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Abstract

Exponential growth of photovoltaic installations in several countries represents a strong motivation for investments in renewable energies.

This paper provides an overview on current methodologies for assessing the photovoltaic potential, with the aim of supporting the selection of optimal sites in a given region of interest. With a special focus on the Italian case, an additional goal of this work is to show that, fast and accurate estimates of the power of new photovoltaic installs can be obtained upon detection of available surface areas (e.g., by cadastral maps or image analysis).

Basic average solar radiation and temperature for some specific areas can be indeed obtained from the available solar maps reported in the geodatabases of the Joint Research Centre of the European Commission (JRC).

On the basis of such data, as an alternative to a query in the on-line Photovoltaic Geographical Information System - PVGIS - (the web-based reference tool for the performance assessment of photovoltaic plants in Europe and also Africa), simple polynomials prove suitable for a quick analysis of solar energy potential applications.

Keywords: Photovoltaic solar energy, Renewable energy, Sustainable energy, Fast energetic analysis

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1. Introduction and motivations

Owing to the the Green Paper [1] and EU directive for 2020 (Directive 2009/28/EC), the interest in renewable energies has experienced a growing evolution in the EU member states. It is known that buildings account for about 40% of the total energy consumption in the European Union [2, 3], and can require even a higher percentage of electrical energy in other countries [4]. In order to reduce the great demand for energy from traditional sources, many existing buildings should be renovated so that lighting, heating and air conditioning would be supplied by renewable energies in the very near future. As a result, one of the main goals for the European Member States is the "nearly zero-energy buildings" (NZEBs) [5, 6] for all new buildings from December 31, 2020, as reported in the directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 [7].

More specifically, in the next years, solar energy can be certainly considered one of the key solutions to reduce the environmental anthropic impact, and effectively respond to the worldwide increase of electricity demand, cost of fossil fuels and difficulty in finding them [8, 9, 10, 11, 12]. It has been reported that the performances of current PV technologies in terms of energy payback time (EPBT), greenhouse gases (GHG) and levelized cost of electricity (LCOE) are already competitive with traditional energy sources [13, 14]. In particular, even for technologies requiring high energy intensity during production (e.g. mono-Si PV systems) a EPBT between 1.7 and 2.7 years can be observed, with the GHG between 29 and 45 g CO_2-eq./kWh, namely an order of magnitude lower than fossil-based electricity [15].

In general, as most of renewable sources, owing to their fluctuating nature PV power plants often need to be properly integrated within other energy systems [16]. Nowadays, in order to make such a source of energy even more accessible to population, many photovoltaic (PV) systems start being (among other applications) part of smart grids (i.e., connected systems of various sources and consumers for optimizing production, gathering, and distribution of the energy) [17, 18], noise barriers on national roads [19], hybrid systems in combination with batteries and wind systems [20], as well as batteries and engines. In the latter case, for instance, a PV penetration up to 22% and a cost around 0.180 \$/kWh has been estimated in different locations of a country with considerable amount of solar radiation such as the Kindom of Saudi Arabia [4]. Studies of the use of PV systems for agriculture (e.g. greenhouse cooling) have been also reported in the literature [21].

The amount of solar radiation in Italy is such that, according to very recent estimates, the cost of PV generated electricity is likely to reach the one of conventional electricity in a few years (i.e. by 2020) [22]. Electricity generated by PV systems in Italy during 2011 and 2012 amounts to about 10,795 GWh and 18,861 GWh respectively, thus showing a growth of about 75% [23]. Concerning the actual production capacity, in 2012 Italy has passed 16 GWp of solar power and, at the end of the same year, 478,331 PV systems have been installed [23].

Italy ranked first worldwide for installed solar power by new PV plants in the 2011 (roughly four times the power in 2010), thus becoming, since that time, the second country in the world for solar power installed, as also visible in fig. 1 [24]. Even though energy by PV systems roughly covers,

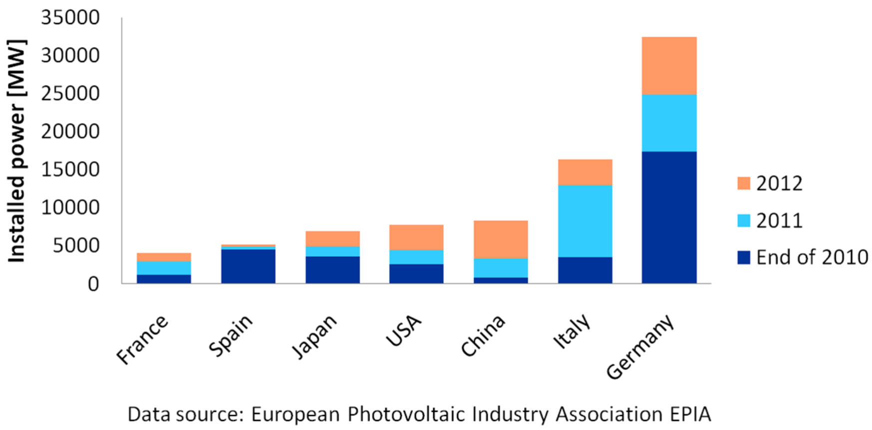

Figure 1: Installed solar power in the leading investor countries.

in general, only about 2.6% of the electricity demand in Europe (EU 27) in 2012, Italy is the first nation providing electricity in the continent by PV grid-connected plants (i.e., 6.7% of the total) [24]. These remarkable results have been achieved also thanks to economic investment incentives provided by the Italian government during recent years (i.e., feed-in scheme program since 2005 [25]). This rapid growth of solar energy production can be considered mostly a consequence of application of the European directives, since 2001, for the promotion of electricity produced by renewable energy sources [26], in accordance with the Kyoto protocol to reduce greenhouse gas emissions on Earth [27, 28, 29].

Moreover, the increase in the installations for the generation of renewable energy is also necessary in Italy to meet the great need of reducing the electricity imported from other nations as well as the marginal cost of generation [30]. In fact, in 2009 in Italy, the total electrical energy consumption amounted to 320 TWh ([31],[23]), whereas the total production in the same country has been of about 275 TWh, with a 14% deficit ca. As a consequence, importation from abroad has been necessary to balance such a difference. As an example, in the Piedmont Region (in 2009) a production of 24.5 TWh ca. against a demand of 26 TWh ca. has been observed (deficit of 6% ca.).

2. Assessing solar radiation: An overview

Even though novel applications and further standard installations of PV systems will still depend greatly on government grants and support for research and development, the amazing increase of interest and installations of solar photovoltaics during the recent years, it also requires the development of tools for fast analysis, design and even testing solar plants.

For instance, in Italy about 7.3% of the territory is estimated to be covered by "artificial covering" [32]. Many detection techniques, for sensing of sites of interest for PV applications, have been analyzed in the literature (see, e.g., [33]). Hence, automatic detection can generate a large number of available information for residential, commercial or industrial areas, in a very short time. In this case, computational tools (similar to the one considered in the sections below) are helpful to quickly estimate the solar energy availability for various potential installations, and thus support the decision of possible future investments in such a renewable resource.

As a consequence, interest for detection of areas suited for solar energy has been developed for many years. For example, Wittmann *et al.* [34] analyzed roof surface areas of a district in Vienna (Austria) by means of photogrammetry, in mid-nineties, for potential solar energy conversion systems.

Later, Hofierka and Kaňuk [35] have presented a methodology for the PV potential assessment in urban areas, on the basis of a 3D city model implemented in a geographic information system (GIS) and also implementing the *r.sun* model [36, 37] for analyzing both spatial and temporal variation of the solar radiation (i.e., *insolation*), now included in the PVGIS [38] utility. In addition, an estimate of potential electricity production can be also reported by the same tool.

Agugiaro *et al.* [39] have described a multi-scale methodology for estimating the solar radiation on building roofs in complex mountainous areas, where shadowing effects by topography or nearby buildings are also included. Also in this case, 3D data are considered to achieve accurate results. Estimates are again performed by means of the *r.sun* model, although within the free open-source Geographic Resources Analysis Support System (GRASS) GIS environment [40].

Very recently, it has been suggested that fuzzy genetic (FG) approaches can be successfully adopted for modeling solar radiation on the basis of input data such as latitude, longitude, altitude and month of the year. More specifically, it has been shown that according to standard statistics indicators, FG outperforms other methods such as artificial neural networks and adaptive neuro fuzzy inference systems [41].

It is worth noticing that the selection of suitable input data for the above modeling methods is an issue *per se*, and should be addressed by appropriate approaches and software such as the Waikato Environment for Knowledge Analysis (WEKA) as discussed and applied to some Indian cities in [42].

Solar radiation can be exploited in a wide range of applications. However, solar engineering typically focuses on thermal processes and photovoltacs [43]. Particularly, concerning the latter, besides the common *PV farms* [44], the building-integrated PV systems (BIPV) represents an attractive solution for rationalizing the use of natural resources, thus alleviating possible issues on land scarceness [45, 46].

In fact, in Italy, the continuous installation of *PV farms* led to an uncontrolled occupation of agricultural terrains [47]. For example, the number of installations in the Piedmont region has reached such a level that in July 2010 the Regional Council has approved a draft law aiming at regulating the use of land destined to photovoltaic systems (Regional Council of Piedmont website [48]).

Those measures against the landscape disfiguring have the aim of both regulating new PV installation and promoting the BIPV systems.

Several studies have been reported on building integrated PV system installations (see, e.g., [49] and [50]), where the available roof surface area is treated as an input parameter. The available surface for PV installations is the *built-up area*, and can be evaluated by means of maps of the land use (i.e. Corine Land Cover, of the European Environment Agency (EEA website [51])). Methodologies for assessing the available roof surface have been recently suggested. To this purpose, A first methodology based on crossed-processing and sampling of various GIS data has been presented and applied to Spain in 2008 [52]. It is worth mentioning also other recent papers discussing similar approaches with applications to several locations (see, e.g., [53] and [54]). In particular, in the work of Nguyen and Pearce [55] a semi-automatic and easy to upgrade algorithm for solar photovoltaic potential is proposed, where also terrain and near surface shadowing effects are included for analyses conducted at a municipal scale (Kingstone, Ontario). The latter approach is based on the free software GRASS [56, 40] and *r.sun* [36, 37].

The work by Asinari and Bergamasco [57, 58] was mostly based on orthoimages and cartography (i.e., cadastral maps) available from North-Western Italy local administrations (i.e., the Piedmont Region and, more particularly the town of Turin).

In [33], geostationary satellites Meteosat 7 imagery are utilized for deriving information on the solar irradiance on large areas with temporal and spacial resolution of up to 30 minutes and 2.5 km, respectively. More recently, in [59], imagery from the Meteosat 9 satellite (within infrared channels) were treated via an optimized artificial neural network model, thus estimating the daily global solar radiation in the region of Andalusia (Spain).

In the work of Carríon *et. al.*, an environmental decision-support system has been developed for the selection of optimal sites for grid-connected photovoltaic plants (with application to a district on the plateau of Granada, Spain). In such an approach, several aspects are taken into proper account such as i) the climate features directly influencing the performance of the solar systems; ii) the land use; iii) the protected areas; iv) orography and v) location [60]. Moreover, in case of competing objectives, the site selection can be based on proper decision-making methods such as the Analytic Hierarchy Process (AHP) as shown in [44] for a specific region of Turkey.

In any case, in order to analyze very large areas, a standard approach is required and also a tool for fast estimation of both global solar radiation and production of electricity by new potential fixed PV systems for any detected area surface. To this purpose, in the literature, spatial mappings of solar energy availability based on simple empirical correlations and only depending on a few climatological multivariates (such as mean temperature, relative humidity, specific humidity) have been utilized for fast estimates of solar radiation [61].

Hence, it is also worth considering alternative approaches for such fast estimates of PV solar energy through geodata analysis and subsequent potential electricity production for new PV installs.

3. Material and Methods

Let us focus on the construction of models for the fast (though accurate) estimate of PV solar energy available in a country of interest.

It is useful to base the analysis on some important parameters in various locations of the chosen country (e.g., Italy), namely i) the yearly solar radiation; ii) the average temperature, and iii) the type of each possible installation (free-standing or building-integrated) of solar modules with crystalline-silicon cells (c-Si).

Clearly, thanks to the procedure generality, those methodologies can be easily utilized to generate models that are applicable to other countries, and prove to be particularly suitable for cases when a limited solar radiation data are available (see, e.g., the study reported in [62], where only old data and/or at a few locations in Bangladesh are available).

3.1. Modeling

Let some representative locations in various regions from North to South of Italy be chosen as a geographical base for the modeling. Among the European Union member states (and other candidates), the latter is of special interest due to a high electricity (yearly) output by a typical 1 kW_p PV system. Regardless of modules mounting (horizontally, at the optimum angle or vertically), Italy is ranked among the first five countries for average, minimum and maximum values (see Figs. 1 and 2 in [63]). In the reported example, only seven sites, in quite different territorial areas (i.e., coast regions, hilly areas, etc.), were selected in or near the towns reported in table 1, where the location coordinates (i.e, latitude and longitude) are specified in the second and third columns and define the exact place for data collection, with the last column showing the average daytime temperature extracted from the available PVGIS database [64]. More specifically, L'Aquila is one of the highest and coldest chief towns in Italy, and it has been included in the (input) list for its extreme characteristics in the country, whereas the chosen place in Sicily is located inland of the province of Syracuse, being one of the hottest areas in Europe.

One of the key aspect of the modeling is the analysis of the temperature and reflectance efficiencies. In this case, the following basic data (to be included in the model) were collected from standard queries using the online PVGIS tool [65] for each aforementioned location and for each azimuth angle here considered (from -90° to +90°, with resolution of 10°):

Province	*Latitude* [°]	*Longitude* [°]	*Altitude* [m] *a.s.l.*	*Temperature* [°C]
Padova	45.42	11.88	11	15.10
Torino	45.11	7.73	209	14.92
Parma	44.78	10.36	55	15.49
L'Aquila	42.34	13.42	637	13.08
Roma	41.97	12.53	54	16.97
Bari	41.10	16.87	26	17.88
Siracusa	37.20	14.95	348	19.37

Table 1: Basic geodata of the places selected for the modeling function

- Estimated losses due to temperature and low irradiance
- Estimated loss due to angular reflectance effects

These values can be elaborated in order to find two fitting functions for modeling the two above efficiencies. Eq. (1) reports the quadratic model for the temperature efficiency, which also depends on the PV installation type (i.e., Free Standing or Building Integrated). Hence, the corresponding equation must be parametrized. Then, table 2 reports the values for the p parameters appearing in (1), depending on the case.

$$\eta_{temp} = p_1 \cdot x^2 + p_2 \cdot x + p_3 \tag{1}$$

	Free Standing	*Building Integrated*
p_1	-0.00028728	-0.00030498
p_2	0.0058443	0.0057622
p_3	0.88201	0.84222

Table 2: Coefficients of the quadratic model for the temperature efficiency

On the other hand, a fourth order polynomial expression can be chosen for modeling the reflectance efficiency, as reported in Eq. (2). In the latter case, this is a function of the azimuth angle (x) only.

$$\begin{aligned} \eta_{refl} \;\; = \;\; & -2.0381e{-}11 \cdot x^4 - 3.0267e{-}10 \cdot x^3 \\ & -1.1934e{-}06 \cdot x^2 + 8.2638e{-}07 \cdot x \\ & +0.97217 \end{aligned} \tag{2}$$

However, more accurately, insolation depends on both the azimuth angle and the tilt angle. Therefore, global irradiation losses, for different orientations of solar panels, must be calculated by defining a scale factor to be applied to the maximum insolation at the chosen azimuth. This can be taken in to account by using a fourth order polynomial expression, a function that has only one independent variable, being the azimuth angle expressed in degrees (absolute value). In fact, during data extraction, insolation has been always considered for solar modules installed with optimal tilt angle (the latter being a parameter which is not treated here as a variable). Eq. (3) reports the expression for the scale factor (SF). In this case, it has been obtained after considering only the insolation data of Rome, while all the previous quantities (i.e., the temperature and reflectance efficiencies) have been extracted by using the related information of all the seven selected places (see table 1).

$$\begin{aligned} SF &= 3.7289e{-}09 \cdot x^4 - 3.463e{-}07 \cdot |x^3| \\ &\quad -1.2739e - 05 \cdot x^2 - 0.000165 \cdot |x| \\ &\quad +1.0007 \end{aligned} \tag{3}$$

Generally, a cubic spline function is preferable to a polynomial for interpolation. However, experimental results described hereafter in Section 4 reports small differences compared to the on-line PVGIS data, so that it is possible to infer that these simple mathematical models (based on polynomials) are sufficiently accurate and reliable for our purposes.

Total efficiency is the product of all the efficiencies, as reported below in (4). Module and installation efficiencies (i.e., η_{mod} and η_{inst}) should be set after considering the type of solar panels and other components (e.g., inverters) used in the PV system.

$$\eta_{tot} = \eta_{mod} \cdot \eta_{inst} \cdot \eta_{temp} \cdot \eta_{refl} \tag{4}$$

Finally, average yearly electricity production Π $[kW]$), for each detected area (e.g., building), can be estimated, taking into account the average yearly insolation H_y $[kWh/m^2]$, the total net area of the solar panels, and the total efficiency η_{tot}, as reported in (5).

$$\Pi = H_y \cdot Area \cdot \eta_{tot} \tag{5}$$

The considered model, for both estimation of the solar radiation and electricity production, are now included in a novel tool that runs on the

MATLAB® environment. By referring to a specific installation, settings of some input parameters (e.g., module efficiency, installation efficiency, etc.) should be set by the user in a provided text file whose format is already defined. Default values are anyway included in the tool if user data are not explicitly reported.

After creating the above model, the following basic information of the environmental conditions of these places can be obtained from some reference geodata extracted from two available databases of the JRC (PVGIS© European Communities, 2001-2012)[63, 66]:

- yearly sum of global irradiation on optimally-inclined surface (kWh/m^2);
- yearly average of daytime temperature ($^\circ C$) [64].

The first database, the classic PVGIS data set based on ground station, refers to the period 1981-1990, whereas the second one is related to the period 1995-2003. Those two databases are mostly used for estimation purposes only.

In fact, the on-line PVGIS database [64] has been recently updated [66], so that the present model is basically based on those available data, but only for a very small set of places, as discussed below. Anyway, despite differences among the aforementioned databases, in section 4 we reports a successful application of the model.

4. Results

As an example, and for validation purposes of the considered polynomial model, data on the yearly solar irradiation, as predicted by PVGIS (whose accuracy has been already evaluated by Kenny et al. [67]), are considered for ten locations in different areas in Italy, and whose basic geodata are summarized in table 3.

The choice has been made after considering the coordinates and altitudes of those places, in order to have a fairly comprehensive benchmark test.

Figure 2 shows all the locations selected for both modeling and testing the tool.

More precisely, all the sites chosen for the testing purpose are indeed far from those selected for the modeling in order to obtain reliable experimental results for the tool validation. In fact, the aim is to show that simple polynomial models can be designed not only to obviously fit the reference places,

Figure 2: Map of the locations for the modeling and testing of the solar radiation estimator.

but also (and more importantly) for constructing a robust estimator all over the country.

Table 4 reports estimation of the average yearly insolation for PV installations, after considering different azimuth angles, in the places selected for the test. Differences of these estimations, with respect to the on-line PVGIS simulation data, are then reported in table 5, where the absolute maximum error is, for the analyzed case, smaller than 2.0%. It is to be noted that Trapani and Bergamo have the worst error (i.e., -1.68 and 1.52 at the azimuth $\pm 90°$ and $\pm 80°$ respectively) with respect to the other places. Nevertheless, this (polynomial) model shows an excellent stability when considering the limited errors reported for any of the selected locations.

Since the scaling factor takes into account the absolute value of the azimuth angle, dimension of the table could be only Mx$(N/2+1)$ instead of MxN, where M is the number of the selected locations and N is the number

Locations	*Latitude* [°]	*Longitude* [°]	*Altitude* [m] $a.s.l.$	*Temperature* [$°C$]
$Bergamo$	45.65	9.70	217	14.23
$Trieste$	45.62	13.80	26	15.30
$Pesaro$	43.87	12.84	33	15.67
$Firenze$	43.80	11.21	38	15.17
$Caserta$	41.07	14.32	61	17.98
$Alghero$	40.57	8.33	15	18.02
$Lecce$	40.35	18.20	36	18.14
$Cosenza$	39.30	16.26	218	18.04
$Cagliari$	39.25	9.12	25	18.81
$Trapani$	38.00	12.55	13	19.46

Table 3: Reference geodata of the sites selected for model testing

of the azimuth angles considered for the test.

Indeed, $N = 180°/step$, where step is the constant angle interval (i.e., 10 degrees in this case). However, sometime there are also differences in the estimation of the global solar irradiation in the on-line PVGIS database when considering both positive and negative azimuth angles. So, in order to present all the results in a standard format, both tables for estimation data and errors (or differences) have the same dimensions.

Figure 3 reports the distribution of the differences reported in table 5, whose standard deviation (σ) is about 0.65. It is worthy of notation that, for an azimuth angle between -45° and 45°, almost all the differences are within the range of $\pm 1.00\%$.

Figure 4 shows the related cumulative distribution function (CDF), which indicates robustness of the proposed model regarding accuracy (i.e., between -2.0 and 2.0%).

Finally, time for the overall estimation of possible PV installations is reduced with respect to manually built queries, but still keeping a good accuracy. For instance, with the tool that has been discussed, estimation of the solar energy and potential electricity production of a high density area of buildings of one square kilometer requires only about one minute for analyzing tens of roofs after considering, for instance, the related surface area and azimuth, whereas traditional estimation would be tens of times slower.

Yearly insolation [kWh/m^2 per year]																			
Azimuth [°]	*-90*	*-80*	*-70*	*-60*	*-50*	*-40*	*-30*	*-20*	*-10*	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*
Bergamo	1260	1269	1292	1323	1354	1384	1408	1426	1436	1441	1436	1426	1408	1384	1354	1323	1292	1269	1260
Trieste	1289	1298	1322	1353	1386	1416	1441	1458	1469	1474	1469	1458	1441	1416	1386	1353	1322	1298	1289
Pesaro	1393	1403	1429	1462	1497	1530	1557	1576	1588	1593	1588	1576	1557	1530	1497	1462	1429	1403	1393
Firenze	1339	1349	1373	1405	1439	1470	1496	1515	1526	1531	1526	1515	1496	1470	1439	1405	1373	1349	1339
Caserta	1476	1487	1514	1549	1587	1621	1650	1670	1683	1688	1683	1670	1650	1621	1587	1549	1514	1487	1476
Alghero	1588	1600	1629	1667	1707	1744	1775	1797	1810	1816	1810	1797	1775	1744	1707	1667	1629	1600	1588
Lecce	1605	1617	1647	1685	1726	1764	1795	1817	1830	1836	1830	1817	1795	1764	1726	1685	1647	1617	1605
Cosenza	1591	1603	1633	1671	1711	1748	1779	1801	1814	1820	1814	1801	1779	1748	1711	1671	1633	1603	1591
Cagliari	1611	1623	1652	1691	1732	1769	1800	1823	1836	1842	1836	1823	1800	1769	1732	1691	1652	1623	1611
Trapani	1642	1654	1685	1724	1766	1804	1836	1858	1872	1878	1872	1858	1836	1804	1766	1724	1685	1654	1642

Table 4: Yearly insolation for different azimuth angles in various locations in Italy

Insolation differences w.r.t. the PVGIS data [%]																			
Azimuth [°]	*-90*	*-80*	*-70*	*-60*	*-50*	*-40*	*-30*	*-20*	*-10*	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*
Bergamo	0.80	1.52	0.94	0.99	1.04	0.29	0.57	0.42	-0.28	0.07	-0.28	0.42	0.57	0.29	0.30	0.99	0.94	1.52	0.80
Trieste	0.70	0.62	0.92	0.97	0.43	0.43	0.07	-0.14	-0.07	0.27	-0.07	0.55	0.77	1.14	1.17	0.97	0.92	1.41	0.70
Pesaro	-0.50	-0.50	-0.07	-0.54	-0.20	0.00	-0.19	-0.25	-0.13	-0.44	-0.13	-0.25	-0.19	-0.65	-0.20	-0.54	-0.07	-0.50	-0.50
Firenze	-0.81	-0.81	-1.22	-1.06	-0.76	-0.68	-0.27	-0.33	-0.26	0.07	-0.26	-0.33	-0.27	-0.68	-0.76	-1.06	-1.22	-0.81	-0.81
Caserta	-0.94	-0.87	-1.05	-0.71	-0.81	-0.55	-0.60	-0.60	-0.41	-0.12	-0.41	-0.60	-0.60	-0.55	-0.81	-0.71	-1.05	-0.87	-0.94
Alghero	0.51	0.63	0.56	0.42	0.41	0.23	0.28	0.39	0.00	0.33	0.00	-0.17	0.28	0.23	-0.18	-0.18	0.56	0.63	0.51
Lecce	-0.93	-0.80	-1.38	-0.88	-0.80	-0.34	-0.28	-0.16	0.00	0.33	0.00	-0.16	-0.28	-0.34	-0.80	-0.88	-0.78	-0.80	-0.93
Cosenza	-0.56	-0.43	0.18	0.66	0.65	1.04	1.08	1.18	0.78	0.55	0.78	0.61	0.51	-0.11	0.06	-0.54	-0.43	-0.43	-0.56
Cagliari	-0.56	-0.43	-0.48	-0.53	-0.46	-0.06	0.00	-0.38	-0.22	0.11	-0.22	0.16	0.00	-0.06	0.12	0.06	0.12	-0.43	-0.56
Trapani	-1.68	-1.55	-0.88	-0.92	-0.79	-0.33	-0.22	-0.11	0.11	-0.11	0.11	-0.11	-0.22	-0.33	-0.79	-0.92	-0.88	-1.55	-1.68

Table 5: Differences between the insolation estimates and the corresponding PVGIS data.

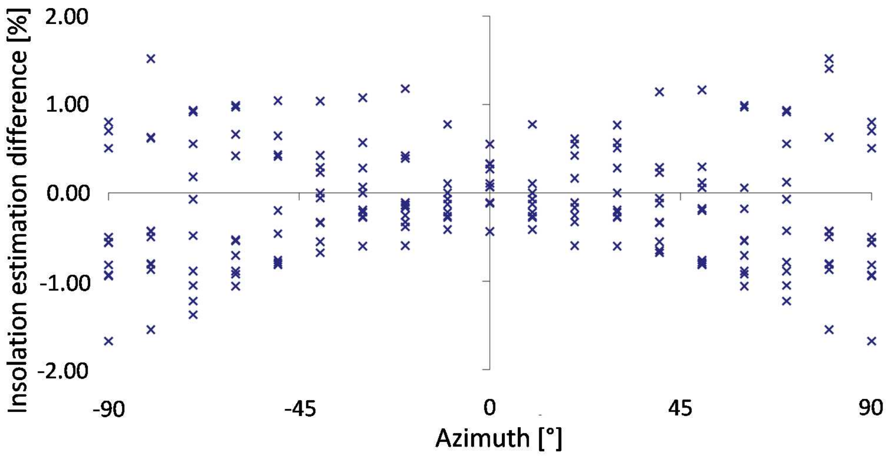

Figure 3: Estimation differences w.r.t. the on-line PVGIS data. Their distribution is here depicted after considering each azimuth angle reported in table 5.

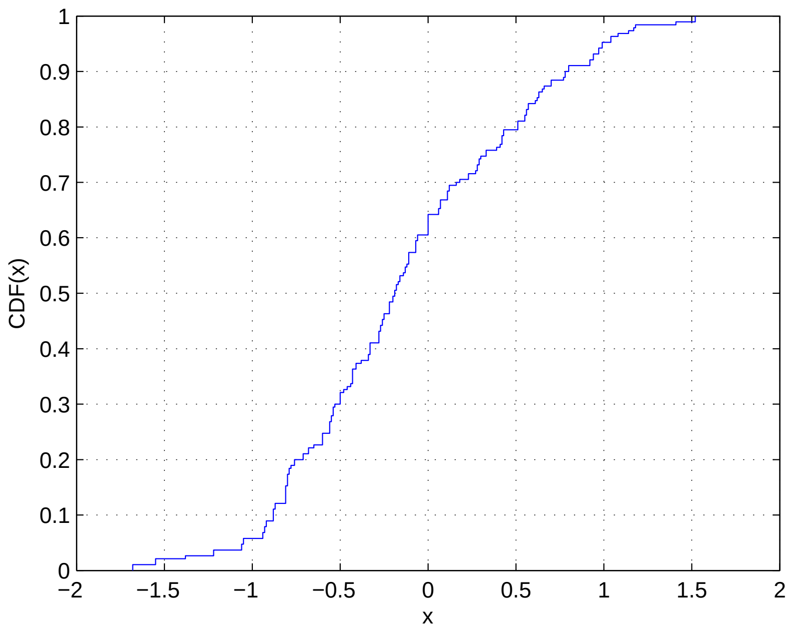

Figure 4: Cumulative Distribution Function (CDF) of the estimation differences (x).

5. Concluding remarks

Owing to limited availability, environmental and social impact of fossil fuels and other traditional/non-renewable energy sources, renewable energies represent the ideal alternative for a sustainable development of our society in the next future [68, 69, 70, 71]. Among all the renewable sources of energy, solar radiation certainly plays an important role. As demonstrated by the review presented in this work, tools for the accurate evaluation of the availability of this resource in large areas are critical for future investments, and remain the object of an active research area where electricity generation and grid enterprises as well as governments are involved.

Moreover, as an additional scope of this study, and with special focus on Italy, a methodology for modeling and implementing an accurate fast estimator of the energy potential assessment of PV systems on building roofs and other available areas, has been also presented. Thanks to mathematical models and some available off-line databases from the JRC's Institute for Energy and Transport automatic estimation of potential PV installs allows a fast research and analysis of new potential sites for solar photovoltaics energy production. The proposed methodology has been tested after considering perspectives on applications of the PV systems in various locations in Italy.

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