An Interactive Tool for Visualization and Prediction of Solar Radiation and Photovoltaic Generation in Colombia

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***Abstract*—This paper presents an interactive tool to visualize solar and meteorological data for 62187 different points in Colombia from 1998 until 2019. Using data with a temporal resolution of 30 minutes and a spatial resolution of 4km^2, four types of averages were calculated for each point, and the resulting data was then displayed using heat maps and five different types of graphs. Additionally, the tool includes two photovoltaic generation models that can be used to get the average generation of a custom solar installation in a specific coordinate. Finally, two different types of linear regression models were defined to obtain the average photovoltaic generation of an installation, and the annual average of five variables in the year 2030.**

I. Introduction

Solar energy has been increasing in popularity over the past decades, mostly because it has a less negative environmental impact than traditional energy sources, as it is renewable and cleaner than fossil fuels. In particular, Colombia is located in the equator and gets abundant solar radiation, but with great variations depending on the location and time of the year [1]. Additionally, Colombia faces several challenges regarding energy supply, relying heavily on hydro-power and with persistently low reserve-to-production ratios in oil and gas. Combined with extreme weather patterns such as El Niño, as well as the advancing climate change, Colombia needs new energy sources, mainly solar and wind, to provide a resilient and reliable energy system. However, due to the vastly different conditions across its territory, high-risk investments, high equipment prices, and insufficient tax incentives, photovoltaic and wind energy are facing many barriers in order to be deployed at a large scale, representing only a 0.1% of installed capacity in 2018 [2].

With the intention of helping decrease the risk in solar energy investments, an interactive tool was created to provide potential investors with more information about solar radiation and meteorological variables in an accessible way. Therefore, the Solar Atlas for Colombia provides historical data in the period 1998-2019, a photovoltaic generation calculator, and linear-regression-based predictions for generation and solar radiation variables in the year 2030. More specifically, the Solar Atlas provides historical data for six solar and meteorological variables: global horizontal irradiance (the total amount of radiation received by a surface horizontal to the ground), direct normal irradiance (the total amount of radiation received by a surface that is always perpendicular to the rays that come in a straight line from the position of the sun), diffuse horizontal irradiance (the terrestrial irradiance received by a horizontal surface that has been diffused by the atmosphere), the solar zenith angle (the angle between the sun's rays and the vertical direction), the average wind speed, and the average ambient temperature. Those variables provide crucial information about the solar conditions of a specific point, which can be used to determine the photovoltaic potential of a system installed there, making it a useful tool that could help develop an energy system based on renewable energy sources.

II. Previous Work

Over the past years, multiple tools have been developed as an effort to collect and allow users to visualize solar radiation and meteorological data in an easy and accessible way. One of the main tools is provided by the National Renewable Energy Laboratory (NREL) [3], which consists of a data viewer tool that provides worldwide solar radiation and meteorological data, shown as multiple base maps and spatial layers that can be accessed through a website.

On a country scale, one of the most complete databases and tools has been developed by the University of Chile in partnership with the Chilean government [4], with the aim of reducing entry barriers to the solar industry in the country. The database provides hourly data from 2004 until 2016 at 90 meters spatial resolution, using cloud detection and characterization methods based on data from GOES EAST satellite, as well as transfer models such as NASA's CLIRAD-SW, to estimate the clear sky solar irradiance.
The Chilean Ministry of Energy developed several tools, known as Explorers, in an effort to provide an accessible and free way of analyzing Chile's renewable resources. In particular, The Solar Explorer [5] is a website that makes

use of the solar database developed, providing an interactive map in which a user can select a specific point and visualize data such as solar irradiance, cloud frequency, ambient temperature, wind speed and elevation. This tool also includes a photovoltaic generation simulator, which allows the user to calculate the electricity generation of a photovoltaic system as if it was installed on a specific point. All data can be visualized in several graphs that show the daily and annual averages of photovoltaic generation, irradiance and other meteorological variables, and the user can compare two graphs from different points at the same time.

Finally, the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) developed the Solar, Ultraviolet and Ozone Radiation Atlas [1], a tool that provides a set of maps that represent the monthly and yearly distribution of global horizontal irradiance, sunshine, number of days without sunshine, ultraviolet radiation, and total ozone, as well as a regional analysis of the yearly average behavior for each variable in the year 2015. The data is taken from 230 global irradiance sensors and 497 sunshine sensors, which is an improvement from the 71 radiometers used and 383 sunshine measurements taken in 2005. However, this tool only has information for the main cities in Colombia in the year 2015, and does not include data for other meteorological variables like wind speed or ambient temperature, whereas the tool proposed in this paper includes data for six different solar and meteorological variables, for all of the Colombian territory, and for 22 years since 1998.

III. Solar Radiation Database and Data Processing

The proposed interactive tool, the Solar Atlas, uses data from the National Solar Radiation Database (NSRDB) [6], a collection of solar and meteorological data that includes three of the most common measurements of solar radiation: GHI (global horizontal irradiance), DNI (direct normal irradiance) and DHI (diffuse horizontal irradiance). The latest version of the database offers gridded data from 1998 to 2019, with a 4×4 km spatial resolution and a temporal resolution of 30 minutes, generated with a physical model known as PSM. This model computes solar radiation from satellite data, specifically by measuring aerosol, water vapor and other meteorological properties, and combining them with satellite-derived cloud properties in the Fast All-sky Radiation Model for Solar applications (FARMS). In addition to the three solar radiation variables, the NSRDB offers data for other atmospheric and land properties such as atmospheric profile, wind direction and speed, snow depth, surface temperature and pressure, which are based on data retrieved from NASA's MERRA-2.

Regarding validation, the latest version of the NSRDB was investigated using surface observations from NREL's SRRL, ARM SGP and SURFRAD sites at Illinois, Nevada, Montana, Mississippi, Pennsylvania, South Dakota, and Colorado. Statistics such as mean bias error, mean absolute error, mean percentage error, and root mean square error were calculated, showing that the GHI values were generally over and underestimated in the eastern and western United States, respectively, with overall percentage biases within 5%. Aditionally, the %RMSEs of the hourly averaged GHI and DNI can reach up to 20% and 40%, respectively, when compared to the surface-based measurements.

Particularly for Colombia, 62187 coordinates were defined using the same spatial resolution provided by the NSRDB, obtaining half-hourly data from 1998 to 2019 for GHI, DNI, DHI, wind speed, surface temperature, and solar zenith angle. It is important to note that, even if the data of the NSRDB was validated using surface observations in several sites in the United States, validation has been very limited in Colombia, with similar work done only in a singular coordinate, as shown in [7]. Due to this, the data in the Solar Atlas is explicitly presented as an initial estimate of solar radiation variables in the country, and the user is warned about the possible inaccuracies in the values.

As mentioned previously, the data obtained from the NSRDB consists of six variables in a temporal resolution of 30 minutes for the period 1998-2019, and for 62187 points defined in a 4×4 km grid in Colombia. For each point, four different types of averages were calculated: daily, monthly, yearly, and hourly by year (a single value calculated for each hour using data from a year, resulting in 24 averages). To show values that better represent the actual behavior of solar radiation variables, only data from the 8:00-17:00 period was used to calculate the yearly, monthly, and daily averages, reducing the amount of zeros that could affect them.

IV. Data Visualization

The Solar Atlas is made up of three main components: interactive maps, historical graphs of the averages, and a photovoltaic generation calculator. In general, a user can select a single point on the map to explore, visualizing a summary of the averages for each variable and several graphs that describe their behavior in the period 1998-2019. Additionally, the user is able to calculate the photovoltaic generation of a system by providing technical information about it. The interactive maps (which represent data from a single year and one of five solar variables), and the historical graphs (that show the calculated averages and historical values of the solar variables) are explained as follows.

A. Variable Maps

There is a map for GHI, DHI, DNI, solar zenith angle, and temperature available for each year in the period 1998-2019. Each map contains the yearly averages of all points, representing the value of the selected variable with a color scale (dark blue for the lowest value and red for the highest). The available maps are shown in Figure 1.

On the left side of the map, there is a summary of the latitude, longitude, elevation, and the yearly averages of the solar radiation and meteorological variables. Inside this panel, the user can access the historical graphs and download the

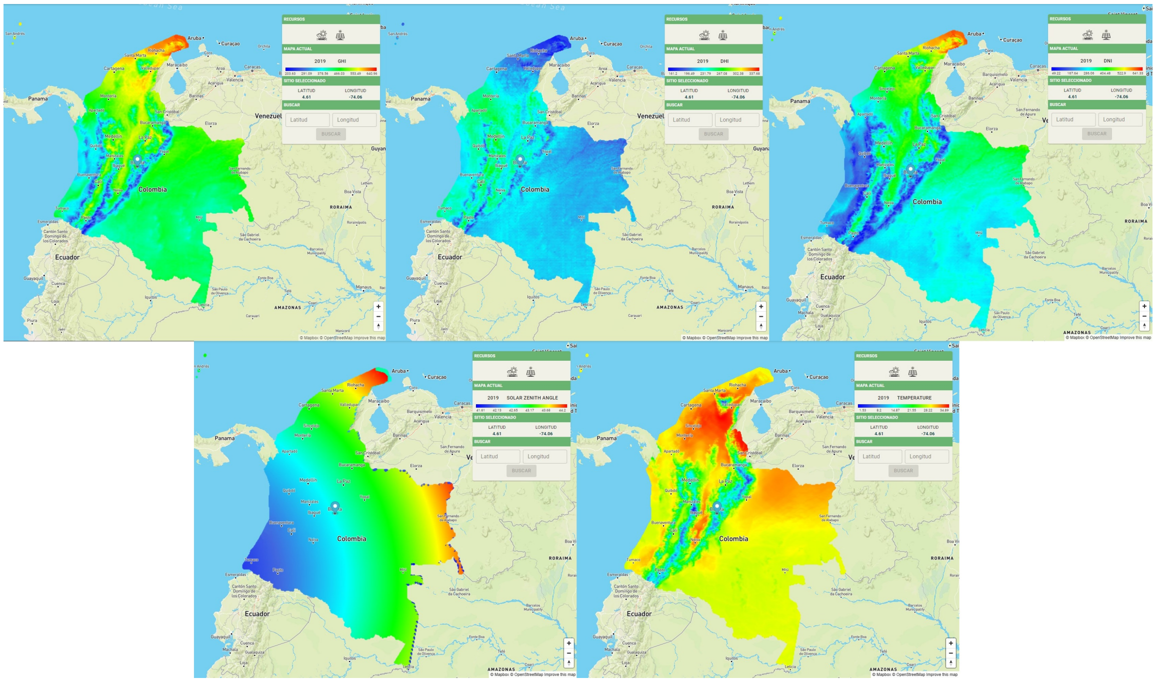

Fig. 1. Available maps (from left to right and top to bottom): GHI, DHI, DNI, Solar Zenith Angle, and Temperature.

averages for the selected coordinate. On the right side, the user can change the current map and access the photovoltaic generation calculator.

B. *Historical Graphs*

The historical data is presented in five different types of graphs depending on the type of averages. Each graph can be generated for the three solar radiation variables, as well as temperature and wind speed. Initially, in the general view of the Solar Atlas, a graph with the global solar radiation (the sum of the diffuse and direct solar radiation) for each month of the current year is shown.

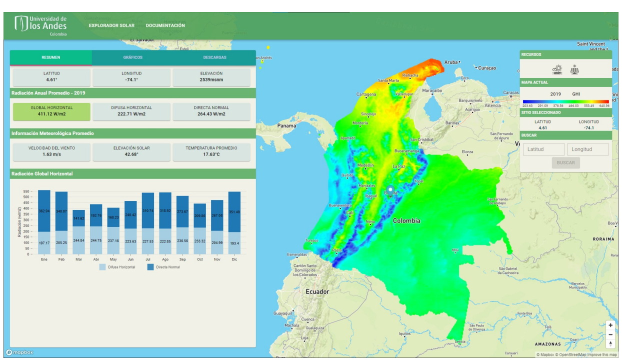

Fig. 2. General view of the Solar Atlas.

In the Graphs tab, the user can generate the following graphs:

1) Monthly Averages: This graph shows the averages per month calculated for a single year. An example can be seen in Figure 4.

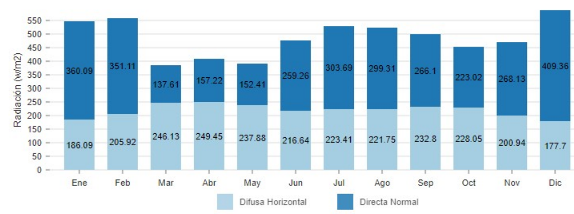

Fig. 3. Global Solar Radiation graph.

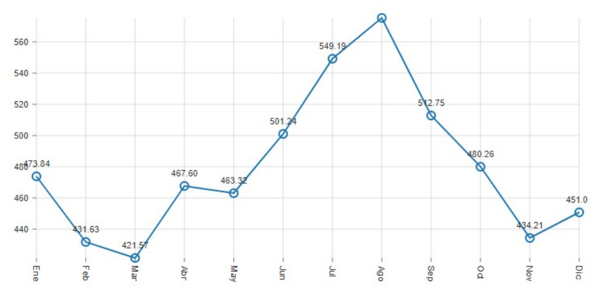

Fig. 4. Monthly Averages graph.

2) Hourly Averages: In this case, the graph shows the averages for each hour calculated using the data of a single year. As illustrated in Figure 5, the averages take into account data from every hour, so low values are still shown to the user.

3) Historical Yearly Averages: The yearly averages in the period 1998-2019 are shown for a single variable. The last value, which appears in a different color, is the predicted average for the year 2030. The method used to calculate this

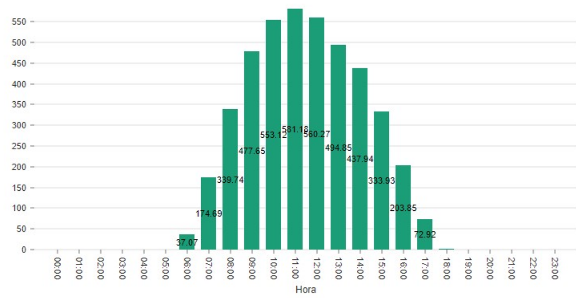

Fig. 5. Hourly Averages graph.

prediction will be discussed in section VI.

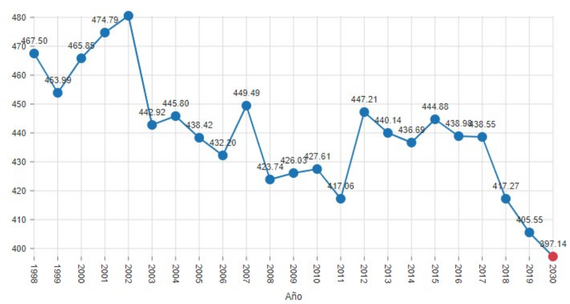

Fig. 6. Historical Yearly Averages graph.

4) Historical Monthly Averages: This graph shows the historical data calculated for each month of all years. A heat map with a color gradient is used, where the highest value is shown in dark blue and the lowest in white.

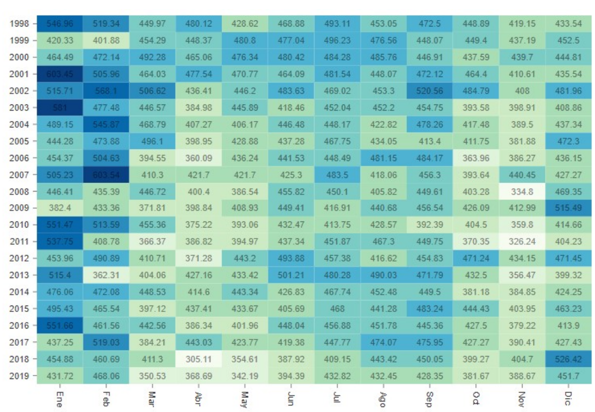

Fig. 7. Historical Monthly Averages graph.

5) Historical Hourly Averages: The final graph shows the historical hourly averages per year, using a heat map with a green scale where the shade is assigned depending on the average value (the highest values are shown in dark green).

V. Photovoltaic Generation Models

The Solar Atlas includes a photovoltaic generation calculator that takes basic information about a solar panel

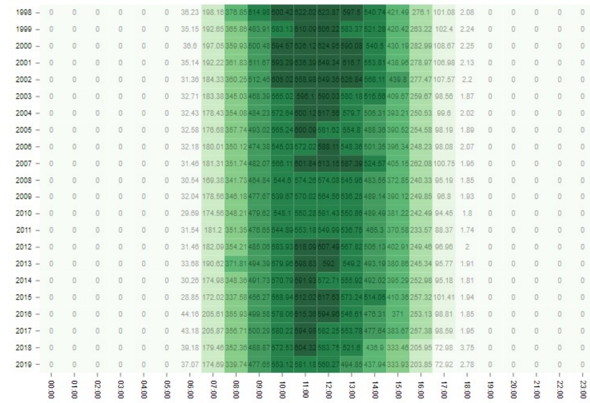

Fig. 8. Historical Hourly Averages graph.

array and calculates the power generation per day and per month. The information needed depends on the generation model chosen by the user, which are based on the models defined in [8], and used in the Chilean Solar Explorer. Each component of the photovoltaic generator calculator is detailed as follows.

A. Inclined Radiation

Both models calculate the power generation of the panel array for each day of a given year. The first variable defined is the declination angle δ, that is, the angle between the equator and a line drawn from the center of the Earth to the center of the sun. This value varies depending on the position of the Earth relative to the sun, so the number of the day d and the latitude ϕ are needed:

$$\delta = 23.45 * sin(\frac{360}{365}(284 + d)) \tag{1}$$

The next variable is the solar angle α, that measures the angle between a line that points to the sun and the horizontal. This is calculated as follows:

$$\alpha = 90 - \phi + \delta \tag{2}$$

The daily averages for the GHI, for the specific coordinate and year selected by the user, are then used to obtain the inclined radiation R_i. Additionally, with the panel array inclination β defined by them, R_i is calculated for each day using the following equation:

$$Ri = GHI * \frac{sin(\alpha + \beta)}{sin(\alpha)} \tag{3}$$

B. Solar Cell Temperature

The solar cell temperature T_c is calculated using the temperature of the panel T_p and the inclined radiation calculated earlier. Initially, T_p is calculated as follows:

$$T_p = Ri \exp^{(a+b*WS)} + T \tag{4}$$

Equation 4 needs the wind speed daily average WS and the ambient temperature average T, as well as the constants a, b and ΔT that depend on the type of setup of the array. Both models support two types of setup: isolated (in this case $a = -3.47$, $b = -0.0594$ and $\Delta T = 3$) or over the roof (where $a = -2.98$, $b = -0.0471$ and $\Delta T = 1$).

With the temperature of the panel, the solar cell temperature can be calculated using the following equation:

$$T_c = T_p + \frac{Ri}{1000}\Delta T \tag{5}$$

C. Nominal Power of the System

The nominal power P_{DCnom}, in kW, refers to the power generated by the panel array in standard conditions, that is, with a global radiation of 1000W/m^2 and a solar cell temperature of 25°C. P_{DCnom} is calculated as follows:

$$P_{DCnom} = \frac{P_{mp}N}{1000} \tag{6}$$

In this case, P_{mp}, in Watts, refers to the maximum power of the panel, and N refers to the number of panels in the array. Both of those variables are defined by the user.

D. Output Power - Basic Generation Model

Equation 7 shows how the power generated by the array of panels changes if the inclined radiation is greater or lower than 125W/m^2.

$$P_{DC} = \begin{cases} \frac{Ri}{Rref} P_{DCnom}(1 + \gamma(T_c - T_0)), & Ri \geq 125W/m^2 \\ \frac{0.008(Ri)^2}{Rref} P_{DCnom}(1 + \gamma(T_c - T_0)), & Ri < 125W/m^2 \end{cases} \tag{7}$$

In both cases, the maximum temperature coefficient of the solar cell γ is used. This constant is given by the user, but a value of -0.5%/°C is commonly used for monocrystalline solar panel cells. In addition to γ, a nominal temperature T_0 of 25°C and a reference radiation R_{ref} of 1000W/m^2 is used.

E. Advanced Generation Model

The advanced generation model is defined based on the I-V curve that describes the behavior of a photovoltaic cell. First, the short circuit current is calculated as follows:

$$I_{sc} = I_{sc,ref}\frac{Ri}{1000}(1 + \alpha I_{sc}(T_c - T_0)) \tag{8}$$

This equation uses the normal short circuit current $I_{sc,ref}$ and the short circuit current temperature coefficient αI_{sc}, both given by the user depending on the type of solar panel being used. The only other constant used in equation 8 is the nominal temperature T_0 of 25°C.
The short circuit current is then used to calculate the current at maximum power of the panel, using the reference current at maximum power $I_{mp,ref}$ given by the user:

$$I_{mp} = I_{mp,ref}\frac{I_{sc}}{I_{sc,ref}} \tag{9}$$

In addition to the short circuit current, the open circuit voltage is calculated with the following equation:

$$V_{oc} = V_{oc,ref} + s\delta(T_c)ln(E_e) + \beta_{Voc}(T_c - T_0) \tag{10}$$

$$E_e = I_{sc}/[I_{sc,ref}(1 + \alpha(I_{sc})(T_c - T_0))] \tag{11}$$

In this case, the reference open circuit voltage $V_{oc,ref}$, the number of solar cells in series s, and the open circuit voltage temperature coefficient β_{Voc} are given by the user. Additionally, the constant $\delta(T_c)$ is defined as 26mV per solar cell. Finally, equation 11 is obtained solving for $\frac{R_i}{1000}$ in equation 8.
The open circuit voltage, and the reference voltage at maximum power $V_{mp,ref}$, are then used to calculate the voltage at maximum power of the panel, as shown in the following equation:

$$V_{mp} = V_{mp,ref}\frac{V_{oc}}{V_{oc,ref}} \tag{12}$$

The DC power generated by the solar panel array is then defined using both the voltage and current at maximum power:

$$P_{DC} = V_{mp}I_{mp} \tag{13}$$

F. DC/AC Inverter and System Loss

The DC power calculated using the basic or advanced generation models can be converted into AC power by defining the efficiency of the DC/AC inverter η. In this case, the default value for this constant is 96%, but the user can change it depending on the solar panel.

$$P_{AC} = \eta P_{DC} \tag{14}$$

The calculator takes into account losses produced by dust (2%), shadows (3%), manufacturing defects (2%), wiring (2%), connectors (0.5%), degradation of the cells caused by incident light (1.5%), down time (3%), and discrepancies between theoretical values and the actual performance of the panel (1%), resulting in a total loss PT of 15%.

$$P_{AC} = P_{AC}\left(1 - \frac{PT}{100}\right) \tag{15}$$

G. Capacity Factor

Finally, the capacity factor is the ratio of the annual average energy production and the theoretical maximum annual energy production of a plant assuming it operates at its peak rated capacity every hour of the year [9]. The System Rated Capacity SRC is calculated using the nominal power of the system, as shown in equation 16.

$$SRC = \frac{P_{DCnom}}{DC\_AC\_ratio} \tag{16}$$

On the other hand, the Annual Energy Production AEP is obtained by calculating the average generation based on the daily power values obtained with one of the two generation models. With the average, the annual energy production is calculated as shown in equation 17.

$$AEP = P_{AC,avg}[kW] \times 24 \left[\frac{hours}{day}\right] \times 365 \left[\frac{days}{year}\right] \quad (17)$$

With the system rated capacity, as well as the annual energy production, the capacity factor is obtained with equation 18

$$CF = \frac{AEP[\frac{kWhAC}{year}]}{SRC \times 24[\frac{hours}{day}] \times 365[\frac{days}{year}]} \quad (18)$$

The resulting array of data, consisting of the power generated by the solar panel array for each day in a specific year, is then used to calculate the average power generation per month, as well as the minimum and maximum power values. The calculator then shows a graph with the calculated values:

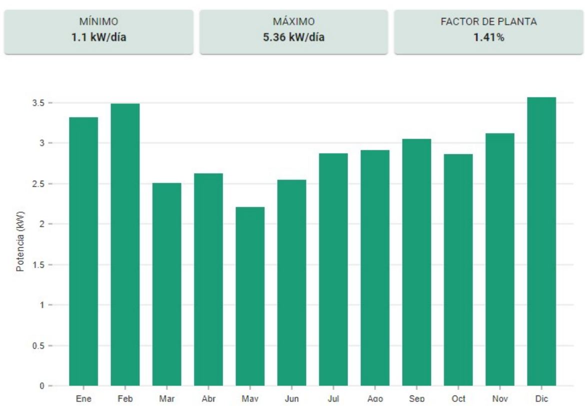

Fig. 9. Average power generation graph.

VI. Radiation and Generation Prediction Models

The Solar Atlas allows the user to predict generation values for the year 2030 by using the same input variables as the ones used by the photovoltaic generation calculator. Similarly, the historical yearly averages graph shows the value predicted for the variable in the year 2030. It is important to note that, because of the small amount of data available to generate a prediction model for a particular coordinate, a Linear Regression was chosen for both scenarios. Therefore, the predicted values are calculated in the short term (9 years), in order to reduce the error and provide a reliable prediction that can be used as a reference by the user.

A. Photovoltaic Generation Prediction Model

In section V, it was mentioned that the generation values are calculated per day for a specific year, thus obtaining 365 (or 366 in leap years) different values. For the purpose of obtaining a similar output for the prediction, 365 linear regressions were calculated for each day and each of the radiation and meteorological variables needed: GHI, wind speed and temperature.

More specifically, the simple linear regression is defined by the two-dimensional linear equation $y = m * x + b$, where the independent variable x refers to the year and the dependent variable y refers to GHI, wind speed or temperature. In this case, the regression takes into account the 22 historical values for a specific day and a specific variable, and obtains two coefficients (a slope and an intercept). For example, to obtain the GHI value for the first day of 2030, a linear regression model is defined with the historical GHI averages for the first day of each year in the period 1998-2019. With the resulting coefficients, the GHI value for the year 2030 is obtained solving for y in the linear equation $y = m(2030) + b$.

With the resulting predicted values, the average power generation predicted per month is calculated by using the same solar array properties given by the user in the calculator. The resulting graph is shown in figure 10.

Fig. 10. Predicted power generation graph.

B. Annual Radiation Prediction Model

In this case, a single linear regression model was defined to get an annual prediction for a specific variable. As with the Photovoltaic Generation prediction model, this regression is defined by the two-dimensional linear equation $y = m*x+b$, where x refers to the year and y refers to one of five variables (GHI, DHI, DNI, temperature or wind speed). Likewise, the annual prediction model takes 22 historical averages as input and returns two coefficients, which are used to predict the annual average in the year 2030 by solving for y in the linear equation $y = m(2030) + b$. The output graph is shown in figure 6.

VII. Technical Description

The Solar Atlas is a website built using a Front-End - Back-End - Database design, that uses a REST API to retrieve data and show it to the user on a web browser. The website is a single-page reactive application, meaning that it is dynamically

updated based on user input, making it similar to a native or mobile app.
Both the Front and Back End were created using NodeJS, a JavaScript runtime environment that allows the execution of JavaScript code outside of a web browser. This allows the Back-End to be continuously listening to requests from the Front-End, effectively working as a server based completely on JavaScript.

A. Database

Because of the nature of the data, the Solar Atlas uses a Document-oriented database, a type of non-relational or NoSQL database that stores data in Documents, which are defined by following a standardized format (in this case data is stored in BSON format). Documents are similar to rows in a relational database, but it is not necessary for two documents to have the same data fields, contrary to rows on a relational table.
The database is implemented using MongoDB, a document-oriented open source NoSQL database system. The data is stored in documents, which contain the values of all variables for a specific average, coordinate, and year. The resulting documents are grouped in collections, which are similar to tables in a relational database, with descriptive names for the year and the type of average that the documents contain. For example, the collection ”1998-d” stores documents with the daily averages in the year 1998.

Collection Name	Documents	Avg. Document Size	Total Document Size	Num. Indexes	Total Index Size	Properties
1998-d	62,187	26.8 KB	1.6 GB	2	1.6 MB	
1998-h	62,187	1.6 KB	99.6 MB	2	1.6 MB	
1998-m	62,187	952.2 B	56.5 MB	2	1.6 MB	
1998-y	62,187	167.0 B	9.9 MB	2	1.6 MB	
1999-d	62,187	26.9 KB	1.6 GB	2	1.6 MB	
1999-h	62,187	1.6 KB	99.6 MB	2	1.6 MB	
1999-m	62,187	952.4 B	56.5 MB	2	1.6 MB	
1999-y	62,187	167.0 B	9.9 MB	2	1.6 MB	

Fig. 11. Example of MongoDB collections created.

Each document contains key-value pairs and a unique identifier (similar to a primary key), so they can be retrieved easily by the Back-End. Additionally, MongoDB allows the definition of indexes to retrieve data in an efficient way. One was defined for the Solar Atlas Database: a two variable index of (latitude, longitude), which speeds up the process of obtaining data for a specific coordinate.

B. Back-End

The Back-End is written in JavaScript, using the Express.js application framework. Particularly for the Solar Atlas, Express was used to create an API that connects with the Mongo Database, retrieving data by defining HTTP endpoints or routes. The general structure of an Express Back-End is shown in Figure 13.

```
{
"_id":"603c7647da3ac82350488fe4",
"latitude":1.93,
"longitude":-78.46,
"GHI":457.61246575342466,
"DHI":256.7941095890411,
"DNI":276.58205479452056,
"Wind Speed":4.0032876712328775,
"Temperature":27.23068493150685,
"Solar Zenith Angle":42.01846027397261
}
```

Fig. 12. Example of a document for the Solar Atlas.

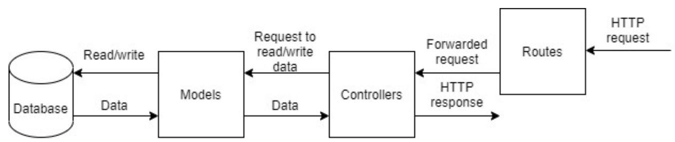

Fig. 13. General structure of an Express Back-End.

Generally, Models define the fields that are stored in each document along with their validation requirements and default values. However, because the data stored in the Mongo database cannot be modified, there are no implemented models and the connection with the database is done directly by using Controllers.
The Controllers are a series of functions that get the requested data from the database (in general they get the data from the models), and return it to the user to view in the browser. In this case, a Mongo client is created using the MongoDB JavaScript library, so Express can create a connection with the database and query data. An example of a Controller is shown in Figure 14.

```
const getYearlyData = (year, latitude,
longitude, callback) => {
  MongoUtils.then((client) => {
    client
      .db("solarAtlas")
      .collection(year + "-y")
      .find({ latitude, longitude })
      .toArray((err, data) => {
        callback(data, err);
      });
  });
};
```

Fig. 14. Example of a Controller in Express.

Express then uses a Router, a special class that acts as a middleware, to read an URL and execute a method depending on its structure. This means that, depending on the URL, the user can access an HTTP endpoint and retrieve specific data, obtaining the corresponding documents in JSON format. An example is shown in Figure 15.

```
router.get("/y/:year/:latlong",
function (req, res, next) {
  latitude =
    parseFloat(req.params.latlong.split("+")[0]);
  longitude =
    parseFloat(req.params.latlong.split("+")[1]);
  getData.getYearlyData(
    parseInt(req.params.year),
    latitude,
    longitude,
    (result, error) => {
      if (error) {
        res.status(500).send(error);
      } else {
        if (!result || !result.length)
            res.status(404).send("Data not found");
        else return res.send(result);
      }
    }
  );
});
```

Fig. 15. Example of a Router in Express.

The router in Figure 15 returns the yearly averages for a specific coordinate and year, and needs a URL that follows the structure ”/y/year/latitude+longitude”. For example, ”http://localhost:3001/y/1998/4.69+-74.1” returns the 1998 averages for the coordinate (4.69, -74.1).

C. Front-End

The Front-End was built using ReactJS, a JavaScript library used to create user interfaces or UI components. In this case React was used to develop a single-page web application, and mainly used to manage states and the rendering state of the Document Object Model (DOM), an interface that treats the resulting HTML document of the website as a tree structure, with each node representing a part of the document.

React is based on entities called components, which are rendered to a particular element of the DOM. A component can receive parameters known as props, which can be simple variables or methods. Most of the components created for the Solar Atlas are functional components, meaning that they are declared with a function that returns a JSX (a hybrid between HTML and JavaScript).

All components have lifecycle methods, which allow the execution of code at set points during their lifetime. Some of the main lifecycle methods are `componentDidMount` (when a component has been created), `componentWillUnmount` (before a component is deleted), and `render`, which is the main method used in the Solar Atlas. Additionally, each component can define states, which are plain JavaScript objects that are managed within the components, similar to variables declared within a function. These states are mostly used to store the current coordinate, year and variable, so that the

```
<div>
    <InfoCard
        coord={selectedCoord}
        onCoordChange={handleCoordChange}
        year={year}
        variable={variable}
        variableLimits={variableLimits}
        content={content}
        reloadMap={reloadMap}
        onYearChange={handleYearChange}
        onVariableChange={handleVariableChange}
        onContentChange={handleContentChange}
        onReloadMap={handleReloadMap}
    />
    <Map
        coord={selectedCoord}
        onCoordChange={handleCoordChange}
        year={year}
        variable={variable}
        variableLimits={variableLimits}
        reloadMap={reloadMap}
        onYearChange={handleYearChange}
        onVariableChange={handleVariableChange}
        onVariableLimitsChange={handleLimitsChange}
    />
</div>
```

Fig. 16. Example of JSX in React.

Solar Atlas can render the corresponding map and retrieve the correct data from the back-end. States also define a function to modify its value, which can then be used with click event listeners or text fields.

Finally, most components define hooks, functions that can be linked to React states and execute code when the state changes. For example, the `useEffect` hook is used inside the app to retrieve data after the component is rendered and when the user selects a point or a year.

On Figure 18, a hook is defined to retrieve back-end data when the coordinate, variable or year is changed. The hook uses the `get` method from the Axios library, which provides an HTTP client for NodeJS to execute the request.

Finally, the user interface was built using the Material-UI library, which provides a set of React components that follow the Material Design pattern. The Solar Atlas uses grid-based layouts in order to create hierarchy and continuity through all components and views, so that the user can easily interact with the app and navigate between features.

VIII. Conclusion

This paper presents an interactive tool and database with solar and meteorological data for Colombia, in the period 1998-2019. The database was built using data from the National Solar Radiation Database, a collection of worldwide solar and meteorological data with a 4×4 km spatial resolution and a temporal resolution of 30 minutes. With a set of 62187 points defined for the Colombian territory, average daily, monthly,

```
const [selectedCoord, setSelectedCoord] =
    useState([0, 0]);
const [year, setYear] = useState(2019);
const [variable, setVariable] = useState("GHI");
const [variableLimits, setvariableLimits] =
useState([0, 0]);
const [content, setContent] = useState(0);
const [reloadMap, setReloadMap] = useState(false);


const handleCoordChange = (newValue) => {
    setSelectedCoord(newValue);
};

const handleYearChange = (year) => {
    setYear(year);
};

const handleVariableChange = (variable) => {
    setVariable(variable);
};

const handleVariableLimitsChange =
    (variableLimits) => {
        setvariableLimits(variableLimits);
};
```

Fig. 17. Example of React states.

```
useEffect(() => {
    if (coord[0] !== 0 && coord[1] !== 0) {
      const getLon = commons.round2(coord[0]);
      const getLat = commons.round2(coord[1]);
      setData(null);

      axios
        .get(
          commons.backendURL + "/api/h/" + year
          + "/" + getLat + "+" + getLon
        )
        .then((result) => {
          if (result.status === 200) {
            var newData = [];
            result.data[0][variable]
            .forEach((hourData, index) => {
              newData.push({
                hour: commons.hours[index],
                Variable: commons.round2(hourData),
              });
            });
            setData(newData);
          }
        });
    }
  }, [coord, variable, year]);
```

Fig. 18. Example of React hooks.

yearly and hourly values were calculated.
As for the data visualization, the averages calculated were represented using a heat map and five types of graphs. The heat map shows the yearly averages for a specific year and for one of five different variables (GHI, DHI, DNI, solar zenith angle, and temperature), and the graphs show historical data for a specific point, including monthly or daily averages for a single year.
Additionally, the tool provides two photovoltaic generation models that allow the user to simulate the behavior of a solar panel installation on a specific coordinate and year. Both models return generation values per day, which are used to get the maximum, minimum, capacity factor, and monthly averages, and visualized with a bar graph.
Finally, predictions for the photovoltaic generation and solar radiation values are also available. The prediction models are based on a two-dimensional Linear Regression, using historical yearly averages to predict the behavior of a solar variable in 2030, or daily averages to estimate the photovoltaic generation of a solar panel array in 2030.

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