ESECI: A Tool for Estimating Solar Radiation in Côte d’Ivoire

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Abstract In this work, we present a tool dedicated to the estimation of solar radiation in Côte d'Ivoire named ESECI. In fact, the unavailability of sufficient quality and quantity of solar data is a limiting factor in any project involving solar energy systems (thermal conversion and photovoltaic conversion). Côte d’Ivoire does not possess a solar irradiance measurement network. Only fourteen (14) weather stations exist to measure sunshine hours from which solar radiation is derived. Moreover, these measures are sometimes incomplete due to lack of monitoring. We have implemented a computer program to calculate solar radiation for any sky. The estimation of solar irradiance takes into account its different components (direct, diffuse and global) on any surface. A comparative analysis between the simulation results and the measurements shows that the model correctly predicts solar irradiance in clear sky and in uniformly overcast sky. For days with frequent cloudy periods, the tool simply calculates the average values of the solar irradiance during the fluctuation times. The results obtained indicate that the tool implemented is an alternative to the lack of data on the solar deposit in Côte d’Ivoire.

Keywords: solar energy systems, sunshine hours, solar irradiation, solar deposit


1. Introduction

A good knowledge of the solar radiation available on the ground in a given locality is important for applications in many fields such as [1], photovoltaic electricity or solar thermal, agriculture and biomass energy, weather forecasting, climate changes, environmental sciences, human health (prevention of skin cancer, etc.), aging and the resistance of materials, architecture and habitat. The variety of these applications requires precise information and knowledge in quantity and quality about solar energy potential. The most direct method of evaluating solar radiation on the ground is to use pyranometric measuring instruments generally installed in automatic weather stations. These instruments give more detailed description of the solar irradiance reaching the Earth’s surface: sunshine duration, global solar irradiance, direct and diffuse components, spectral distribution, etc. Due to the high investment, maintenance and calibration costs, meteorological stations are not always equipped with all the appropriate measuring instruments. The other alternative is to provide models for estimating solar radiation reaching the ground. In Côte d'Ivoire only sunshine durations are measured in the fourteen (14) meteorological stations declared to the World Meteorological Organization (WMO) and operational, to determine solar irradiation. In addition, the distribution density of these stations is low, around one station for 23,000 km². Thus, the available sunshine data is limited only to existing weather stations. However, solar radiation data provide useful information on how this energy arrives on a surface located in a given locality and during a certain period [2]. These data must be reliable and easily available for their use in all requesting fields. Its unavailability prevents, for example, the design, sizing, performance evaluation and optimization of solar energy systems.

In recent years researchers utilized reliable solar models with ground or satellite-based datasets to generate solar radiation data under high spatial resolution [3,4]. These databases exist in many countries:

- The National Solar Radiation Data Base (NSRDB) provides publicly open data on solar radiation and meteorological data over the USA and regions of the surrounding countries;
- The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) proposed the International Weather for Energy Calculations Version 2.0 (IWEC2) in 3012 stations outside the USA and Canada;
● The Test Reference Year (TRY) was developed by the Chartered Institution of Building Services Engineers (CIBSE) in 14 stations in the United Kingdom;
● The China Meteorological Bureau and Tsinghua University built a Chinese Standard Weather Data (CSWD) in 270 stations in China;
● The Satellite Application Facility on Climate Monitoring (CM SAF) collaboration provides a number of different solar radiation data sets at hourly time resolution and spatial resolution of a few km, covering Europe and Africa;
● The Land Surface Analysis Satellite Application Facility (LSA-SAF) collaboration makes data from the Meteosat Second Generation satellites available at 15 min resolution;
● The National Oceanic and Atmospheric Administration (NOAA) provides Geospatial solar radiation data for the Americas;
● Time series of solar radiation data are available from the SODA web site for single sites, as well as from the National Solar Radiation Database covering the Americas (from which limited area solar radiation maps at hourly resolution are also available).
● Meteonorm software is a comprehensive climatological database containing solar radiation data.

This list is not exhaustive. However, the most available solar radiation data found in such datasets are hourly long-term averaged values. Instantaneous irradiance is difficult to obtain. Those databases do not cover all the geographical areas of the world. Satellite radiation measurement are note precise in estimating ground solar radiation since they require atmospheric models to estimate the solar radiation at ground level [5]. Satellite data have the advantage of having much greater spatio-temporal coverage [6,7].

For the establishment of those data sets, methods and models have been developed on purpose by researchers all over the world to modeling solar radiation. Consequently, other scientists have implemented the validated models and methods into computer programs to crate software tools for solar energy applications. Software tools are covering different categories for their specific field of application like simulation, analysis, planning, economic evaluation, monitoring and so forth [8]. Those dedicated to weather forecasting and use to the estimation and forecasting of global solar radiation are based on the numerical weather prediction (NWP) model like Global Forecast System (GFS) of the National Oceanic and Atmospheric Administration (NOAA) of USA, North American Mesoscale Model (NAM) also linked to the NOAA, The European Centre for Medium-Range Weather Forecasts (ECMWF). Those tools accurately estimate and forecast solar radiation but they need much data as inputs and are time consuming.

Software tools specially dedicated to solar radiation estimation and forecasting are scarce. Bed Raj et al. reported the use of RadEst 3.00 software to estimate daily global radiation at Nepalgunj, Nepal [9]. The software has implemented four temperature-based models for the estimation of daily global solar radiation. H. Ambartia implemented a clear sky model in a software to estimate solar radiation in Indonesia [10]. Kherbiche et al. have presented a solar radiation estimation tool designed in Matlab GUIs for Algeria that implemented a clear sky model namely the Perrin de Brichambaut model [11].

With increasing demand for solar energy in various domains and increasing interest in researching in thermal conversion, photovoltaic conversion, low energy building, urban climates planning it is an urgent need for better tools to estimate solar irradiation at local scales. Any technical analysis of renewable energy and its implementation requires computer tools. Numerous software tools have been developed worldwide in thermal energy systems, photovoltaic systems and building design and building energy simulation. The commonly used software tools are TRNSYS, HOMER, RETScreen, SAM, Sunny Design, Archelios, Polysun, PV Syst, PV*SOL, PVGIS, PV Watts, PVMAPS, eQUEST, DOE2, ECOTECT, ArcGIS, SOLINE, CITIESIM, SUN Tool, ESP-r, Elephant, Rhinoceros. In common, those multi-application software tools contain meteorological databases including solar radiation data on horizontal and tilted surfaces at hourly time scales. Some of them have implemented models and methods to estimate solar radiation or allow the user to enter their own meteorological data. Few of them are free. Most are commercial software. Apart from their high costs, these software tools require many input data that are not often available in most of the meteorological stations.

Côte d’Ivoire is a country in West Africa located between latitudes 4 ° N and 10 ° N and longitudes 2° W and 9° W that belongs to the humid inter-tropical zone where there are frequent cloudy periods. According to the country’s Ministry of Petroleum, Energy and Renewable Energies, Côte d’Ivoire average annual sunshine hours vary between 2,000 and 2,500 hours from the south to the north. The average global horizontal solar irradiation available per day is between 2,500 Wh/m² and 5,250 Wh/m². These values show that Côte d’Ivoire has exploitable solar potential for solar energy applications. Over the past 20 years, active researches have been carried out in various areas of renewable energy in Côte d’Ivoire such as solar thermal [12] (collectors, cookers, stills, dryers, refrigerators), solar panels [13], biomass energy [14]. Most of those researches are experimental studies or modeling on solar energy systems. None of them relate to the simulation of solar energy systems due to the lack of adequate data on solar radiation. Computer simulation is a powerful tool extensively used for investigating efficiency of solar systems from performance analysis models implementation. Therefore computer simulations bridge the recognition on the improvement of efficiency in real life behavior [8]. The global solar radiation is an important weather variable for that purpose.

Côte d’Ivoire has elaborated a document called PANER 2016-2020/2030 (Plan d’Actions Nationales des Energies Renouvelables) in 2016 [15] in which the country intends to increase the share of renewable energies in its global energy production from 1 % to 16 % in 2030. To achieve this objective, Cote d’Ivoire has launched a project for the design and construction of an off-grid photovoltaic power station with a capacity of 25 MW in Korhogo in the north.
Two other grid-connected solar farm projects are planned in Laboa and Touba with a total capacity of 60 MW in the west of the country. To carry out the design and simulation of these projects, the meteorological data of these localities are essential, especially the solar radiation data.

To overcome the lack of data on solar energy potential in Côte d’Ivoire this work aims to implement a tool to estimate solar radiation named ESECI (Essai de la Simulation de l’Ensoleillement en Côte d’Ivoire) based on few inputs. The novelty of the study is to propose a tool using only sunshine duration to estimate and forecast global horizontal solar irradiation reducing the inputs parameters.

2. Methods and Material

2.1. Theoretical Aspect

Côte d’Ivoire does not have meteorological stations able to measure solar irradiance reaching the ground. The Société d’Exploitation et de Développement aéroportuaire, aéronautique et Météorologique (SODEXAM) in charge of measuring this renewable resource does it from the measurement of sunshine hours in the existing 14 meteorological stations. This work aims to model the solar energy resource of Côte d’Ivoire. To achieve this, a literature review has been made first to search the various existing models as well as their constraints in terms of input data; an important parameter in the flexibility of the models. Strongly instructed by this theoretical knowledge, we have chosen five main models validated in the literature for the simulation of solar radiation in Côte d'Ivoire namely the Capderou model, the Ångström-Prescott model, the Collares-Pereira and Radl model, the Liu and Jordan isotropic model and the anisotropic Hay-Davis-Klucher-Reindl (HDKR) model. The Capderou model [16] is a clear sky model which permits from astronomical, geographical, geometric, physical and meteorological factors to calculate the deterministic component of solar radiation from the sun until its arrival at the ground level crossing a standard atmospheric layer. Generally, incident solar radiation breaks down into beam and diffuse radiations. The model evaluates for a given day, those two components reaching any surface. The model is used to predict solar radiation at any site of interest in Côte d’Ivoire where the latitude, the longitude and the altitude are known. To model the dynamic effect of clouds and atmospheric constituents in attenuating solar radiation, we opted for the Ångström-Prescott model [17,18]. From the data of 9 weather stations of Côte d’Ivoire we have calibrated the annual Ångström-Prescott coefficients [19] and using a multivariate regression method we generalized the Ångström-Prescott coefficients to each site on all the extent of the Côte d'Ivoire territory [20] as a function of latitude and altitude. The relevant results obtained by the proposed model permit to easily calculate the monthly mean daily global horizontal irradiation of 81 sites through relative sunshine duration data. The determination of the diffuse irradiation on a horizontal surface is undertaken using the Collares-Pereira and Rabl model [21] and the Erbs, Klein and Duffie model [22] depending on the clearness index values. The corresponding direct irradiation is deduced by difference.

The anisotropic model HDKR (Hay-Davis-Klucher-Reindl) [23,24,25,26] or the isotropic Liu and Jordan model [27] comes in addition to calculate the monthly mean daily global irradiation on an inclined surface depending on the state of the sky. From the monthly averaged daily irradiation, we switched to the hourly average global irradiance in order to follow its temporal evolution during a day with cloudy periods. To complete this we used another Collares-Pereira and Rabl model [21] to determine the global horizontal solar irradiance. With the Liu and Jordan model [28], we calculate the diffuse horizontal solar irradiance. All the calculations undertaken are carried out for an average day of each month called the typical day of the month. More details can be found in each reference cited above.

2.2. The Different Calculation Modules

2.2.1. Clear Sky Model Module

This module implements the Capderou model into a computer program. To operate, the module needs a number of parameters as useful input data. These are: the geographic coordinates of the site; its name, latitude, longitude and altitude; the date and time of the measurements; the time step of the calculations (from 1mn to 1h); the nature of the sky (clear sky or sky with clouds); the surface parameters (the inclination of the surface, the azimuth of the surface with respect to the south); and the albedo of the ground set at 0.2.

The physical quantities calculated by the module are the measurement time, the hour angle, the declination of the sun, the azimuth of the sun, the height of the sun, the diffuse, direct and global solar irradiances and the daily solar irradiations (direct, diffuse and global).

2.2.2. Ångström-Prescott Model Module

This module has implemented the Ångström-Prescott model into a computer program. The first input parameters of the module are those of the clear sky module. To supplement these input parameters, the module reads the site's monthly sunshine duration data and calculates the Ångström-Prescott coefficients according to the location latitude and altitude. These preprocessed data are stored on the hard drive in a directory.

The module undertakes for each month the calculations of the maximum sunshine hour, the clearness index, the relative sunshine duration, the top atmosphere’s irradiation, the Ångström-Prescott coefficients, the monthly mean daily direct, diffuse and global irradiations.

A summation of certain calculated quantities leads to the determination of the annual value of maximum sunshine hour, the direct, diffuse and global irradiances.

2.2.3. Collares-Pereirra and Rabl Model Module

This module implements the dynamic model of Collares-Pereira and Rabl, the Erbs, Klein and Duffie model, the Liu and Jordan models and the HDKR model as a computer program. This module uses as input certain physical quantities calculated by the clear sky module, namely the two tables of measurement hours, the hourly
angle of the sun, the declination of the sun, the azimuth of the sun and the height of the sun, as well as the daily average monthly irradiations (diffuse, direct and global) calculated in a cloudy sky. In fact, the dynamic model of Collares-Pereira and Rabl uses the monthly mean daily irradiations to calculate the hourly solar irradiiances during a day for a sky with clouds from sunrise to sunset.

The module provides as outputs, the measurement time, the hour angle, the declination of the sun, the azimuth of the sun, the height of the sun, the diffuse, direct and global solar irradiances as well as the daily diffuse, direct and global irradiances.

2.2.4. 2D Graphics

This module, as its name suggests, is a graphic output which helps users to visualize certain physical quantities calculated in the form of 2D curves or histograms. The module uses as input the measurement times, the temporal solar irradiance (diffuse, direct, global), the monthly mean daily irradiations and the months of the year.

The module is composed of specific functions grouped into two categories: functions for constructing 2D curves and those for constructing histograms. The histograms display the monthly mean daily irradiances over a year. These irradiances can also be visualized by 2D curves. On the other hand, only 2D curves are visualized when dealing with instantaneous solar irradiances.

2.2.5. Structure of the ESECI Program

The tool we have implemented is a coherent arrangement of the various modules described above supported by a graphical user interface (GUI). The complete computer program (ESECI) has its overall structure supported by the following organization chart:

![Flowchart of the ESECI program](image-url)
For coding, we used the C programming language. The tool implemented lay on a graphical interface supplied by GTK+ (GIMP Toolkit). This choice is quite simply based on the fact that this set of libraries is free software placed under the LGPL2.1 license and its native language is the C programming language. For the graphics output we use PLPLOT, a free library of written scientific graphics in C programming language under LGPL license and can be easily integrated into GTK+

2.3. Solar Radiation Data

To validate the tool, solar radiation data are collected from various sources. With a micro-weather station apparatus containing an Eppley pyranometer we have measured global horizontal solar irradiance at the Laboratoire d’Energie Solaire in Abidjan, Côte d’Ivoire during the year 1999. The measurement scale is 5 min and the accuracy is 3.5%. In 2017 a similar measurement has been done at the Laboratoire de Technologie in Abidjan, Côte d’Ivoire with a Kipp & zonen SMP3 pyranometer. The time scale is 1 min and the accuracy is less than 3%.

Daily monthly average horizontal global solar radiations have been collected from the following databases:

- HelioClim-1 which gathers satellite data on a 20x20 km resolution grid covering all the countries of the world. These data are freely accessible on the SoDa website www.soda-pro.com and cover the period from 1985 to 2005;
- HelioClim-3 which is an improvement of HelioClim-1 by reducing the resolution to a 3 to 5x3 grid at 5 km. These data are not free of charge but those going from February 2004 to December 2006 are freely accessible on the website mentioned above;
- SODEXAM, which contains agro-meteorological data from 14 weather stations in Côte d’Ivoire, including ten-day sunshine hours and the corresponding solar irradiations. These data are chargeable but free to access on the WAMIS website www.wamis.org. They begin in March 2004 and are completed over the months of the year.

3. Results and Discussions

3.1. Daily Measurements in Clear Sky

Clear sky conditions are rare in Côte d’Ivoire weather climate. From the measurements of 1999, we have extracted those of the 03/15/1999 which reflect the measurements during a clear sky day. Using the ESECI program, we have simulated the same measurements for Abidjan on the same date. The results obtained are shown in Figure 2.

Looking at the two curves we notice that they follow the same pace throughout the day. This easily shows that the ESECI tool performs better in clear sky conditions. Consequently, the tool does not react to the cloudy passage which occurs between 10:15 am and 11:00 am. In addition, the model slightly overestimates the global solar radiation from noon. This observation is simply explained by the fact that the model is based on clear skies which vertical column contains little water vapor and a lack of cloud formation or in the inter-tropical zone where Côte d’Ivoire is located, the relative humidity is very high and it helps to attenuate direct solar irradiance. Clouds are almost permanent and influence the direct solar irradiance through their transmittance. The combination of these two phenomena is at the origin of the decrease in solar irradiance observed in the measurements.

3.2. Daily Measurements in an Overcast sky

Figure 3 shows that the two curves have the same shape and the same trend. Before 10:00 and after 14:30 ESECI tool overestimates the solar irradiance due to the clouds. Between 11:00 and 1430 the discrepancy disappears gradually when reaching the maximum solar irradiance toward 12:00. The tool can predict the solar radiation with acceptable values in uniform overcast condition.

![Figure 2. Evolution of the global horizontal irradiance by a clear sky at Abidjan on 03/15/1999](image-url)
3.3. Daily Measurements by a Sky with Cloudy Passages

From data of 2017, we have chosen the measurements of the 03/29/2017 which reflect the measurements of a day covered by cloudy periods. We simulated the same measurements using the ESECI tool. The results are shown in Figure 4 below:

Figure 4 shows an overestimation of the global solar irradiance during the times when the clouds are stagnant (between 7 a.m. and 11 a.m. then between 2:40 p.m. and 5 p.m.) by the ESECI tool. This observation is explained by the fact that the model does not take into account the instantaneous transmittance of clouds. It simply calculates an hourly average irradiance value from the monthly mean daily irradiation. This is what is clearly observed between 11 a.m. and 2:40 p.m. So, in a day with frequent cloudy periods, the solar radiation simulated is very unpredictable.

3.4. Annual Measurements by Any Sky

During a month or a year, there is a succession of clear sky days and cloudy sky days. This set is referred to as “any sky”. From the HelioClim-1, HelioClim-3 and SODEXAM databases, we used the two common years of 2005 and 2006 to compare the monthly mean daily global horizontal irradiation. Those data are old but they are the only free data available for Côte d’Ivoire.
Using the ESECI tool, we have simulated the monthly mean daily irradiances for the years 2005 and 2006 at Abidjan. The results obtained are shown in Figure 5 and Figure 6.

Figure 5 shows that the monthly mean daily global irradiation curves follow the climatic profile of the site of interest presenting three distinct zones. High values corresponding to strong irradiances of up to 6000 Wh/m² covering the months from January to May (dry season). Low values which groups together average irradiances of the order of 3500 Wh/m² spreading regularly over the months of June to August (big rainy season). Moderately values with irradiances of around 5000 Wh/m² spread over the months of November to December (small rainy season).

We notice that the HelioClim-1 model overestimates the monthly mean daily global irradiation except in September compared to the ESECI model and that of SODEXAM which achieves an underestimation. On the other hand, the ESECI model is a good compromise between the other two models and provides average irradiation values close to the values measured for certain days.

![Figure 5. Monthly average daily global horizontal irradiation at Abidjan in 2005](image1)

The curves in Figure 6 show a regular evolution for each model.

![Figure 6. Monthly average daily global horizontal irradiation at Abidjan in 2006](image2)
The HelioClim-3 model keeps the overestimation of the irradiation, the SODEXAM model underestimates it and the ESECI model plays its role of compromise between the two models. Ultimately, ESECI model gives the average of the irradiations of the other two models. This remains an important asset in determining the monthly mean daily global irradiation of a site in Côte d'Ivoire.

3.5. Error Analysis

Monthly mean daily global horizontal irradiation is estimated using ESECI. A comparison is made between the estimated and measured values using data of the year 2017. The different values measured and estimated are in Table 1.

Table 1. Monthly average daily horizontal global irradiation (Wh/m²/day) for the year 2017 at Abidjan

<table>
<thead>
<tr>
<th>Months</th>
<th>Measured</th>
<th>ESECI</th>
<th>SODEXAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4375</td>
<td>4499</td>
<td>4079</td>
</tr>
<tr>
<td>February</td>
<td>4689</td>
<td>4779</td>
<td>3947</td>
</tr>
<tr>
<td>March</td>
<td>4909</td>
<td>4992</td>
<td>3932</td>
</tr>
<tr>
<td>April</td>
<td>4800</td>
<td>5076</td>
<td>3906</td>
</tr>
<tr>
<td>May</td>
<td>4256</td>
<td>4452</td>
<td>4005</td>
</tr>
<tr>
<td>June</td>
<td>3131</td>
<td>3335</td>
<td>3288</td>
</tr>
<tr>
<td>July</td>
<td>3325</td>
<td>3515</td>
<td>3393</td>
</tr>
<tr>
<td>August</td>
<td>3247</td>
<td>3502</td>
<td>3139</td>
</tr>
<tr>
<td>September</td>
<td>3366</td>
<td>3825</td>
<td>3034</td>
</tr>
<tr>
<td>October</td>
<td>3844</td>
<td>3936</td>
<td>3007</td>
</tr>
<tr>
<td>November</td>
<td>4356</td>
<td>4723</td>
<td>3353</td>
</tr>
<tr>
<td>December</td>
<td>3358</td>
<td>4027</td>
<td>3603</td>
</tr>
</tbody>
</table>

Three comparative methods are used:
- The root mean square error (RMSE)
  The RMSE provides information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the estimated and measured values. Its literal expression is:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (c_i - m_i)^2} \quad (1)$$

Low value of RMSE is desired showing the closeness of the estimated and measured values.
- The mean bias error (MBE)
  The MBE shows the overestimation or the underestimation of the estimated values.

$$MBE = \frac{1}{n} \sum_{i=1}^{n} (c_i - m_i) \quad (2)$$

Low value of MBE is expected.
- The mean absolute percentage error (MAPE)
  The MAPE is a measure of the model accuracy of the predicted method.

$$MAPE = \frac{100}{n} \sum_{i=1}^{n} \left| \frac{c_i - m_i}{m_i} \right| \quad (3)$$

Values of MAPE less than 10% show a good precision of the model.

In the above equations, $c_i$ is the estimated value, $m_i$ the measured ones and $n$ the number of observations.

The statistical indicators calculated are listed in Table 2.

<table>
<thead>
<tr>
<th>Models</th>
<th>RMSE (Wh.m⁻².day⁻¹)</th>
<th>MBE (Wh.m⁻².day⁻¹)</th>
<th>MAPE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESECI</td>
<td>302.36</td>
<td>252.08</td>
<td>6.82</td>
</tr>
<tr>
<td>SODEXAM</td>
<td>603.65</td>
<td>-414.17</td>
<td>11.61</td>
</tr>
</tbody>
</table>

According to Table 2, The MBE values indicate that the SODEXAM model (-414.17 Wh/m²/day) largely underestimates the values of the monthly mean daily global irradiation over the year while the ESECI model (252.08 Wh/m²/day) slightly overestimates them. The RMSE underlines that there is an important deviation between the SODEXAM (603.65 Wh/m²/day) values and the measured ones compared to the ESECI (302.36 Wh/m²/day). The MAPE confirms that the ESECI model (6.82%) is more accurate than the SODEXAM model (11.61%).

In the light of the comparative analyzes carried out and the results of the statistical error indicators, ESECI tool estimates, with a good precision, the solar irradiations at time scales ranging from one minute to one hour. Moreover, these quantities are determined on any surface and for any orientation; and even on vertical surfaces. ESECI predicts for any surface the monthly average daily irradiations during a year with an absolute relative error of the order of 5%. For the moment in Côte d’Ivoire, SODEXAM only provides monthly mean daily irradiation data in 14 meteorological stations with sometimes missing values. These data do not cover the entire territory of the country. On the other hand, the ESECI tool has the possibility to generate solar radiation values (direct and diffuse components) in all localities of the country and at various time steps without missing values. The solar radiation values obtained will be used to constitute a local database in addition to those of SODEXAM. Availability of a complete and accurate solar radiation database for each specific region of Côte d’Ivoire is essential in the design and study of solar energy systems. These data can help to create local maps of the solar energy potency in Côte d’Ivoire and, on a larger scale, lead to the country’s solar deposit for the purpose of worldwide marketing, designers and manufacturers of solar equipment. Having the solar deposit of Côte d’Ivoire easy to know where to install a suitable solar device. Sizing and design, simulation modeling and rating, economic analysis, performance evaluation, system responses to clouds, implementation studies of solar systems that require multi-scale solar radiation data will be facilitated for the country. However, there is no other way to obtain accurate solar radiation data than by measurements. So, efforts should be made to create a solar radiation measurement network across the country to improve the ESECI tool.

4. Conclusion

We have implemented a solar radiation calculation program for estimating the solar deposit in Côte d’Ivoire. The tool estimates hourly solar irradiances and the monthly mean daily irradiations for any type of sky and on any surface. The comparative analysis of the values obtained by simulation with the measurements made in
Abidjan shows that the tool performed better in clear sky days and for days with uniform cloud cover. On the other hand, the model does not react to frequent cloudy periods during the day. Beyond that, the program estimates the monthly mean daily irradiations with good accuracy throughout a year. The comparative analysis made with real measures in Abidjan has validated the ESECI tool and shows that it is an alternative for the determination of solar radiation at any site in Côte d’Ivoire, unlike SODEXAM, whose scope of weather data is limited to the 14 functional meteorological stations with sometimes missing values. Despite its simplicity, the ESECI model provides consistent solar radiation values in accordance with the different climatic zones of the country while respecting the particularities of each season. By using the ESECI tool, solar radiation values are generated to constitute a database of the solar resource for Côte d’Ivoire useful for the study of solar energy systems.

References