, 7]. Annual electricity output for flat-plate PV is calculated using SolarGIS models and time series of solar radiation and temperature to consider large geographical differences in the region [8]. The models integrate published and validated PV performance algorithms to simulate shading, module surface reflectivity, non-linearities in the conversion efficiency of PV modules due to irradiance/temperature outdoor conditions and in the other components [9, 10, 11, 12].

In SolarGIS, the typical uncertainty of GHI yearly summaries is lower than ±3.5% (probability of occurrence 80% for 89 validation sites). In mountains, complex coastal zones, high latitudes, snow regions, and regions with high aerosol concentrations (air pollution) the uncertainty can be as high as ±7.0%. In very extreme cases higher deviation has been observed.

Uncertainty for DNI yearly summaries in SolarGIS is typically lower than ±7% (probability of occurrence 80% for 48 validation sites). In more complex geography, uncertainty of yearly DNI can be as high as ±12% (deviations up to 15% from local measurements have been sporadically observed), especially in regions where aerosol content is high and dynamically changing, in humid regions, high latitudes, high mountains, snow regions, complex deserts with occasional occurrence of snow and water, urbanized and industrialized areas. Higher uncertainty is also considered in regions with limited availability of high-quality ground measurements [13, 14].

For PV output calculations, air-temperature data were available for a period 1994-2010 in hourly time-step with spatial resolution 30 arcsec (app. 1 km). Dataset is calculated from NOAA NCEP data sources and disaggregated by SolarGIS method to reflect variability induced by terrain.

4 RESULTS

The key factor for successful analysis of this type is quality of input data. The recent analysis [15] of the six solar resource databases shows the qualitative differences. SolarGIS GHI and DNI values are considered as the reliable source of data and thanks to improved performance of satellite-to-irradiance model and implementation of new generation atmospheric parameters [6, 7] the database provides the best results in global scale.

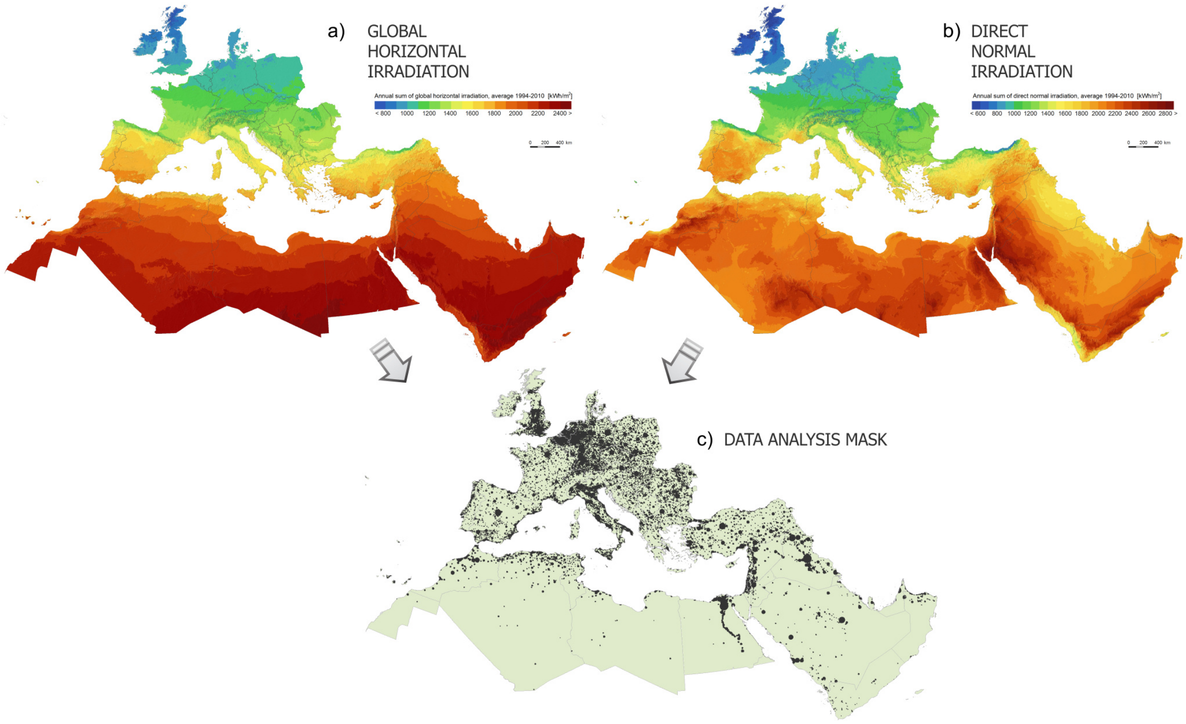

Figure 1: Extraction of relevant input data for statistical analysis, a) Map of annual sum of global horizontal irradiation, yearly average 1994-2010; b) Map of annual sum of direct normal irradiation, yearly average 1994-2010; c) data analysis mask include urban and large industrial areas and their hinterland.

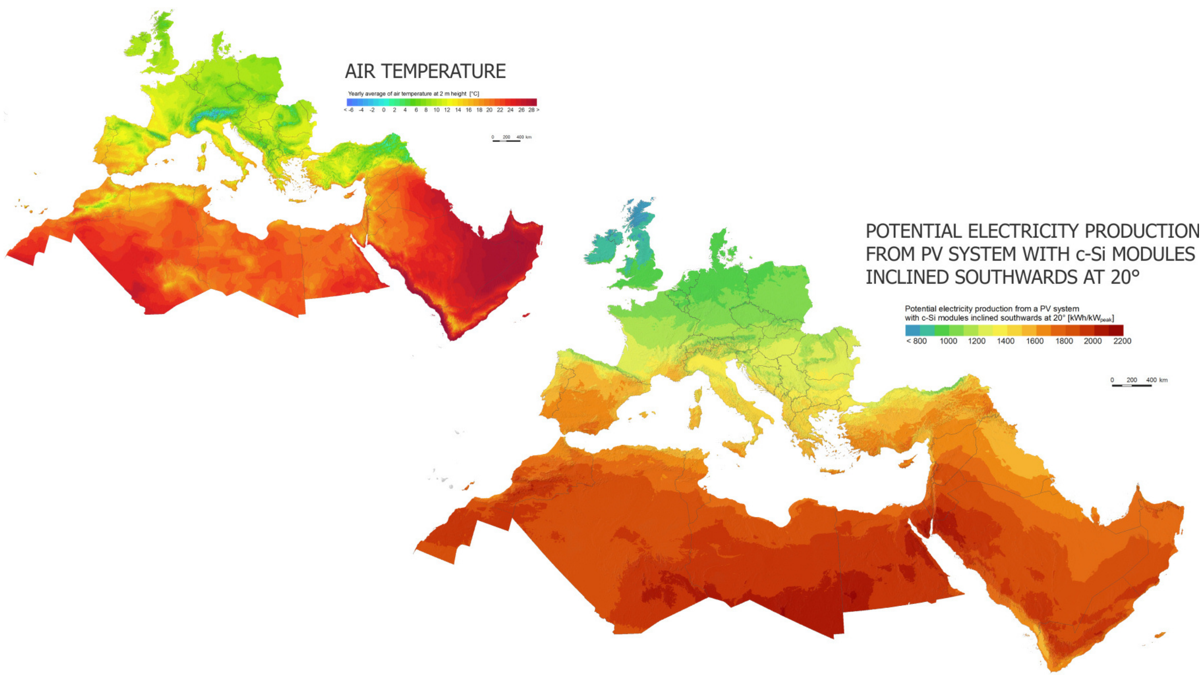

Figure 2: EU-MENA region – air temperature map (long-term annual average) and potential electricity production map for a defined PV system.

The average annual distribution of GHI and DNI in EU-MENA countries is presented on Figures 1.a and 1.b. In the analysis we included only populated areas, presented (Figure 1.c). This approach selects more representative data for evaluation of solar potential of each country. Implementation of this method does not influence the results for countries with regularly distributed population (most of European countries). But it has great relevance to countries situated in North Africa and Arabian Peninsula.

After applying zonal statistics, where zones were defined by country borders, MIN, MAX, MEAN, and RANGE values (Tables 1 and 2) were considered and ranks of the countries were constructed (Figures 3 and 4).

Table I: Annual **GHI** potential per country [kWh/m^2]

COUNTRY	MIN	MAX	RAN-GE	MEAN
Yemen	1965	2456	491	2286
Saudi Arabia	1746	2425	679	2216
Libya	1818	2356	538	2002
Egypt	1954	2348	394	2126
Algeria	1462	2340	878	1829
Jordan	1934	2281	347	2083
Oman	1972	2272	300	2202
Israel	1879	2253	374	2008
UAE	2029	2222	193	2164
Morocco	1468	2163	695	1897
Qatar	2055	2160	105	2134
Syria	1703	2124	421	1945
Bahrain	2018	2115	97	2086
Spain	1040	2105	1065	1659
Lebanon	1571	2079	508	1903
Iraq	1600	2055	455	1898
Tunisia	1584	2017	433	1830
Cyprus	1749	1968	219	1902
Greece	1345	1914	569	1637
Turkey	1026	1907	881	1661
Portugal	1304	1872	568	1632
Italy	1035	1831	796	1494
Albania	1264	1653	389	1556
France	993	1627	634	1259
Montenegro	1282	1566	284	1468
Serbia	1205	1559	354	1472
Croatia	1211	1546	335	1334
Bulgaria	1192	1545	353	1406
Bosnia and Herz.	1163	1539	376	1315
Serbia	914	1465	551	1358
Switzerland	956	1437	481	1233
Romania	1024	1416	392	1301
Slovenia	1063	1397	334	1270
Moldova	1202	1351	149	1276
Hungary	1144	1316	172	1266
Austria	868	1313	445	1194
Slovakia	1030	1256	226	1182
Germany	934	1224	290	1066
Czech Republic	970	1190	220	1109
United Kingdom	764	1136	372	972
Poland	828	1133	305	1071
Netherlands	973	1108	135	1025
Belgium	992	1105	113	1052
Denmark	932	1083	151	987
Ireland	844	1014	170	926
Average	-	-	-	1571

Table II: Annual **DNI** potential per country [kWh/m^2]

COUNTRY	MIN	MAX	RAN-GE	MEAN
Jordan	1895	2712	817	2300
Saudi Arabia	1245	2661	1416	2065
Syria	1609	2609	1000	2109
Israel	1781	2600	819	2098
Egypt	1804	2560	756	2080
Yemen	1314	2533	1219	2047
Lebanon	1323	2483	1160	2014
Algeria	1139	2473	1334	1818
Morocco	1186	2458	1272	1903
Libya	1604	2358	754	1986
Oman	1706	2268	562	2006
Spain	707	2242	1535	1762
Turkey	631	2153	1522	1632
Tunisia	1345	2123	778	1814
Portugal	864	2105	1241	1743
Cyprus	1654	2100	446	1968
Iraq	1304	2096	792	1686
UAE	1652	2056	404	1907
Greece	1070	2006	936	1576
France	712	1904	1192	1184
Italy	746	1891	1145	1474
Qatar	1625	1888	263	1836
Bahrain	1554	1804	250	1747
Albania	1055	1677	622	1524
Switzerland	663	1660	997	1160
Croatia	966	1628	662	1224
Bosnia and Herz.	867	1609	742	1174
Montenegro	1085	1585	500	1444
Serbia	911	1575	664	1369
Bulgaria	859	1512	653	1273
Serbia	513	1380	867	1209
Slovenia	770	1362	592	1142
Austria	525	1345	820	1077
Romania	714	1293	579	1168
Moldova	1043	1254	211	1171
Germany	616	1221	605	921
Hungary	907	1196	289	1138
Slovakia	768	1156	388	1051
United Kingdom	438	1094	656	777
Denmark	803	1068	265	915
Czech Republic	681	1065	384	965
Poland	498	1052	554	951
Netherlands	771	983	212	851
Belgium	686	964	278	879
Ireland	524	805	281	685
Average	-	-	-	1485

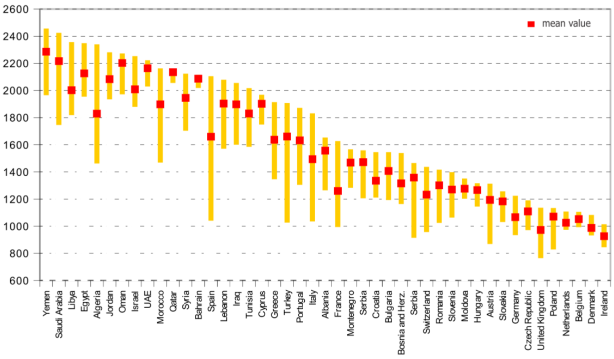

Figure 3: Ranking of EU-MENA countries based on the annual average **GHI** solar resource mapped in urbanised and industrial areas

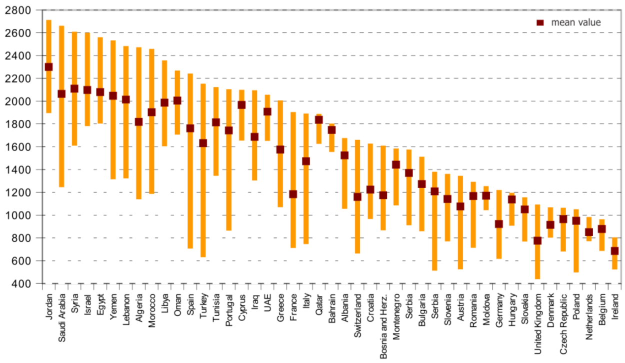

Figure 4: Ranking of EU-MENA countries based on the annual average **DNI** solar resource mapped in urbanised and industrial areas

4 DISCUSSION

The electricity production and consumption is expected to take place in and around populated and industrial places, thus the analysis excluded uninhabited areas. Compared to the previous studies, the ranking of countries is based on MAX values. This approach provides more realistic overview of the solar resource potential in countries, MEAN and MIN values are provided, too.

Similar approach can be adapted for the assessment of potential electricity production from PV. SolarGIS facilitates all necessary data and methods to calculate such characteristics for various PV technology options and system settings. Here we introduce the first dataset (Figure 2). The analysis and comparisons with other alternatives will be carried out in the next study.

4 CONLUSION

The work is based on the use of high-quality solar database, validated in several campaigns, including international cross-validation [15]. This database shows significant accuracy improvements referring to the known issues in Europe [16] and uncertainties in MENA countries. New DNI country information is revealed for the assessment of CPV potential. Besides values, the study delivers also information about the uncertainty.

Ranks of countries are based on MAX values rather than average values, while the solar power plants are typically planned in the regions with the highest solar resource.

Similar approach for assessment of potential electricity production from PV systems can be applied. In this study, a PV map for c-Si modules inclined southwards at 20° is presented. Additional PV scenarios will be carried out in the next study for various PV technology options.

More information can be obtained from the SolarGIS web site http://solargis.info, and the interactive tools iMaps and pvPlanner.

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