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Papers

Mapping of solar potential for electric micro-generation: The case of the city of Ilhéus

Mapeamento do potencial solar para microgeração de energia elétrica: o caso da cidade de Ilhéus

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Abstract
The aim of this study was to map the solar potential for micro-generation of electricity in the urban center of a medium-sized Brazilian city located in the south of the state of Bahia, Brazil. The method is based on the manipulation, in a geographic information system, of layers of information that represent the characteristics of roofing areas, global solar irradiance and micro-generation of solar energy. The results indicate global solar irradiance values of the order of 4.2 kWh/m^2/day that, when collected by solar panels distributed on the roofs of the city, will produce, on average, 520.5 kWh/month of electric energy per residence. Given this scenario, the city of Ilhéus has the potential to produce 19.76 GWh/month of energy, behaving as a 27.44 MW power plant, equivalent to the output of medium-sized hydroelectric plants and the modern wind farms that can be found in the country.

Keywords: Solar energy, micro-generation, urban center, Ilhéus city.

Introduction

Renewable sustainable energy production sources are gaining increasing prominence amidst growing concern about global climate change caused by the emission of greenhouse gases, principally derived from fossil

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fuel combustion. These greenhouse gas emissions, coupled with the uncertainty on nuclear power production related to the associated potential for environmental tragedies, have meant that so-called “green energy” (hydroelectric, eolic, geothermal, biomass and solar) has gained space, receiving political attention in many countries (Choi *et al.* 2011).

Of the so-called “green resources”, solar energy stands out as one of the most promising alternative sources of energy. In general, solar radiation has a wide range of applications, but interest remains largely concentrated on thermal and photovoltaic processes (Bergamasco *et al.*, 2011).

In Europe, the case of Germany shows the growing application of public polices to incentivize the implementation of solar energy generation, in spite of the country’s moderate insolation potential. The same is true for other European countries like Spain, Italy, Greece and the Czech Republic, where similar public policies have also been enacted. However, the technology for solar energy generation is not yet widespread around the world, and a lack of information seems to be one of the main reasons for it (Súri *et al.*, 2007).

Solar energy can be harnessed to generate electricity either by the use of large-scale, industrial solar energy plants with major power generation capacity, or by means of many small, distributed solar energy production plants, which can be located on the rooftops of commercial or residential buildings. Since they are grid-connected, the dissemination of solar energy generation plants helps the electric system in two ways: by supplying the electricity demands of the building itself and, when excess is produced, by feeding it back into the public grid.

According to Torres (2012), the growth of electric energy consumption in Brazil, which is attributable to both demographic and economic expansion, is contributing to the debate about the energy generation model. In this sense, it is essential to consider a variety of alternatives that can help to provide for the need to expand and diversify the country’s electric generation facilities. In this context, small (residential) solar energy plants can potentially help.

In 2012, the Brazilian Electricity Regulatory Agency (ANEEL) condensed these discussions into the Normative Decision 482 (ANEEL, 2016), which establishes the general conditions for the access of micro and mini-generation systems to the public grid. The ND sets the rules for the electric energy payment system, i.e. the payment that the user (or the microgenerator) receives for the energy fed into the public grid.

According to this resolution, microgeneration consists of electric energy production from small power plants (installed energy generation capacity of less than 100 kW), which use hydraulic, solar, eolic, biomass or co-generation sources, and are connected to the public distribution grid from installations in the consumption units (i.e. residential or commercial buildings). Therefore, this study focusses on the microgeneration of electric energy from solar radiation.

The potential for generation of electric energy from solar radiation varies from country to country, since geographic latitude is the main parameter to determine the annual incidence of solar energy. In this context, the solar generation potential of countries like Brazil is approximately twice as superior as that of Germany (Torres, 2012). Despite that, this energy source is still not widely used in the Brazilian energy matrix. According to the Brazilian Ministry of Mines and Energy, renewable energy sources represent 43.5% of the Brazilian energetic matrix, while solar energy is less than 1%. However, there are estimates supporting that up to 18% of residences in Brazil will install photovoltaic (PV) systems, potentially generating 8,7 TWh of energy, or 13% of the total residential demand. In order to reach such figures, it will be necessary to stimulate consumers (whether residential, commercial, industrial or rural) to move towards the use of renewable energy generation sources, especially photovoltaics. Currently, the register of solar microgenerators available on the ANEEL website (ANEEL, 2017) indicate the existence of 16,209 PV power plants distributed across various Brazilian States, with an installed generation capacity of 180,276 kW.

At each microgeneration plant, solar panels are arranged in accordance with geometrical features relating to the incidence of local solar radiation. In general, solar panels in Brazil should face north and be inclined at an angle (with respect to the horizontal plane) that may vary according to the local latitude. In the case of Ilhéus, with a latitude of 14°47´26"S, it is about 15°. This configuration is compatible with the rooftops typically used in Ilhéus, enabling users to attach the panels to the north-facing rooftops, following the slope of the roof itself. However, the geometry of solar radiation incidence in relation to the arrangement of the panels in the rooftops is not the only factor that can influence energy generation potential, and certain other variables must be considered. Among them, we can include relief and the use and occupation of the land. With respect to relief, generally flat areas are not affected by obstacles and topography. On the other hand, shadows and shading may be pronounced on sloping surfaces, such as in hilly or mountainous regions. With respect to land use and occupation, the features of rooftops, positioning of the land, housing typologies and socio-economic profile can impact on both the configuration and the expected energy production.

The annual energy consumption of a given microgenerator, which reflects the consumer's socio-economic profile, is intrinsically related to and impacts on the sizing the system, with implications for the expected solar energy generation. In general, the total capacity of the solar panels is proportional to the expected amount of energy that one wants to produce. Therefore, consumers of electric energy should have systems designed to be compatible with their energy demands. However, in order to calculate the size of the PV microgeneration system desired, it is also relevant to know how much energy the user is willing to produce to supply its own demand. This can be estimated as being a given fraction of the user's electric energy needs, since the plant can be projected to supply, for instance, 25%, 50% or even 100% of the actual consumption.

To summarize, to provide an estimate for the potential of a given region for solar energy production it is important to know certain variables including geographical position (mainly the latitude), the incidence of the solar radiation field, the positioning in the landscape (relief), the roof's housing typology characteristics and consumer profiles. Nowadays, these different layers of information can be manipulated in geographic information systems (GIS) suites to carry out data cross-correlation and to obtain, as a final product, a scenario for the electric solar energy generation potential of a given place, which, in this case, is the urban area of the city of Ilhéus, located in the south of the state of Bahia.

Methods

We adopted a five-step method was adopted to achieve the objectives of this study, as illustrated in the flowchart in Figure 1.

The objective of the first step was to organize the plano-altimetric cartographic base and then prepare a digital terrain model (hereafter, DTM) of the studied area in a given Geographical Information System (GIS), with a pixel resolution of 1 m^2, compatible with the original cartographic base scaled at 1:2000.

The process that allowed us to build the DTM can be summarized in the following way. As a function of both the size of the urban area of Ilhéus and the existing plano-altimetric database, the cartography was developed with a scale of 1:2000 using digital topographical maps. Besides the plano-altimetric data, such as roadways, blocks and drainage, this database also contains altimetric information in the form of contour lines for every 1m, providing the necessary level of detail to build up a detailed cartographic database.

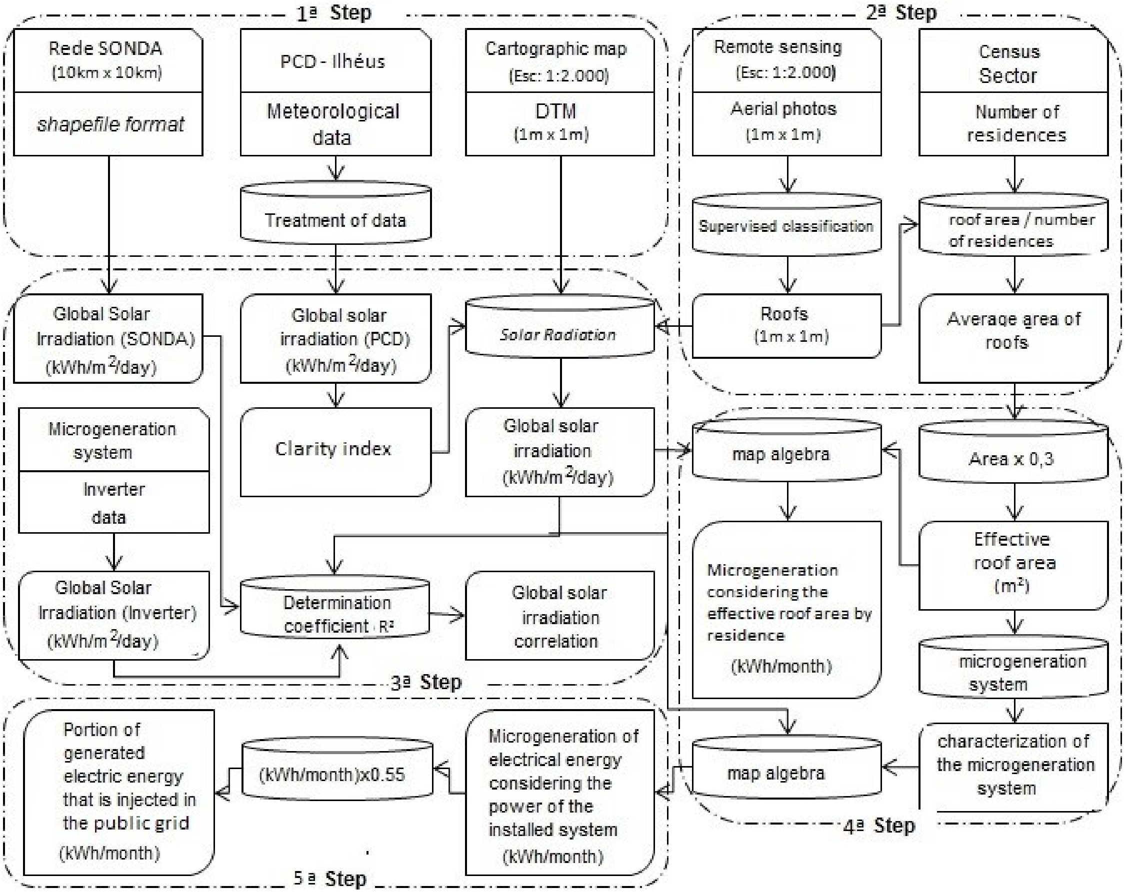
To proceed further and prepare the DTM, both the altimetric and the topographical maps were combined and manipulated in a GIS environment; more specifically using the ARCGIS 10 *Spatial Analyst* module, where the vectorial structure of the contour lines were converted into grids representing the hypsometry of the relief of the area. The pixel resolution obtained in the DTM is 1m by 1m, compatible with the original scale of 1:2000.

In the second step, the rooftops of the city's buildings were mapped using a supervised classification method with images taken from aerial photography, also with a pixel resolution of $1m^2$. To accomplish this task, the tools *Create Signatures* and *Maximum Likelihood Classification*, from (ARCGIS 10) *Spatial Analyst* routine, were used.

The rooftops were classified into three categories: ceramic roof tiles; fiber cement roof tiles; and/or exposed slab roof. Since it is almost impossible to isolate the roofs of every single residential building, especially in densely populated areas, it was decided to measure the total roof area and then divide it by the number of residences (for this given area). The database from the Brazilian Institute of Geography and Statistics' (IBGE) sector censuses (Brasil, 2015) has been employed. Then, an average roof area per residence is used for each census sector. Regarding the roof geometry, it was assumed that it was always flat, since the solar panels can be artificially inclined (i.e., by means of mechanical support) to any desired inclination in order to optimize solar energy harvesting.

The objective of the third step was to map the distribution of solar irradiation in the studied area. Data from two different climate monitoring networks have been analyzed, namely, the Data Collection Platform (in Portuguese, *Plataforma de Coleta de Dados*, or PCD) and the National Environmental Data Organizing System (SONDA) network (in Portuguese: *Sistema de Organização Nacional de Dados Ambientais*; INPE, 2016).

Figure 1: Flowchart showing the five methodological steps



Source: the authors, 2018.

Global solar irradiation data collected locally by a PCD station in Ilhéus was obtained for the years 2001 to 2015. After data processing, a daily mean value was obtained for each month of the year, as described in detail by Pereira *et al* (2017). The SONDA network, on the other hand, provided global solar irradiation in the form of shapefiles (see Pereira *et al*. 2006 for details and interpretation of such files).

In the context described herein, and considering the knowledge of global solar irradiation incidence in the studied area, the representative factors and the physical scale of the collected information are influenced by the accuracy of the mapping to be developed. In the case of the global solar irradiance provided by the SONDA network, the grid pixel has a size of 10 km x 10 km. On the other hand, the PCD data is meaningful only for the very point where the station is located in Ilhéus. Therefore, concerning the mapping proposed for this study, it was necessary to obtain the global solar irradiation in the adopted scale, or in other words, for each pixel of 1 m^2. In this scenario, the local relief represented in the GIS by the DTM will be one of the variables that will influence the global solar irradiation incidence. In order to account for that, the *Solar Radiation* tool from ARCGIS 10 was used.

Solar Radiation is a tool used to analyze the incidence of solar radiation in a given area, based on an algorithm developed by Fu & Rich (2000). Following this method, it is possible to obtain the direct, diffuse and global irradiance for each point, as a function of its position on the topographical surface. As a by-product, we can build maps of solar insolation for the studied area. To run such a procedure, the main entrance parameter in the *Solar Radiation* routine is restricted to the DTM grid generated in the first step of our methodology. Furthermore, it is also necessary to provide the clarity index, which tells us about the mean behavior of the atmosphere (cloud cover) in the studied area. This parameter can be obtained independently by studying the total irradiance for a given day of the year (provided by the local PCD, for every 3 minutes) and comparing it with the expected value at the top of the atmosphere (TOA). The ratio between these two numbers provides the clarity index (Myers, 2013). The PCD data was used to evaluate the clarity index, as well as the *Solar Radiation* tool, and both models were compared in order to validate the mapping performed.

The objective of the fourth step was to quantify the potential for microgeneration of solar energy in each residence using the Map Algebra application of the ARGGIS 10 software. Each polygon of the mapped roofs, together with the global solar irradiation calculated in the preceding step will impact on the energy generation potential. Attention must be paid to the fact that not all of the potential surface is available for installation of solar PV panels. Therefore, it was defined that 30% of the total roofing area obtained in step 2 of our algorithm will actually be used for this purpose. Furthermore, it is also important to consider the efficiency of both the inverter and the PV panels. Table 1 shows different scenarios involving the methodology adopted here, considering typical PV power, area and efficiency. Hereafter, for a certain associated effective/useful area (i.e., the area covered by PV panels on a given roof, which is always 30% of the total roof area), a given number of PV panels as well as a given inverter will be employed, as summarized in Table 1.

Table 1 – Different scenarios for the implementation of microgeneration solar PV energy systems, as a function of effective roof cover of the buildings.

Effective roof area (m^2)	Inverter power (W)	Number of solar panels (250 W)	Area of solar panels (m^2)
< 15m^2	1.500	6	9,6
15 - 25m^2	3.000	12	19,20
25 – 50m^2	5.000	20	32
50 – 75m^2	10.000	40	64
75 – 100m^2	15.000	60	96
> 100m^2	20.000	80	128

Org.: from Authors, 2018.

According to Table 1, an effective roof area of 15 m^2 (maximum) can receive the installation of a 1500 W solar energy microgeneration system, composed of 6 PV solar panels of 250 W (per panel). Since each panel has an area of ~ 1.6 m^2 , the total area in this case will be 9.6 m^2. Consequently, the power of the installed microgeneration plant increases with the effective area available (since more panels can be added until the whole effective area is covered). It should be noted that the values given for the inverter's power are compatible with those that are easily available in the market.

Therefore, to obtain data in the GIS environment the above-mentioned model can be summarized by the following formula: monthly potential for microgeneration of electric energy = {[area of solar panels (m^2) * solar irradiation ($kWh/m^2/day$)] * panel efficiency (0.15)*30}.

In the fifth step, Map Algebra is used again to balance the production of solar electric energy with consumption data, allowing us to evaluate the portion of the solar energy production that would be fed into the grid-tie system (public grid). The potential for solar energy generation obtained for a given studied area (after the fourth step described above) will then be divided into two components: one that represents the quantity of PV energy generation that will effectively be used by the consumers themselves, and the complimentary value (if less than 100%) that will be fed (as an excess in the energy production) into the public grid. We will assume that 45% of the energy generated will be used in the building itself and that the remaining 55% will be fed back into the system. These figures have been obtained from the (temporal) monitoring of a microgeneration plant that is already installed and functioning in Ilhéus city.

Finally, the model will be compared with energy production, self-consumption and feed-in data from a real (i.e., already installed) microgeneration plant. These data have been obtained from a plant located in Ilhéus city, with installed power of 1500 W. The monitoring consists of assessing the difference between the amount of energy generated (measured by the inverter installed in the plant) and the amount of energy fed-in (provided by public utility digital meters, for instance) to the system (i.e., that leaves the building).

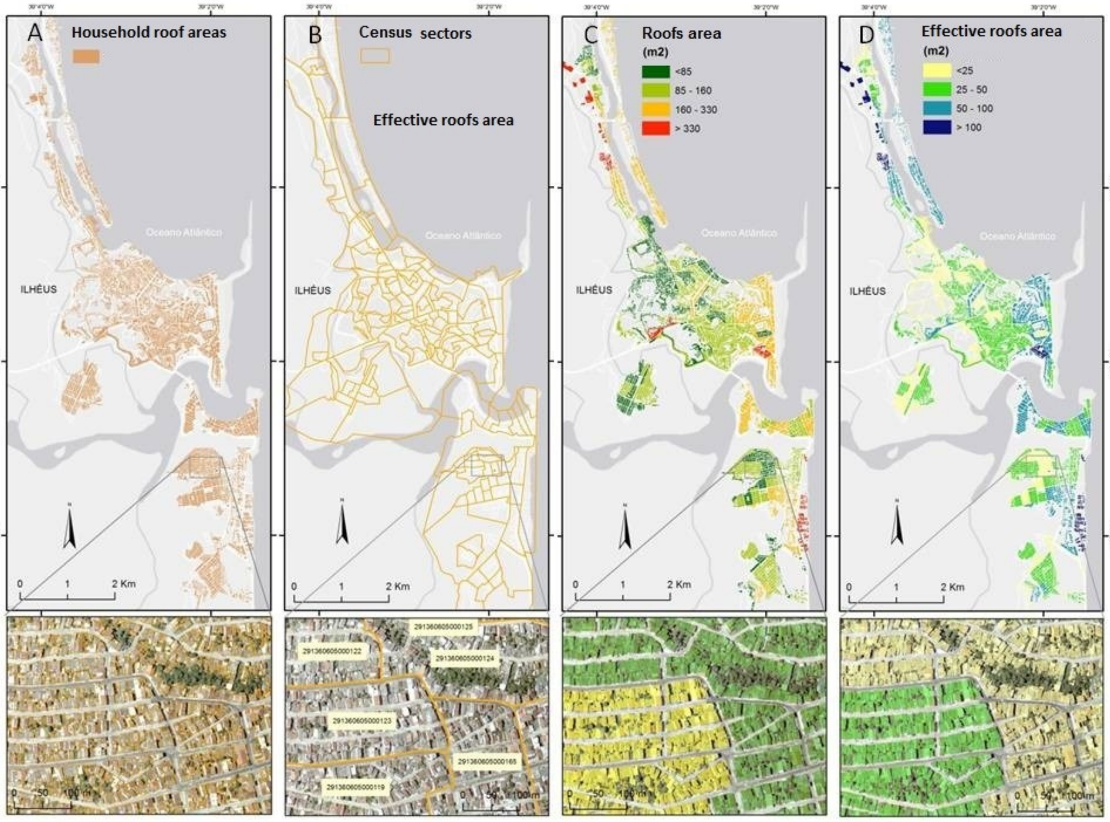
Results

Application of the supervised classification method to the aerial photography images permitted the delimitation of the roofing areas of the buildings (see Figure 2a). As previously mentioned, in the most densely-populated areas the roofs of different buildings were merged by the algorithm, due to their close proximity. We must then bear in mind that, in these specific cases where crowded regions are considered, an average area for the roof (per household) is used instead of individual areas. In any case, we can always calculate a mean value for the roof area, per building, and the result for a given census sector is presented in Figure 2c. These (major) roof polygons have an area of 4.48 km^2, depicting roof areas from a minimum of 23 m^2 up to a maximum value of 707 m^2. The mean value for roof area is 118 m^2. The total number of mapped households is around 38.000.

It is important to re-emphasize that once a value for the roof area is obtained, the effective area that is actually used to model the installation of a given PV micro generating power plant is only 30%. Therefore, the total area covered by the PV solar panels in this context would be 1.34 km^2, varying from 7 to 212 m^2 (for different buildings), with a mean value of 35 m^2 (per building).

Regarding the incidence of solar radiation in the studied area, we know that the incoming radiation field is composed by two components, the direct radiation that comes directly from the sun, and the diffuse radiation that consists of the radiation scattered in the atmosphere (in the case of incidence on a horizontal plane) and may include the contribution of reflected ground radiation (in the case of a surface tilted with respect to the horizontal plane). For inclined surfaces, we must know the local albedo in order to properly take into account the whole diffuse field. For the sake of simplicity, we will not consider tilted surfaces here and all of our estimates will be based on the global (i.e., direct plus diffuse) solar radiation field received by a horizontal surface, thereby discarding the contribution of the ground-reflected component of the albedo.

Figure 2 – Total and effective roof areas per household for the studied area.



Source: the authors, 2018.

We know that both (diffuse and direct) components represent a fraction of the solar radiation field that reaches the top of the atmosphere. The absence of the atmosphere would imply that 100% of the radiation field reaching the ground would be composed of the direct component. The total irradiation that reaches the top of the atmosphere is estimated for each day of the year, assuming that it will be given by Equation 1 below (Liou, 2002):

$$S = S_0 \left(\frac{r_0}{r}\right)^2 \int_{-H}^{+H} \cos\theta \, \frac{dh}{2\pi} \qquad \text{(eq.1)}$$

In this equation, $S_0 = 1366.1 \text{ Wm}^{-2}$ is the solar constant, $(r_0/r)^2 = 1 + 0.033\cos(2\pi d_n/365)$ is the eccentricity correction factor (assumed constant for a given day of the year, d_n) where $r_0 = 1$ astronomical unity, and θ is the solar zenithal angle (considering a horizontal plane); -H e +H are the limits (in hour angle) that correspond to sunrise and sunset, respectively.

This integral has a known analytical solution, and it is given by equation 2 (Liou, 2002):

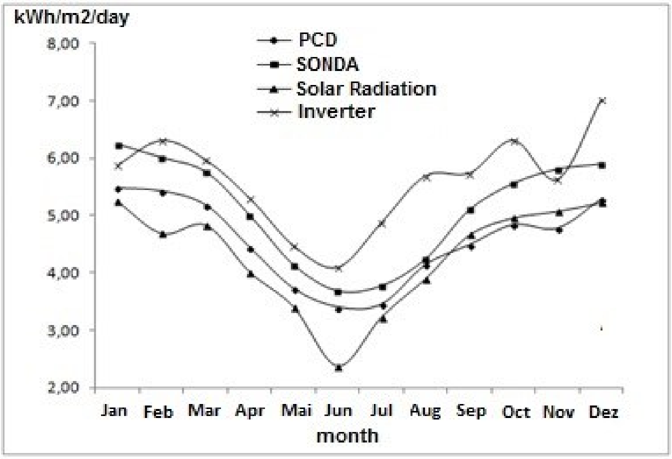
$$S = S_0\left(\frac{r_0}{r}\right)^2 \cdot \frac{1}{\pi}[\mathrm{H} \cdot \sin\phi \sin\delta + \cos\phi \cos\delta \sin H] \qquad \text{(eq.2)}$$

Again, H is the (sunrise) hour angle for the day in question, ϕ = -14.78 is the latitude of Ilhéus and δ is the Sun declination angle. The mean value calculated for the irradiation at the top of the atmosphere is 9.75 kWh/m^2/day. By comparing it with its ground counterpart, we can then estimate the clarity index, which quantifies the mean atmospheric transparency for Ilhéus.

According to Myers (2013), the clarity index can be defined by the ratio between the global solar irradiation field reaching the ground and the irradiation calculated for the top of the atmosphere. This clarity index will effectively evaluate both the atmospheric and climatic influences on the (actual, measured) ground solar irradiation.

In order quantify both the direct and the diffuse radiation fields it is necessary to measure or to model them. When modeled, the values obtained must be compared with those measured for further validation and calibration of the procedures. For the studied area, the SONDA network data was used, providing global solar irradiation ranging from 3.68 up to 6.24 kWh/m^2/day, giving a mean value of 5.1 kWh/m^2/day (see Figures 3 and 4a). With this number and the one that we have already found for the top of the atmosphere, we obtain a clarity index of the order of 0.52 for the studied area.

Figure 3 – Mean daily value, per month, of the global solar irradiation extracted from SONDA (squares), Ilhéus PCD station (bullets), Solar Radiation routine modeling (triangles) and from microgeneration plant monitoring (crosses).

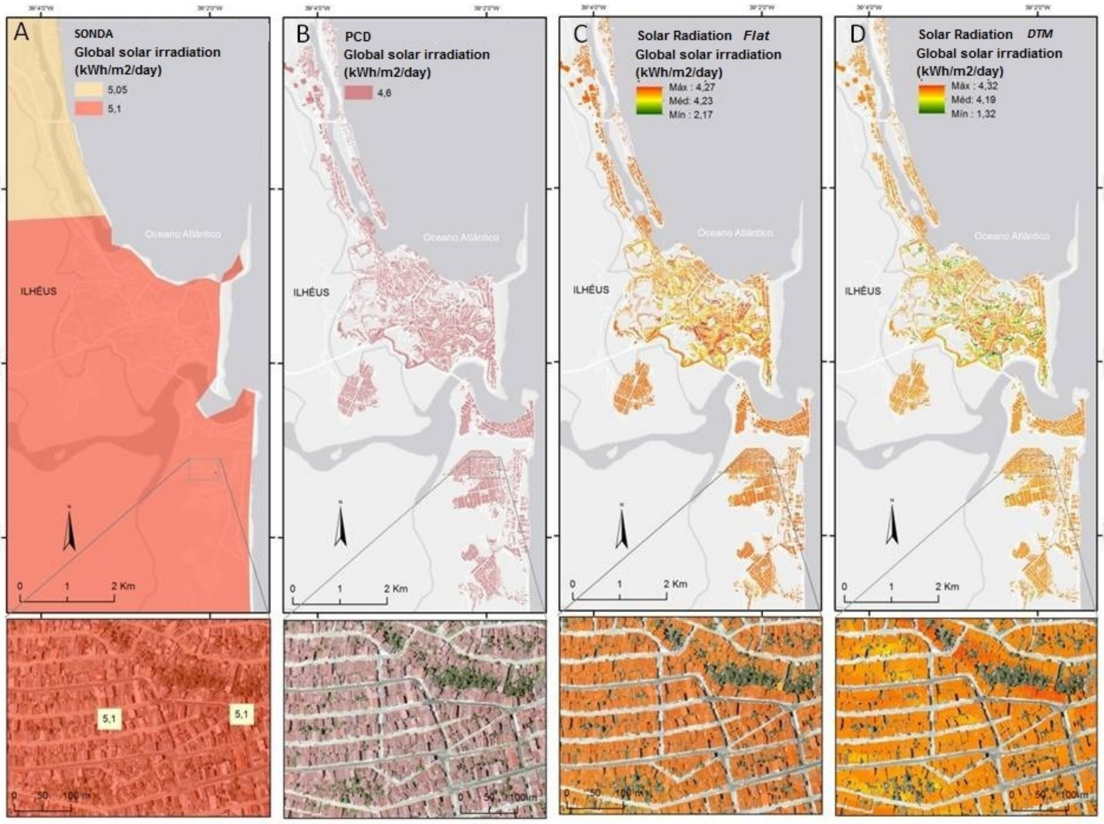


Source: The authors, 2018.

On the other hand, if we consider the Ilhéus PCD data, we obtain on average 4.6 kWh/m²/day for global solar irradiation, which is comparable to but smaller than the figure presented by the SONDA network (5.1 kWh/m²/day). The monthly behavior for the global solar irradiation can be seen in Figure 3. Using the PCD data, we can estimate a clarity index value of 0.47.

Using a clarity index of 0.47 as an input parameter for geoprocessing in the *Solar Radiation* tool, we obtain mean values for global solar irradiation from 4.23 kWh/m²/day (for a horizontal plane) to 4.19 kWh/m²/day (considering the local relief; see Figures 4c and 4d). In the case of the horizontal plane, slight differences in both latitude and shading (promoted by the local relief) are responsible for the departure from the mean value for global solar irradiation. Furthermore, there is also the influence of relief slope orientation, which means that the north-facing ones tend to receive a higher quantity of solar radiation (take into account the whole year). Considered together, these facts may perhaps explain the different daily mean values obtained for global solar irradiation using the *Solar Radiation* application.

Figure 4 – Global solar irradiation obtained from different methods for the studied area.



Source: the authors, 2018.

Data was also analyzed from an already installed solar PV microgeneration plant. This system is located at the coordinates 14°86'S and 39°03'W. Using data collected by the inverter we have been able to estimate global solar irradiation (incident in tilted planes: the PV plates) for each month of the year (daily mean values). It was observed that estimated solar global irradiation varies from 4.10 kWh/m^2/day (in June) to 7.02 kWh/m^2/day (in December), with a mean value of 5.61 kWh/m^2/day. The clarity index evaluated in this way is 0.57, which is slightly higher than the one found using both the SONDA network and the PCD data, as well as that obtained using the *Solar Radiation* tool.

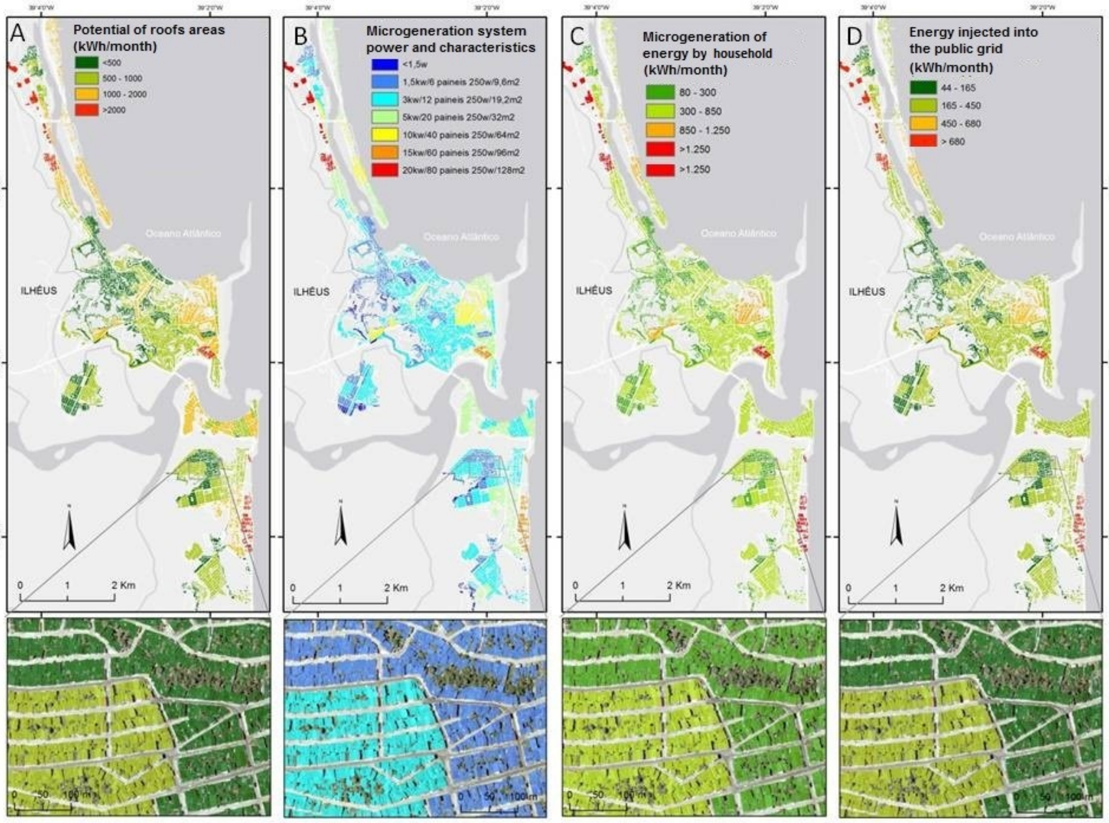
The result from the *Solar Radiation* tool was compared with data from both the PCD station and the microgeneration plant. Using the R^2 statistical coefficient as a correlation parameter, we obtain $R^2 = 0.84$ (from *Solar Radiation* result and the PCD station data) and $R^2 = 0.78$ (from *Solar Radiation* result and the solar microgeneration plant, inverter data).

The higher values for global solar irradiation and the clarity index obtained from the microgeneration plant are actually to be expected since the solar panels are inclined (in relation to the horizontal plane). Furthermore, half of them (3 panels) face towards the North, while the other half face to the West. Although this arrangement of the panels has surely been chosen in order to optimize the plant energy output it will certainly affect our estimates for the global radiation field, since it will contain a significant contribution from the diffuse radiation field.

The detailed knowledge of global solar irradiation for each pixel of the model permitted the estimation of solar energy that should be received by the roof areas and then processed by PV panels in order to generate electric energy. Our results are consistent with a scenario in which the potential for electric energy generation, considering only the effective roof area for the households, attains values from 121.3 kWh/month to 4,048.5 kWh/month, with a mean value of 882.4 kWh/month per household. Figure 5a shows the energy output expected for each micro generation unit, separated into classes.

Once the typology of equipment expected to be used and installed has been defined (see Table 1 and Figure 5a), it is possible to actually calculate the quantity of energy to be generated by the households distributed in different census sectors, as depicted in Figure 5c. The values observed range from 73.14 up to 2,442.8 kWh/month, or 520.46 kWh/month per unit on average.

Figure 5 – Electric energy microgeneration potential and expected values for feed-in to the public grid, for households in Ilhéus-BA.



Source: the authors, 2018.

These data from energy microgeneration are related to the total energy produced by the system inverter once triggered by the PV solar panels. However, once the electricity enters the household's internal circuit part of it can be consumed by electronic devices or home appliances (or other devices that are switched on). Thereafter, only a given fraction will be returned to and fed into the electric public utility. The data from the monitored microgeneration plant showed a ratio of total production to feed-in to the grid of about 0.55. That means that for each 100 kWh of energy produced, 55 kWh will be fed into the public grid. When such a rate is applied to the expected energy production, we estimate that 286 kWh/month/unit will be fed back into the public grid (limited by a minimum of 45.5 kWh/month and a maximum value of 1,343.5 kWh/month, per household; see Figure 5d).

Considering the entire area studied and all of the different systems and roof sizes, our calculations point towards a scenario for electric energy production that amounts to 19.79 GWh/month, with 8.9 GWh/month being consumed at the production units, while 10.9 GWh/month is expected to be fed into the city's grid system in order to supply the demand elsewhere.

Final remarks

Different layers of information were manipulated using a Geographic Information System (GIS) environment, leading to the conclusion that, in the city of Ilhéus, global solar irradiation on a horizontal surface is of the order of 4.2 kWh/m^2 per day. This quantity, when received by PV panels, generates 0.63 kWh/m^2 per day of electric energy, amounting to 19.76 GWh/month when all of the 38,000 households are considered to have an installed PV system of approximately 27 m^2 (this is the mean value expected for the effective roof area per micro generation unit). This is almost enough energy to supply the overall electric energy consumption of the city of Ilhéus, which is 20.3 GWh/month (SEI, 2017).

This prediction is slightly underestimated, however, because an input parameter was used in the models that calculated the clarity index using the values measured in a horizontal plane (data from the Ilhéus PCD station). We should expect that, for the same insolation regime, north-facing tilted surfaces will receive a larger quantity of energy per year when compared with horizontal surfaces (over the period of a year). On the other hand, our estimates are fairly realistic in the sense that this same clarity index considers both atmospheric and climate conditions. In other words, the daily clarity index incorporates the degree of cloud cover and the existence of rainfall and/or particles in the atmosphere. This index is found to vary between two extremes over the year: it can be as low as 0.3 (on rainy days) and as high as 0.7 (with clear skies). In Cerqueira & Gomes (2019), the temporal variability of such an index for the Ilhéus city is explored, along with its season trends and its implications in the forecasting of PV microgeneration behavior.

Based on the present analysis we can predict that Ilhéus city has the potential to generate electric energy that is comparable with a power plant of 27.44 MW, which represents less than 1% of installed capacity for electric energy generation in the state of Bahia (which is 8,016 MW), or, alternatively, of its electric energy generation output of 1,857.4 GWh/month (SEI, 2017). This generation output is equivalent to that of the medium-sized hydroelectric power plants located in Bahia state, such as the Funil (30 MW) and Pedras (20 MW) plants – both operated by the São Francisco Electric Company (or Chesf, in Portuguese) – or with modern Eolic parks, such as Saraíma (30 MW), Pedra Branca (30 MW) and Caetité 2 (30 MW).

In summary, we conclude that a medium-sized city such as Ilhéus, with ~ 180,000 inhabitants, is capable of producing enough electric energy from distributed solar energy PV microgeneration plants to supply its own demand.

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References

ANEEL - Agência Nacional de Energia Elétrica. **Resolução Normativa Nº 482, de 17 de Abril de 2012.** Available in: <http://www.aneel.gov.br/cedoc/ren201248 2.pdf>. Access in: 01 dezembro 2016.

ANEEL - Agência Nacional de Energia Elétrica. **Unidades consumidoras com geração distribuída.** Available in: <http://www2.aneel.gov.br/scg/gd/GD_Estadual.asp>. Access in: 30 outubro de 2017.

BERGAMASCO L, ASINARI P. Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: Further improvements by ortho-image analysis and application to Turin (Italy). **Solar Energy**. 2011; 85: 2741–56. https://doi.org/10.1016/j.solener.2011.08.010

BRASIL. Empresa de Pesquisa Energética. **Retrato dos novos projetos solares fotovoltaicos no brasil**. Available in: http://www.epe.gov.br. Access in: 30 maio 2017b.

BRASIL. Intituto Brasileiro de Geografia e Estatística. **Sinopse do Censo Demográfico 2010. Agregados por setores censitários**. Available in: https://censo2010.ibge.gov.br/sinopseporsetores/. Access in mar. 2015.

BRASIL. Empresa de Pesquisa Energética. **Balanço Energético Nacional 2017 – Ano base 2016: Relatório Síntese**. Available in: <http://www.epe.gov.br>. Access in: 01 dezembro 2016.

BRASIL. Empresa de Pesquisa Energética. **Estudos da demanda de energia - 2050: nota técnica DEA 13/15**. Available in: http://www.epe.gov.br/Estudos/Documents/. Access in: 05 janeiro de 2017.

CERQUEIRA, A.H., GOMES, R.L. Análise histórica da irradiação global no município de Ilhéus/BA. **Revista Brasileira de Energia Solar.** 2019; submetido.

CHOI Y, RAYL J, TAMMINEEDI C, BROWNSON J. PV Analyst: Coupling ArcGIS with TRNSYS to assess distributed photovoltaic potential in urban areas. **Solar Energy**. 2011; 85:2924–39. https://doi.org/10.1016/j.solener.2011.08.034

FU P, RICH P M. **The Solar Analyst 1.0 Manual**. Helios Environmental Modeling Institute (HEMI), USA. 2000.

INPE. Instituto Nacional de Pesquisas Espaciais – **Rede SONDA, Sistema de Organização Nacional de Dados Ambientais.** Available in: http:// http://sonda.ccst.inpe.br/. Access in 01/12/2016.

INPE. Instituto Nacional de Pesquisas Espaciais – **SINDA, Sistema Integrado de Dados Espaciais.** Available in: http://sinda.crn2.inpe.br/PCD/SITE/novo/site/historico. Access in 01/10/2017.

LIOU, K. N. 2002. **An introduction to Atmospheric Radiation**, 2nd Edition, (Elsevier)

MYERS D R. Practical modeling for renewable energy applications. **Solar Radiation**; 2013; CRC Press.

PEREIRA, E.B., MARTINS, F.R., DE ABREU, S.L. E RUTHER, R. 2006, in **Altas Brasileiro de Energia Solar**, INPE.

PEREIRA, Y. C.; GOMES, R. L. ; CERQUEIRA, A. H. Análise de dados históricos de radiação solar acumulada coletados pela PCD de Ilhéus-BA. In: XVII SIMPÓSIO BRASILEIRO DE GEOGRAFIA FÍSICA APLICADA E I CONGRESSO NACIONAL DE GEOGRAFIA FÍSICA, 2017, Anais, Campinas. https://doi.org/10.20396/sbgfa.v1i2017.2465

SEI. Superintendência de estudos Econômicos e Sociais do estado da Bahia. **Sistema de Informações Municipais.** Available in: http://sim.sei.ba.gov.br/sim/tabelas.wsp. Access in 15/10/2017.

SÚRI M, HULD T, DUNLOP E, OSSENBRINK A. Potential of solar electricity generation in the European Union member states and candidate countries. **Solar Energy**. 2007; 81:1295–1305. https://doi.org/10.1016/j.solener.2006.12.007

TORRES, R.C. **Energia solar fotovoltáica como fonte alternativa de geração de energia elétrica em edificações residenciais**. 2012. Dissertação (Mestrado). Universidade de São Paulo, São Carlos, 2012.

IBGE.