TEMPLATE OF TERM OF REFERENCE FOR LEGAL ENTITIES - SBQC

MINISTRY OF MINES & ENERGY – MME
NATIONAL ELECTRICITY SYSTEM OPERATOR - ONS

META PROJECT
Technical Assistance Project for the Energy and Mineral Sectors

WORLD BANK
INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT – IBRD

Loan: 9074 - BR

Term of Reference for Subproject 24-2 of the STEP Acquisition Plan
Contracting of Consultancy 2

Subproject 24-2 – Real-Time Solar Photovoltaic Generation Forecasting

December/2023

TERM OF REFERENCE - TOR of Subproject 24-2 of the STEP Acquisition Plan – Contracting of Consultancy 2

Subproject 24-2 – Real-Time Solar Photovoltaic Generation Forecast.

1 CONTEXTUALIZATION

The expansion of the installed capacity of photovoltaic power stations in recent years, added to the high growth projection of this source, specifically, in the Northeast, South and Southeast regions of Brazil, imposed on the National Electric System Operator (ONS) the need to improve the representation of this highly variable source of generation.

In this sense, it is extremely important that the forecasting of generation by solar photovoltaic source be made with sufficient precision both for the Real-Time Operation of the Brazilian National Interconnected System (SIN) and for the planning of the SIN Electric Energy Operation.

The solar photovoltaic source has several known benefits for Brazil in different levels: in the socioeconomic level, as it generates direct and indirect jobs and savings for the consumer; in the environmental aspect, as it is a renewable resource with less impact compared to the generation of other energy sources, mainly originating from fossil fuels; in the strategic level, given that a high volume of solar radiation reaches the surface in almost all of the Brazilian territory, enabling the implementation of generation closer to the load, which increases electrical safety.

Currently, solar photovoltaic generation accounts for 16% of the energy matrix, including central and distributed power stations. Furthermore, significant growth is expected for the coming years. As an example, the installed capacity of centralized generation at the end of October/2023 was 10 GW, expected to reach close to 19 GW in 2027. In terms of distributed generation, the installed capacity exceeds 23 GW (October/2023), expected to reach 40 GW in 2027.

2 JUSTIFICATION

Solar photovoltaic generation forecasting has uncertainties associated with meteorological factors, causing inevitable deviations, which require a greater operating power reserve to meet load variations, and the need for hydrothermal re-dispatch in cases of significant deviations. Such circumstances increase the cost of operation, generating more charges that reflect higher costs to consumers. Furthermore, the growth potential of solar sources in the Brazilian energy matrix has produces the need to obtain a better prediction of the generation from this source with greater accuracy in the different forecasting horizons, thus contributing to greater assertiveness for the operation of the SIN, and also for planning the Brazilian electrical system.

Therefore, it is important that the ONS has models and tools capable of assisting the system operation with greater predictability and assertiveness in forecasting the generation of this variable source.

3 OVERVIEW OF SUBPROJECT 24-2 OF THE ONS

Within the scope of project META II, the ONS has already started the selection process to contract with the first consultancy for Subproject 24 (Subproject 24-1 – Very Short and Short-term Solar Photovoltaic Generation Forecasting). The major purpose of the first consultancy is to develop a forecasting model for solar photovoltaic generation, considering the short- and very short-term horizon, which spans from one day to one month ahead.

Now, in Subproject 24-2 – Real-Time Solar Photovoltaic Generation Forecasting, we seek to specifically develop a solar photovoltaic generation forecast model, considering the real-time horizon, which extends from minutes to twenty-four hours ahead. The development of this model must include the use of different solar generation forecasting methodologies, considering machine learning techniques, regressive modeling, smart persistence, in addition to using numerical weather forecasting, as well as methodologies for analysis and processing of solarimetric and meteorological data observed *in situ* and derived from satellite.

The structure of the solar photovoltaic generation forecasting model will consist of five major modules:

(i) Database;

(ii) Intrahourly Forecasting;

(iii) Cloud Motion;

(iv) Day-ahead forecasting;

(v) Combined Model

Figure 1 shows the schematic diagram of the model that must be developed in the consultant's environment, following technological architecture specifications compatible with those used by the ONS.

Each module must include the results of studies performed, the computer codes developed, training, documentation, as well as a detailed description of the necessary information for execution. The entire developed structure must be hosted in a computational cloud environment, compatible with the ONS's structure, in order to allow centralized and safe storage.

Each module (I, II, III, IV and V) must be built to work independently, i.e., the input and/or output files must be standardized so they can be used in the execution of all other modules with no previous dependency. An exception to this condition of independence can be seen in module I, where the data can initially be obtained from different sources. However, it is expected that such information will be standardized to feed subsequent modules.

The arrows in the figure indicate a linear flow between the modules, i.e., solar photovoltaic generation forecasts will be produced independently in modules II to IV, using the information available in the database as input. Then, in module V, techniques that make it possible to combine the forecasts obtained independently must be evaluated in order to achieve the best possible forecast of solar photovoltaic generation, considering the real-time horizon of the ONS. It should be emphasized that the generation forecasts must have a time resolution of 5 minutes for the first half hour, followed by a 30-minute interval until 24 hours ahead. Furthermore, the execution of the chain of each module should be configurable to be updated at regular intervals throughout the day.

The details of the functionalities of each module and the data to be provided are presented below.

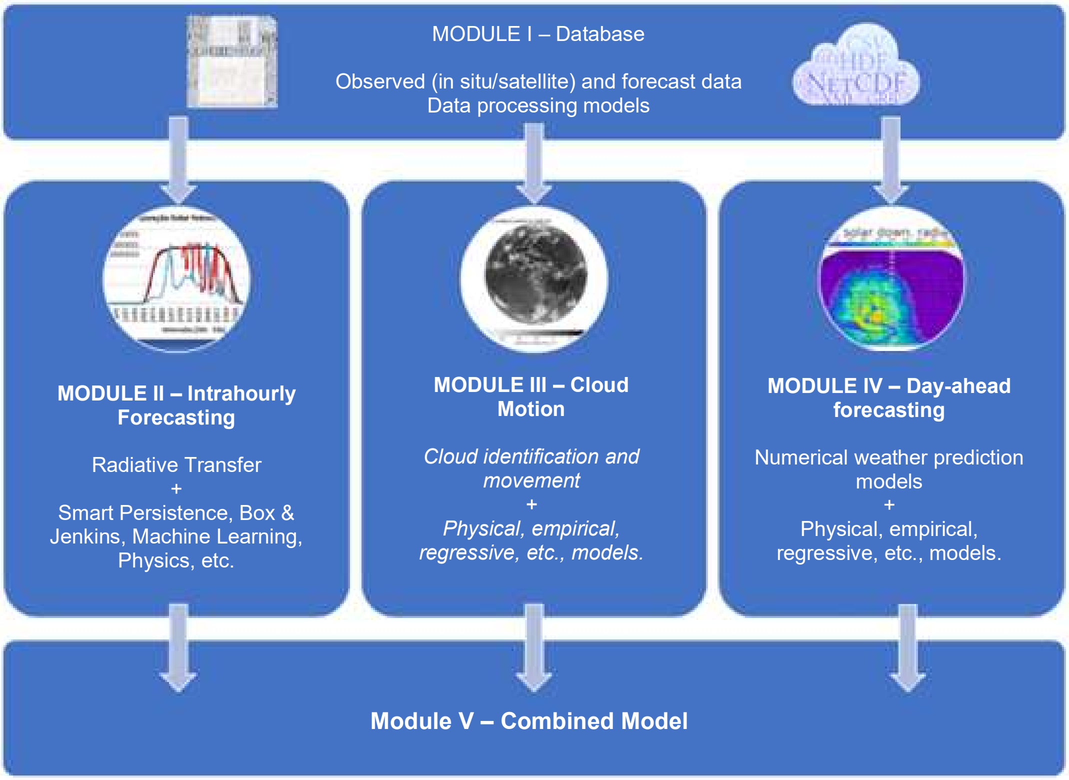

Figure 1 Schematic diagram of the real-time solar photovoltaic generation forecast model

3.1 Database

The five modules that make up the structure for the real-time solar photovoltaic generation forecast will consume and produce data from different sources, types and space-time resolutions. Therefore, a proper architecture is needed for storing and providing data, as well as standardizing such data to be used by modules which are subsequent to the database.

The data that will be used as input for the models may vary in terms of origin and storage format. Image data must be stored in systems that allow versioning and extraction of groups of images quickly, from varying timespans. Satellite data must be properly georeferenced, stored in an optimized way to extract specific information or information from specific areas, allowing the construction of time series of such information. Data observed *in situ* can be stored in databases optimized for time series or, to address horizontal scalability issues, in compressed files in formats optimized for data tables, partitioned according to some aggregation criteria, such as *Apache Parquet*. Plant registry data, such as installed capacity, number of photovoltaic panels, location, panel type, among others, can be stored in relational databases.

Read and write permissions for each piece of data must be configurable, and any accesses or changes must be registered, in order to make the processes performed auditable, safe and reproducible in the future.

In order to make up the database for the studies and development of the models forecast in each module of this project, the ONS will provide a previously structured database, containing observed data from solarimetric and weather stations in Brazil, as well as forecasts from publicly available meteorological models. Furthermore, the format of the files containing such data will be previously defined, in order to enable their use as input for subsequent modules.

Given the natural variability of the solar resource, the project should consider incorporating satellite data into the database, previously provided by the ONS, and also complementary information that is identified as reference and/or relevant information that make it possible to improve the quality of the observed data, as well as the evaluation, validation and correction of solar photovoltaic generation forecasts.

3.2 Intrahourly Forecast

In module II, forecasts of solar photovoltaic generation must be produced for up to 1 hour ahead, with high time resolution.

Different methodologies and techniques have been used in the literature to produce forecasts of solar photovoltaic generation in the intrahourly horizon. Therefore, it will be necessary to review the state of the art of the forecasts in this horizon, in order to define the best techniques to be tested and used to design models that can be developed and tested. The determination of the official model for this module must be made after evaluating a historical period of forecasts, comparing at least two different techniques, so that it is representative to validate the use of the forecasts. The analysis must be based on statistical measures that allow quantifying the quality of forecasts, and must consider at least the seasonality of weather conditions in solar generation power stations.

3.3 Cloud Motion

The forecast of solar photovoltaic generation for a few hours ahead is generally based on cloud motion. Therefore, the ONS needs systems capable of collecting satellite data and images, and processing this information so it can be used as input for developing forecast models for solar photovoltaic generation.

Thus, in module III, a system for collecting and quality controlling satellite images must be developed, which will be used as input for studies that allow identifying cloud cover and forecasting its movement, using things such as cloud vectorization techniques. In addition, physical and optical properties of the cloud cover must be extracted, allowing its subsequent application to radiative transfer models, as well as the evaluation of the cloud cover characteristic and its relationship with the generation of photovoltaic energy.

Then, the result of the vectorization of cloud fields must be used to forecast the movement of clouds through extrapolation techniques. To select the vector that best represents cloud motion, block matching criteria are usually used. Other techniques, however, can be proposed, but must be compared to the one most widely used. Based on the forecast of cloud motion, techniques must be used to calculate the forecast of solar photovoltaic generation for the horizon of up to 6 hours ahead.

The entire system developed in this module, and its respective solar photovoltaic generation forecast model, must be created in an open source programming language, and properly documented, for example, in R or Python language, etc. Furthermore, additional data (such as satellite data) used as input for the solar photovoltaic generation forecast model developed in this module must be integrated into the database (module I).

3.4 Day-ahead forecast

In module IV, forecasts of solar photovoltaic generation must be produced for up to 24 hours ahead, based on forecasts of meteorological variables generated by Numerical Weather Prediction (NWP) models. It should be emphasized that, currently, the forecast of solar photovoltaic generation for 24 hours ahead is made by the ONS using an original methodology, based on Box&Jenkins class models and the estimation of hyperplanes for each half-hour of the day by grouping of photovoltaic power stations. The forecasts made are specific, i.e., based on deterministic photovoltaic generation paths.

Forecasts produced by NWP models can be improved/enhanced using post-processing techniques such as bias correction techniques. Then, such forecasts must be used to produce the solar photovoltaic generation forecast, using different methodologies (e.g., regressive models, artificial intelligence/machine learning), in order to select the most appropriate one for the model to be developed in this module.

A historical period of forecasts must be evaluated so that it is representative for validating the model developed in this module, considering at least the seasonality of meteorological variables throughout the year. Forecasts should be validated by comparing observed data from solarimetric stations and from weather station networks. The analysis must be based on statistical measures that allow quantifying the quality of irradiance and solar generation forecasts.

3.5 Combined Model

Module V of the real-time solar photovoltaic generation forecast model must integrate the forecasts produced in previous modules, creating a single forecast for up to 24 hours ahead, which can have a time resolution of 5 minutes in the first half hour, and 30 minutes for up to 24 hours ahead.

In this module, a performance evaluation of previously developed models must also be performed, in order to determine weights for the generation forecasts obtained, so that the final forecast can be optimized for real time, or even generate a probabilistic forecast of the photovoltaic solar generation for all solar farms. Therefore, different performance evaluation techniques and combination of forecasts must be used and evaluated to design the final model. All codes developed must be provided and properly documented.

4 PURPOSE & SCOPE

4.1 Project purposes

The purpose of the project is to provide highly accurate solar photovoltaic generation forecast models for application to the real-time horizon, i.e., up to 24 hours ahead. The models must consider the use of different techniques and methods, according to the scope of the forecast, as well as different input data, such as meteorological variables, technical data from solar farms, historical generation series, satellite data, and forecasts from numerical weather prediction models. These models must meet real-time operation processes.

4.2 *Specific scopes and goals*

Although the focus of this project is real-time solar photovoltaic generation, the products of this project provide benefits beyond such scope. Among the activities planned for development, the construction of a model capable of combining solar photovoltaic generation forecasts with different time resolutions, as well as different scopes, stands out. For this, the combined model must employ forecast evaluation techniques, applying weight to different methodologies of solar photovoltaic generation forecast. The studies applied to the development of this model will provide a significant gain to the ONS, allowing the methodology applied here to be used in other areas that use forecasts, such as wind generation, load and streamflow forecasts.

The subproject will also allow the ONS to have their own system for acquiring satellite images, which can be used in other areas of the organization, contributing with real-time weather monitoring activities, for instance, in addition to serving as input for future developments associated with Distributed Micro- and Mini-Generation (DMMG) forecasts.

Furthermore, it is expected that this subproject can contextualize the state of the art of the methods applied to forecasting solar photovoltaic generation in the intrahourly horizon.

Taking these aspects into account, it should be emphasized that, in addition to monitoring and managing this subproject, the ONS is interested in the technical team taking part in all of the specification and development stages, maintaining the exchange of information, technical knowledge, experiences, aiming at absorbing the technologies studied and adopted in this project, considering the possibility of expanding the use of these technologies to other areas of the ONS. All models and tools tested and analyzed, even if they do not show good results for this project, must be briefly documented to meet the interests and goals of the ONS in order to add knowledge, given that their use may be interesting for other areas that perform forecasting and monitoring within the Operator.

To achieve the specific goals, the products from this project will be validated by the technical team. Validation details will be covered later in this document. The ONS values the transparency of its processes with agents in the electricity sector. Thus, it is understood that society will be able, at an appropriate time, to have access to the detailed documents and records of the technologies, mathematical models used and/or developed, as well as the algorithms of the forecast models, which will be open source and documented. Therefore, after the completion of the project, the ONS will own the rights to the delivered products, and may use, change and disclose all or part of the products.

5 EXPECTED RESULTS & PRODUCTS

5.1 Structure required to operationalize the solar photovoltaic generation forecast system

The operationalization of the real-time solar photovoltaic generation forecast system must include the methodological developments and the adequacy of the computer infrastructure in force at the ONS. Although the implementation of the system in the operational routine of the ONS is a later step, it is important to develop this system considering the environment in which it will be used. Therefore, deliverables involving operational models are expected to include an environment in which it is possible to perform such models, in order to enable their validations.

5.2 Expected products

The project is split into five macro steps, which correspond to the development of each of the modules shown in Figure 1. In Tables 1 to 5, the expected products for the project steps and their respective stages are listed.

Table 1 - Products of Subproject 24-2 Step 1 – Contracting with Consultancy 2

Products	Activities
Product 1	Organization and processing of the database

Table 2 - Products of Subproject 24-2 Step 2 – Contracting with Consultancy 2

Products	Activities
Product 2	Literature review on the state of the art and determination of methodologies for intrahourly solar photovoltaic generation forecast
Product 3	Development of the clear sky model
Product 4	Prototype of intrahourly forecast models using the selected methodologies
Product 5	Solar photovoltaic generation forecast for the intrahourly horizon

Table 3 - Products of Subproject 24-2 Step 3 – Contracting with Consultancy 2

Products	Activities
Product 6	System for acquiring satellite images, identifying and forecasting cloud
Product 7	Prototype of the cloud motion forecast model and its application in forecasting solar photovoltaic generation
Product 8	Solar photovoltaic generation forecast based on satellite data

Table 4 - Products of Subproject 24-2 Step 4 – Contracting with Consultancy 2

Products	Activities
Product 9	Obtaining the numerical weather prediction and defining variables of interest for forecasting solar photovoltaic generation
Product 10	Prototype of the solar photovoltaic generation forecast model for the 24-hour horizon, using forecasts from NWP models
Product 11	Solar photovoltaic generation forecast for the 24-hour horizon, using forecasts from NWP models

Table 5 - Products of Subproject 24-2 Step 5 – Contracting with Consultancy 2

Products	Activities
Product 12	Prototype of the combined model for solar photovoltaic generation forecast, considering the probabilistic forecast
Product 13	Solar photovoltaic generation forecast using the combined model

6 SCOPE OF WORK AND PROJECT BOUNDARIES

The project is split into five steps, namely:

(i) the first step related to the structuring of the database and developing methodologies for processing and making up records, if necessary;

(ii) the second one is focused on the development of a solar photovoltaic generation model for the intrahourly horizon;

(iii) the third step is associated with the development of the solar photovoltaic generation forecast model based on satellite data and cloud motion forecast;

(iv) the fourth step corresponds to the forecast of solar photovoltaic generation for up to 24 hours ahead, based on forecasts from NWP models;

(v) the fifth and final step refers to the development of the combined model, which will produce the solar photovoltaic generation forecast for the entire real-time horizon.

The ONS will provide a previously structured database, made up of data seen at solarimetric and weather stations in Brazil, as well as forecasts from meteorological models which are publicly accessible. It should be emphasized that the availability of observed data of a private nature will be made by respecting the confidentiality terms associated with the data. If the need to use other verified or forecast data not contained in the database is identified, this information must be defined, structured, made viable and delivered by the consultant during project development.

In addition, considering the state of the art of the numerical modeling of the atmosphere, the use of other numerical weather prediction models which the ONS does not yet have operationally may be proposed. If the consultant has to incur operational or acquisition costs to use data history or model history from other institutions, the cost-benefit ratio involved must be submitted and discussed with the technical team of the ONS. If the execution of NWP models not operationally executed by large meteorological centers is proposed, all relevant information for future implementation must be detailed, such as version of the model(s), initial and boundary conditions, parameterizations used and settings. The validation(s) must be submitted, comparing with existing numerical models and observed meteorological data. The consultant must present the benefits that using these non-operational models can bring to the ONS, in comparison with other publicly available models. In this case, they must also follow the ONS guidelines for operating the model(s) indoors, respecting the infrastructure available for execution, or in a third-party environment, providing all necessary information.

There are several products in this subproject based on computational implementation of mathematical models for generation forecast. However, some of the software products must be used in chain by the ONS, i.e., assigning the outputs of a program to the next one in the sequence. The entire body of software developed for a given product must respect common design standards, i.e., have standardized input arguments and output objects. Thus, products containing deliverables of computer codes of the project become modular and may be developed independently.

It should be emphasized that all computer programs delivered must be so along with their respective user manuals and technical documentation. In addition, training meetings must be planned for its implementation, which can be held online or in-person as agreed upon between the ONS and the consultant. In this regard, the development team must propose, at first, a training schedule, with possible adjustments depending on the complexity and/or need for clarification by the technical team of the ONS. It should also be emphasized that all of the codes/programs/systems, as well as documents, must be thoroughly tested and validated by the consultant before the deliverables in the milestone of each product, as each deliverable will undergo validation and approval by the technical team of the ONS.

In addition, it should be emphasized that the architecture of the developed systems must be adequate to the infrastructure used by the ONS.

The forecasts produced by the models developed in this project must at least include the real-time horizon, that is, up to 24 hours ahead, considering different time resolutions along the horizon. To comply with the processes of the ONS, model results must be updated throughout the day, as new observations and forecasts become available. It should be emphasized that individual forecasts per power stations will be needed, which will be added later, according to the needs of the various processes of the ONS.

The following items describe in detail the products of each step, presented in Tables 1 to 5. A proposal meeting the demand for all requested products must be presented, describing them clearly, coherently and with the proper level of detail so that one can understand how each product will be developed. Deliverables involving the development of codes must include a user manual containing instructions for installing and executing each code, and the codes must be properly commented. In addition, as previously mentioned, products including the final versions of the models to be executed by the ONS must include the proper training to the technical team of the ONS.

For the purposes of this subproject, all information passed on by the ONS shall be considered confidential, as well as all products developed in this subproject shall be the exclusive property of ONS.

6.1 Step 1: Structuring of the real-time solar photovoltaic generation forecast database

This step consists of a single product, which consists of structuring a reliable, robust database that can be used in the development of the real-time solar photovoltaic generation forecast models.

The quality of data from solar farms, as well as data from other sources, must be assessed. This data must be consolidated and organized, containing a structure that enables future data to be incorporated, in addition to receiving data from other modules of this subproject, such as satellite data that will be used in module III.

The specific needs to be addressed in this step are presented in their single product below.

6.1.1 Product 1: Organization and processing of the database

Information with the verified data history, grouped by power plants, will be used extensively in the development of all other products of this subproject. Therefore, it is of great importance that this data is easily accessed not only during the execution of the project, but also after its completion.

As the amount of information tends to scale over time and with the number of existing instruments and power stations, it is necessary to make considerations regarding the performance of the system that stores and provides the data.

In this product, an environment must be structured for storing verified and processed data using methodologies that allow the automatic consistency of the data provided by the ONS. This environment must also be capable of providing data with a performance that enables the execution of applications developed in all other products of this project.

In addition to the verified data, ideally, this environment must be scalable to store data from different meteorological models, which must contain the same quantities/variables, but with different space and time resolutions, besides to satellite data. Thus, the entire project can be developed with quick access to data for training, validation and execution of the models associated with each product.

All data must be written and stored in a standardized manner, in order to facilitate its use to all other planned modules. The database environment must be built using the resources and flexibility of public cloud technology, with due access constraints upon authentication and authorization for reading and writing information. The technology will be defined, collectively with the consultant, during the development of this product, in order to identify what best meets the needs of this project in line with the infrastructure of the ONS.

The following must be delivered at the end of the development of this product, along with the database:

(i) documentation with the description of the variables contained on the base, and how they are written/read;

(ii) documentation describing the data processing process;

(iii) architecture diagram;

(iv) database structure creation scripts;

The database must be structured in order to receive the data used in this step and all of the information of all products developed in this project. This product will be validated by the technical team of the ONS, based on a test plan proposed by the consultant in order to assess database efficiency, as well as the existence of possible bugs. If the database provisioning step involves infrastructure automation steps, the means must be provided for the technical team of the ONS to be able to reproduce what was done.

6.2 Step 2: Development of solar photovoltaic generation forecast methodologies and models in the intrahourly horizon

Different methodologies and techniques have been used in the literature to produce solar generation forecasts according to the horizon and time resolution of the forecast. For intrahourly forecasts, several techniques can be applied using data and knowledge models (regressive models, models based on artificial intelligence, smart persistence models, etc.), together with radiative transfer models, mainly applied to clear sky conditions.

In this step, a model must be developed to produce solar photovoltaic generation forecasts for the horizon of up to 1 hour ahead, with high time resolution. However, before starting to develop the model, the consultant must make a literature review on the state of the art of solar photovoltaic generation forecasts in the intrahourly horizon. This literature review must support the choice of appropriate methodologies to develop the official model. Next, the model design process must begin by using and adapting a model for clear sky conditions, using techniques associated with the radiative transfer process. Finally, the methodologies considered most appropriate for intrahourly forecasting, considering the specificities of the ONS, must be applied to produce the solar generation model. This methodology will be validated by the technical team of the ONS and the official model to be used in the horizon of this step will be chosen. It should be emphasized that forecasts must be continually updated, considering their high time resolution and the availability of new data.

Therefore, this step consists of 4 products which will be further detailed as follows.

6.2.1 Product 2: Literature review on the state of the art and determination of methodologies for intrahourly solar photovoltaic generation forecast

Due to the growing number of techniques and methodologies that can be applied to design a solar photovoltaic generation forecast model for the intrahourly horizon, the state of the art on this topic must be well-known. Thus, this product must include a literature review based on scientific articles, dissertations, theses, technical notes, as well as other documents which can characterize what has been used in the major centers responsible for forecasting solar photovoltaic generation in the world.

After collecting this information, a pre-selection of techniques that may be more appropriate to the Brazilian reality must be made, considering the data provided by agents in the industry, measured in solar farms, and the suitability of different models and techniques that may be tested and applied by the ONS. After this collection, the consultant must point to a set of models that can be developed and tested in a future product. These models and techniques will be pre-selected along with the technical team of the ONS.

The primary deliverable of this product will be a report containing the literature review, and methods that allow analyzing the methodologies and techniques that can be applied to the development of the intrahourly generation forecast model for the ONS. The major methods to be used must be evidenced in this report. The proposal regarding this product must describe, in a clear and structured manner, the procedures to be adopted to provide all the requested information.

6.2.2 Product 3: Development of the clear sky model

The forecast of intrahourly solar photovoltaic generation can be made using different techniques and methods, however, models based only on data can produce forecasts that have no physical sense, exceeding the maximum generation that could be obtained, i.e., the generation in a certain time with a clean atmosphere (clear sky conditions, without aerosols and/or gases that absorb solar radiation). Therefore, having a clear sky model suitable for the conditions observed in solar farms is important, whether to act as a limiter for data and knowledge models, such as regressive models or models based on artificial intelligence, or to be used as a reference for smart persistence models.

Therefore, in this product, a model capable of forecasting irradiance in solar farms under clear sky conditions must be developed. If systematic errors are identified in the forecasts produced, methods to correct such errors must also be studied and implemented.

The delivery of this product comprises the technical report with the description of the radiative transfer model used to calculate irradiance under clear sky conditions, as well as the technique for removing possible systematic errors. The developed computational codes must also be delivered, along with a user manual, describing the model's input/output data and containing its instructions for execution.

It should be emphasized that, to evaluate the proposals which are inherent to this product, in addition to the clarity and level of detail of the procedures that will be used, the technical team of the ONS will consider the originality of the proposal, the suitability of the proposed clear sky model, and the techniques and metrics appointed for the removal of errors and validation of the model developed. Furthermore, it is important to emphasize that the model developed in this product can also be applied to other modules of this subproject, seeking to improve irradiance and/or solar photovoltaic generation forecasts.

6.2.3 *Product 4: Prototype of intrahourly forecast models using the selected methodologies*

After the indication of the best methods and techniques to be used for the development of solar photovoltaic generation forecast models in the intrahourly horizon, through the literature review proposed in Product 2, the prototypes of the solar photovoltaic generation forecast models must be developed in this product for up to one hour ahead. Based on comparisons with the observations, this product must also indicate which model has the best performance to be operationally implemented.

Thus, the delivery of this product corresponds to the codes of the model prototypes to be developed and evaluated, along with a detailed technical report, indicating the performance of the models. The analyzes performed must emphasize the potentialities and possible inabilities of the tested models. The report must also describe in detail the techniques used to develop the prototypes of the models, and will be used as a reference for choosing the solar photovoltaic generation forecast model in the intrahourly horizon that will be operationally implemented.

The proposal for this product must describe, in a clear and coherent manner, how the performance of the model will be assessed, as well as a brief indication of the models, methods and techniques that may be suitable for testing is expected, even if they have not been defined.

6.2.4 *Product 5: Solar photovoltaic generation forecast for the intrahourly horizon*

This product consists of the implementation and operation of the model indicated as the most suitable for forecasting solar photovoltaic generation in the intrahourly horizon, from the performance evaluation performed in Product 4.

The model must be adapted for operation in an operational environment to be agreed upon between the consultant and the technical team of the ONS. It is expected that the model will be able to make forecasts in an operational manner, using, as input data, those available in the database that will be structured in Product 1 and have a standardized output to be used in module V of this subproject. The time for performing the model cannot be an impediment to its operational application, and, if it depends on long training times, these must be previously performed, at times other than that of the forecast. The model must undergo a period of operational validation with the ONS, which must verify their performance for a minimum period of one week. It should be emphasized that the forecasts produced by this model must be continually updated, considering both the high time resolution at which they are produced and the availability of new data.

The consultant must offer proper training to the technical team of the ONS, in order to ensure the maintenance of the operational execution of the model.

The final delivery of this product must include a user manual for the model, containing the specification of the methods used, as well as instructions for its installation and operation. In addition, all codes developed must be provided in an open source language. If any operational flaws are found, the consultant must make adjustments to repair the model, which will be tested again for a minimum period of one week.

For this product, the technical team of the ONS will evaluate the level of detail of the information provided in the proposal, with the technical recommendations and adequacy of the implementation of the model with the ONS. The computer language that will be used to develop the model will also be considered, as well as the indication of a test routine for operational validation of the model.

6.3 Step 3: Development of solar photovoltaic generation forecast methodologies and models using satellite data

Among the techniques used for forecasting real-time solar photovoltaic generation, the one based on cloud motion forecast can be emphasized. Therefore, in this step a system for acquiring satellite images and data must be developed, followed by the employment of techniques for identifying and/or vectoring clouds, in order to forecast cloud cover movement. Based on cloud motion forecast, it is expected that a solar photovoltaic generation forecast model can be developed for the horizon of up to 6 hours ahead. The forecasts of this model must be continually updated, according to the availability of new satellite data and to the time resolution of the forecasts to be proposed.

All of the codes developed for satellite data acquisition, along with the systems used for identification, cloud motion forecast, in addition to the solar photovoltaic generation forecast model itself, must be provided at this step. Below is a more detailed description of the products to be delivered.

6.3.1 Product 6: System for acquiring satellite images, identifying and forecasting cloud motion

The main input for forecasting the solar photovoltaic generation of module III is cloud cover observed by satellite. Thus, this product corresponds to the development of a system to acquire observed satellite data, followed by the identification of clouds to forecast their movement.

The system to be developed must be able to geo-reference the acquired data, and also validate its quality. Furthermore, it is expected to be possible to extract physical and optical properties from the cloud cover, allowing its subsequent employment and use along with radiative transfer models, as well as an assessment of the characteristic of the cloud cover and its relationship with the generation of solar photovoltaic energy.

The system must be developed in an open source programming language, and must be able to write standardized files to be used as input for the model to be developed in Product 7. The files with the acquired satellite data must make up the database structured in module I of this subproject. The developed system must respect the infrastructure available with the ONS for internal execution.

Based on the data acquired and stored in the database, an algorithm must be included in this system to identify clouds according to their characteristics. Several satellite channels/bands can be used together to identify the cloud cover, or even level 2 or 3 satellite products, since they are temporally adapted to the needs of real-time solar photovoltaic generation forecasting. The characteristics of the cloud identification system must be described according to the method adopted, indicating its strengths and weaknesses. Furthermore, the algorithm developed here should indicate the cloud blocks, at each satellite observation time step, which will then be used to forecast cloud motion.

Finally, based on the identified cloud cover, the developed system must forecast cloud motion. One of the techniques that can be used must consider the grouping of pixels with cloud cover and its vectorization, however, alternatives to this technique can be proposed. The methodology used to forecast cloud motion must be described in the user manual. As mentioned before, the entire system must be written in open source code, which will be validated by comparing cloud motion forecasts with observed data.

Thus, the delivery of this product corresponds to the source code of the developed system, and its respective documentation, containing a user manual with a description of the code, as well as instructions for installing and running the system, in an operational manner.

The proposal must properly state the satellite images and data that will be acquired, as well as the techniques used to extract properties and characteristics of cloud cover, as well as justify the data that will be acquired, sizing the necessary database structure. The techniques to be used for detecting and forecasting cloud motion must also be properly appointed, showing how cloud cover blocks will be identified, and what technique will be used to forecast cloud motion. The cloud motion forecast horizon must be proposed by the consultant, and will be considered in the evaluation of the proposal, as well as the methods for evaluating the performance of such forecasts. Finally, the originality, coherence and clarity of the activities proposed for the development of this product will be evaluated.

6.3.2 Product 7: Prototype of the cloud motion forecast model and its application in forecasting solar photovoltaic generation

Based on the cloud motion forecast, developed in Product 6, this product should describe the methodologies that can be used to forecast solar photovoltaic generation by applying cloud motion forecasts.

In addition, a prototype of the solar photovoltaic generation forecast model must be developed in this product. The performance evaluation provided in Product 6 should also be used here to define the solar generation forecast horizon, as well as the time resolution used in the forecasts.

The delivery of this product corresponds to the source code of the model prototype developed with a report containing a description of the methodology used in its development and a description of the model input data.

6.3.3 Product 8: Solar photovoltaic generation forecast based on satellite data

This product is the implementation and operation of the model proposed in Product 7. The model must be adapted for operation in an operational environment to be agreed upon between the consultant and the technical team of the ONS. The model must make the forecasts in an operational manner, and its output must be standardized to be used in module V of this subproject. Just like the model designed in module II, the time for performing this model cannot be an impediment to its operational application and, if it depends on long training times, such step must be previously performed, without affecting the performance of the forecast in real time.

The model must undergo a period of operational validation with the ONS, which must verify their performance for a minimum period of one week. The forecasts produced here must be continually updated, according to the availability of new satellite data and to the time resolution of the forecasts to be proposed.

The consultant must offer proper training to the technical team of the ONS, in order to ensure the maintenance of the operational execution of the model. If any operational flaws are found, the consultant must make adjustments to repair the model, which will be tested again for a minimum period of one week.

The final delivery of this product must include a user manual for the model, containing the specification of the methods used, as well as instructions for its installation and operation. In addition, all codes developed must be provided in an open source language.

For this product, the technical team of the ONS will evaluate the level of detail of the information provided in the proposal, with the technical recommendations and adequacy of the implementation of the model with the ONS. The computer language that will be used to develop the model will also be considered, as well as the indication of a test routine for operational validation of the model.

6.4 Step 4: Development of solar photovoltaic generation forecast methodologies and models for the 24-hour horizon, using forecasts from NWP models

In order to encompass the whole real-time solar photovoltaic generation forecast horizon, using forecasts from NWP models is also appropriate. Global and/or regional models can be used to obtain the forecast of meteorological variables which are intrinsic to solar generation, and, based on the forecast of these variables, produce generation forecasts for up to 24 hours ahead.

Therefore, in this step, we seek to develop a system for forecasting solar photovoltaic generation based on the forecast of meteorological variables derived from numerical weather prediction models. Below is a more detailed description of the products to be delivered.

6.4.1 Product 9: Obtaining the numerical weather prediction and defining variables of interest for forecasting solar photovoltaic generation

The forecasts of meteorological variables of interest for forecasting solar photovoltaic generation can be obtained from the outputs of operational models from major meteorology centers around the world, such as the USA's National Centers for Environmental Prediction (NCEP), and the European Center for Medium-Range Weather Forecasts (ECMWF), maintained by several countries in the European commonwealth, or by models to be acquired or implemented operationally in the ONS by the consultant.

In this product, the variables predicted by NWP models that will be used in the solar generation forecasting process must be defined and obtained. The need to continually update these forecasts throughout the day is emphasized, considering they are updated every 6 hours. To obtain forecasts of meteorological variables, 3 possibilities for the system to be developed should be considered:

- If the consultant chooses to use publicly available forecasts, the codes developed for obtaining the forecasts must be provided to the ONS;

- If the alternative chosen is to acquire results from operational models that need to be acquired at a cost, the benefits that the use of such models can bring to the ONS must be presented, in comparison with other publicly available models, and also a cost estimate must be prepared for the ONS to produce generation forecasts based on the suggested models. Furthermore, a comparison of forecasts with a history of observed data of at least 3 years must be presented. In this case, the consultant must also provide all of the codes developed to obtain forecasts;

- If the need to use NWP models that are not operationally implemented by large meteorological centers is diagnosed, the consultant may propose using such models, presenting the benefits that they can bring to the ONS, in comparison with other publicly available models. The consultant must detail, in a report, all of the information which is relevant for future implementation, such as the version of the model(s), initial and boundary conditions, domains to be used, physical parameterizations adopted, settings, data flow and computer structure. In this case, they must also follow the ONS guidelines for operating the model(s) indoors, respecting the infrastructure available for execution, or in a third-party environment, providing all necessary information. Finally, the consultant must provide all of the codes necessary to execute the suggested model(s). The codes must be properly commented, in order to facilitate training the technical team of the ONS or of third parties for their execution.

As delivery of this product, the consultant must provide a user manual for the system developed to obtain forecasts of the meteorological variables of interest, with a detailed description of each step of the developed system, in addition to full instructions for implementing it. This system must produce a log file, detailing the execution of each step of the process, and also pointing out any execution errors that may occur. The consultant must offer proper training to the technical team of the ONS, in order to ensure the maintenance of the operational execution of the developed system.

Furthermore, the consultant must provide a report justifying the option for the meteorological variables to be used in the process. To evaluate the proposal presented for this product, the technical team of the ONS will consider the level of detail of the information provided in the proposal, with the technical indications and suitability of the system implementation with the ONS.

6.4.2 Product 10: Prototype of the solar photovoltaic generation forecast model for the 24-hour horizon, using forecasts from NWP models

This product is the definition of a methodology which is appropriate to forecast solar photovoltaic generation on the horizon of up to 24 hours ahead, using the forecasts of meteorological variables obtained from Product 9, followed by the development of the model to forecast generation using the methodology stated.

Several methods can be used to forecast solar photovoltaic generation using the forecasts of meteorological variables from NWP models, such as empirical methods, regressive methods, methods based on artificial intelligence or even physically based methods. In this regard, the consultant must, at first, survey such possibilities, pointing out the advantages and disadvantages of each method, so that the most appropriate one to forecast generation can be defined, considering the location of solar farms in the different Brazilian regions. Then, the solar photovoltaic generation forecast model for the horizon of 24 hours ahead must be developed.

The delivery of this product corresponds to the source code of the prototype of the developed model, as well as a report containing a description of the methodology used in its development, and a description of the input data and output files.

6.4.3 Product 11: Solar photovoltaic generation forecast for the 24-hour horizon, using forecasts from NWP models

This product is the implementation and operation of the model proposed in Product 10. The model must make the forecasts in an operational manner, and its output must be standardized to be used in module V of this subproject. The time for performing the model cannot be an impediment to its operational application. The need to update forecasts throughout the day is emphasized here, i.e., it is necessary to consider updating forecasts every 6 hours, as new outputs of the NWP model are obtained.

The model must undergo a period of operational validation with the ONS, which must verify their performance for a minimum period of one week. The consultant must offer proper training to the technical team of the ONS, in order to ensure the maintenance of the operational execution of the model. If any operational flaws are found, the consultant must make adjustments to repair the model, which will be tested again for a minimum period of one week.

The final delivery of this product must include a user manual for the model, containing instructions for its installation and operation. In addition, all codes developed must be provided in an open source language.

For this product, the technical team of the ONS will evaluate the level of detail of the information provided in the proposal, with the technical recommendations and adequacy of the implementation of the model with the ONS. The computer language that will be used to develop the model will also be considered, as well as the indication of a test routine for operational validation of the model.

6.5 Step 5: Development of the combined model for obtaining the real-time solar photovoltaic generation forecast

The solar photovoltaic generation forecasts produced in Step 2, Step 3 and Step 4 are made for different time horizons and have different resolutions. Thus, in this step, a model capable of combining these forecasts must be developed in order to generate a unified forecast, both deterministic and probabilistic, of solar photovoltaic generation in the real-time horizon. This model must be able to receive the operational forecasts produced by the previous modules, evaluate the performance of each of them, considering their horizons, and give weights to their contributions to obtain the official generation forecast. Mathematical tools which are appropriate to evaluate forecast performance must be used, as well as to select the method to be used to determine forecast weights. At the end of this step, the ONS will have a model that is suitable for real time, which will be used to forecast all of the solar farms with centralized generation of the SIN.

Below, each of the products of this last step of the project is presented in more detail.

6.5.1 Product 12: Prototype of the combined model for solar photovoltaic generation forecast, considering the probabilistic forecast

In order to determine the weight of each model's contribution for the final forecast of real-time solar photovoltaic generation, it is necessary to, at first, evaluate the performance of such forecasts. The consultant must propose metrics to evaluate the performance of the models developed and operationalized in the previous products/steps. Such metrics will be used to determine the contribution of each of the previous methodologies for the final official forecast.

Models which are capable of better evaluating and distributing these weights can be proposed. Such models can be based on regressive and/or artificial intelligence techniques. Therefore, it is necessary to evaluate and justify using the technique to be adopted.

As weights are used for solar photovoltaic generation forecasts, they can be used to produce a probabilistic solar photovoltaic generation forecast in the real-time horizon. In order to optimize this process, this product also requires the production of such probabilistic forecast, resulting in scenarios of maximum and minimum forecast generation, as well as the use of quantiles representing the dispersion of the forecast, in order to assist decision making in an operating environment.

A minimum evaluation period must be considered in order to cover the seasonality of solar generation behavior in different regions of the country. All of these aspects must be evidenced in the consultant's proposal in a clear and detailed manner, and will be considered for evaluating the proposal.

The delivery of this product corresponds to the source code of the developed model, as well as a report containing a description of the methodology used in its development, and its advantages and disadvantages compared to other methods. The report must also contain an evaluation of the performance of models developed in previous modules, in order to support the adopted options.

6.5.2 Product 13: Solar photovoltaic generation forecast using the combined model

After defining the model that will determine the weights of forecasts in Product 12, it must be implemented in the operating environment.

This product consists of adapting the model developed for operation in the ONS operating environment. It is expected that the model will be able to go through a validation round, which will verify if it presents the results that were obtained during its development. Graphical outputs of the forecast results should also be proposed here, in order to support the monitoring and updating of forecasts during real-time operation.

In the final delivery of this product, the model is expected to perform its forecasts in an operating environment, consuming data from appropriate sources, in specified formats and producing output data for the same environment. It is also expected that the time required to implement the model will not be an impediment to its operating application.

This is the final product and target of the subproject, therefore, the consultant must deliver the product with enough time in advance to allow interaction with the ONS and monitoring of execution in the ONS environment for a minimum period of 2 weeks. If corrections are necessary, a period will be agreed for monitoring after the adjustments made by the consultant have been completed. After the operationalization and due corrections, if any, the ONS will verify the accuracy of the information for a minimum period to be agreed with the consultant. In addition, situations of failures in the process which have not been previously forecast may occur during this period, and require corrections, if such failures are associated with the consultant's development.

Along with the operationalized model, including the graphical outputs of the generated forecasts, a user manual for the model must be provided to the ONS, containing all of its specifications, as well as instructions for its installation and operation. The consultant must also offer proper training to the technical team of the ONS, in order to ensure the maintenance of the operational execution of the model.

For this product, the technical team of the ONS will evaluate the level of detail of the information provided in the proposal, with the technical recommendations and adequacy of the implementation of the model with the ONS. The computer language that will be used to develop the model will also be considered, as well as the indication of a test routine for operational validation of the model.

7 DEADLINE/SCHEDULE

The following schedule will independently address each of the steps of Subproject 24-2. The deadlines are defined in calendar months, from the beginning of the project, and the period of the products can run in parallel. The total period of the agreement, including all of the steps, must be 17 months.

All products that require delivery of codes must include training on how to use such codes.

In addition, weekly or fortnightly meetings should be planned to discuss the progress of activities. Such meetings shall be adjusted according to project needs.

7.1 Step 1 – Structuring of the real-time solar photovoltaic generation forecast database

Step 1 consists of structuring a reliable, robust database that will be used in the development of the real-time solar photovoltaic generation forecast models.

This step consists of a single product, which involves not only the preparation and structuring of the database, but also the preparation of all documentation that describes it, also containing the computer codes necessary for its formation. Table 1 characterizes the deliverables of this step, and also points out the estimated duration for the development of this product and its percentage agreement value. Payment in installments is considered according to the specificity of each by-product. It should be emphasized that, in general, a gradual increase is considered for the portions of deliverables of the products of this subproject, i.e., the values of the last portions of each product will, in most cases, be higher than the values of the first portions.

The number of deliverables is described under "Deliverables" in Table 1, and each delivery must occur at the end of the designated period, which is calculated by the ratio of the total product time by the number of deliverables. For instance, for Product 1, a partial report must be delivered in the middle of the 2nd month (containing all of the research within that work period), and at the end of the 3rd month, a final report (containing everything that was achieved, including the descriptive documentation of the database and possible computer codes which are necessary for its maintenance/updating). It should be emphasized that the final delivery must comprise all partial deliveries, however, there may be separate documents, since not all research items used during product development need to be referred to in the final document.

Table 1 STEP 1 activity schedule.

Expected Product				Duration	% of the agreement
Product	Type	Description	Deliverables		
1	Report, development and training	Database preparation, with documentation pertaining to its structuring and means of access	(Partial delivery, at the end of 45 days, of the Report containing the description of the environment) + (documentation and implementation of the database + codes and training by the end of the 3rd month)	3 months	6% in 2 installments

7.2 Step 2 — Development of solar photovoltaic generation forecast methodologies and models in the intrahourly horizon

In Step 2, a model will be developed to produce solar photovoltaic generation forecasts for the horizon of up to 1 hour ahead, with high time resolution. This step comprises the delivery of 4 products, and the delivery schedule for each product, with its duration and percentage value of the agreement, is shown in Table 2.

Table 2 STEP 2 activity schedule

Expected Product				Duration	% of the agreement
Product	Type	Description	Deliverables		
2	Report	Literature review on solar photovoltaic generation in the intrahourly horizon, and determination of the forecasting methodologies to be developed	(Report with partial description at the end of the 2nd month) + (Final report by the end of the 4th month)	4 months	8% in 2 installments
3	Report, development and training	Development and Implementation of the radiative transfer model for clear sky conditions	(Partial description at the end of the 2nd month) + (codes and manual + training at the end of the 4th month) + (final report by the end of the 5th month)	5 months	8% in 3 installments

4	Report and development	Prototype and performance evaluation of models tested for intrahourly forecast	(Partial description at the end of the 2nd month) + (Partial description at the end of the 4th month) + (codes of developed prototypes + final report by the end of the 6th month)	6 months	10% in 3 installments
5	Report, development and training	Implementation and operation of the model for intrahourly solar photovoltaic generation forecast	(Partial description at the end of the 1st month) + (codes and manual + training at the end of the 3rd month)	3 months	5% in 2 installments

7.3 Step 3 — Development of solar photovoltaic generation forecast methodologies and models using satellite data

Step 3 is aimed at developing a forecast model for solar photovoltaic generation based on the cloud motion forecast observed by satellite. This step involves the development of 3 products, whose delivery schedules, with their duration and percentage value of the agreement, are shown in Table 3.

Table 3 STEP 3 activity schedule

Expected Product				Duration	% of the agreement
Product	**Type**	**Description**	**Deliverables**		
6	Report, development and training	Satellite images acquisition system, cloud identification and cloud motion forecast	(Partial description at the end of the 2nd month)+ (Partial description at the end of the 4th month) + (codes and manual + training + final report by the end of the 7th month)	7 months	12% in 3 installments
7	Report, development and training	Development of the solar photovoltaic generation forecast model using satellite data	(Partial description at the end of the 2nd month) + (codes + final report at the end of the 5th month)	5 months	8% in 2 installments

8	Report and development	Operating implementation of the solar photovoltaic generation forecast model using satellite data (product 7)	(Partial description at the end of the 1st month) + (codes and manual + training at the end of the 3rd month)	3 months	5% in 2 installments

7.4 *Step 4 – Development of solar photovoltaic generation forecast methodologies and models for the 24-hour horizon, using forecasts from NWP models*

In Step 4, a system for forecasting solar photovoltaic generation will be developed based on the forecast of meteorological variables derived from numerical weather prediction models. The step consists of the delivery of 3 products, and the delivery schedule for each of them, with their durations and percentage agreement values are shown in Table 4.

Table 4 STEP 4 activity schedule

Expected Product				Duration	% of the agreement
Product	**Type**	**Description**	**Deliverables**		
9	Report, development and training	System for obtaining forecasts of meteorological variables	(Partial description at the end of the 2nd month) + (codes and manual + training + final report by the end of the 4th month)	4 months	7% in 2 installments
10	Report, development and training	Development of the solar photovoltaic generation forecast model using NWP	(Partial description at the end of the 2nd month) + (codes + final report at the end of the 4th month)	4 months	7% in 2 installments
11	Report, development and training	Implementation of the solar photovoltaic generation forecast model using NWP	(Partial description at the end of the 1st month) + (codes and manual + training at the end of the 3rd month)	3 months	5% in 2 installments

7.5 *Step 5 – Development of the combined model for obtaining the real-time solar photovoltaic generation forecast*

The fifth and final step of this subproject involves the development of a model capable of combining the forecasts made in modules II, III and IV, in order to generate a unified forecast of solar photovoltaic generation in the real-time horizon. The step involves the development of 2 products, whose delivery schedules, with their duration and percentage agreement value, are shown in Table 5.

Table 5 STEP 5 activity schedule

Expected Product				Duration	% of the agreement
Product	**Type**	**Description**	**Deliverables**		
12	Report and development	Evaluation of the models of generation and development of the combined model	(Report with the evaluation of forecast performance and methodology for determining the weights of the combined model at the end of the 2nd month) + (development of the combined model prototype + codes + final report and training by the end of the 5th month)	5 months	10% in 2 installments
13	Report, development and training	Operational implementation of the combined solar photovoltaic generation forecast model	(Partial description at the end of the 2nd month) + (codes and manual + operational implementation and training at the end of the 4th month)	4 months	9% in 2 installments

Table 6 shows the start and end months, approximately, of each activity of the schedule of the photovoltaic generation forecast model for the real-time horizon.

Table 6 Schedule of activities of the photovoltaic forecast model for the real-time horizon

	Activities	**Months**																
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Step 1	Product 1																	
Step 2	Product 2																	
	Product 3																	
	Product 4																	
	Product 5																	
Step 3	Product 6																	
	Product 7																	
	Product 8																	
Step 4	Product 9																	
	Product 10																	
	Product 11																	
Step 5	Product 12																	
	Product 13																	

8 TEAM QUALIFICATION AND SPECIFICATION

The consultant must have a multidisciplinary team, i.e., consisting of technical profiles that are in accordance with the characteristics and needs of this project. In general, the institution must have, among their staff, a project manager and the key professionals to achieve the purpose of this TOR.

The technical team of the ONS must take active part in the project and may support the development, since it has the capacity to contribute to the topics addressed and may give the necessary support for the better progress of the project.

Key team professionals will be assessed based on the evidence presented in their CVs. The know-how and experience required for key team positions must be evidenced through professional performance, scientific articles, participation in research and R&D projects, and program patents. It should be emphasized that the evidence presented must be linked to the services/subjects that are the purpose of this subproject.

8.1 Key Team

Meteorologist/Physicist (Specialist, PhD): The professional must have a university degree in Physics or Meteorology with a postgraduate, master's or doctoral degree in areas related to the products of this project. He/She must have at least 10 years' experience in research and development and/or professional performance related to the scope of the project, in addition to fluent English. Moreover, the professional must demonstrate knowledge and experience in analysis and processing of meteorological and solarimetric data, atmospheric modeling, and use of satellite data. It is desirable that the professional has know-how in open-source programming language, experience with computational intelligence and/or machine learning, and experience with processing and forecasting using raw data and satellite images.

Engineer: The professional must have a university degree in Electrical Engineering with a master's and/or doctoral degree in areas related to the products of this project. He/She must have at least 10 years' experience in research and development and/or professional performance related to the products of this project. The professional must demonstrate knowledge and experience in the Brazilian Electric Sector - SEB, mainly in power generation using solar photovoltaic sources. It is desirable that the professional speaks fluent English and have knowledge of open-source programming language and computational modeling.

Computer Scientist: The professional must have a university degree in Computer Engineering, Computer Science or Information Technology, with a postgraduate, master's and/or doctoral degree in areas related to the products of this project. He/she must have at least 10 years' experience in developing and applying machine learning techniques, open-source programming languages, statistical modeling focused on forecasting models and building data processing tools. In addition, he/she must have knowledge in storing and structuring large volumes of data and operating systems in public cloud environments. Ideally, they should have knowledge of image treatment and processing techniques.

Mathematician/Statistician: The professional must have a university degree in Mathematics or Statistics, with a postgraduate, master's and/or doctoral degree in areas related to the products of this project. He/she must have at least 10 years' experience in research and development, and/or professional performance related to forecasting models, mathematical and/or statistical models, in addition to open-source programming languages. Desirable: knowledge in optimization, machine learning, SEB and speak English fluently.

Technical Coordinator: The professional must have a university degree in Engineering, Meteorology, Computer Science, Mathematics or Physics, with a master's and doctoral degree in areas related to this project. He/She must have at least 10 years' experience in research and development, and/or professional performance related to the products of this project, in addition to working as a coordinator of multidisciplinary teams and project monitoring. Ideally, the professional must be experienced in project management in line with PMBOK® 6's or 7's good practices, and knowledge of project management tools and swift methodology. The professional must speak fluent English and Brazilian Portuguese, and must demonstrate knowledge and experience in the SEB.

8.2 Support team

The support team is a team of professionals provided by the consultant to perform part of the services together with the key team, as per this TOR. The sizing of the support team must be determined by the consultant. Therefore, the sizing of the support team must be described in the technical proposal.

The support team must be multidisciplinary and consist of professionals with university degrees in Meteorology and/or Physics, Electrical or Civil or Environmental Engineering, Computer Science or Computer Engineering or Information Technology, and in Mathematics and/or Statistics.

As this is a team that will work on the developments of this subproject, it is understood that the support team must have knowledge compatible with that requested for the key team. It is of paramount importance that the support team, in addition to being a professional extension of the key team, has all the complementary knowledge required by the key team to develop the products of this subproject. The support team must meet some key requirements, including experience in: analysis and processing of meteorological, solarimetric and solar photovoltaic generation data; numerical modeling of the atmosphere; remote sensing of the atmosphere; numerical weather forecast correction techniques; mathematical and/or statistical models for forecasting; computational intelligence; and machine learning.

8.3 Team characteristics

The technical team must be made up of professionals with knowledge and experience in the following subjects: Brazilian Electric System; artificial intelligence; multivariate statistical methods; solar photovoltaic energy; data feeding and processing methodologies; mathematical forecast models; machine learning; numerical weather prediction models; remote sensing of the atmosphere; data storage and structuring; and advanced programming in languages such as R, PHYTON, JULIA, among other languages intended for data analysis and forecast models.

It is necessary that the general formation be complied with and appropriate for exercising each position referred to for the key and support teams.

The team must be able to develop and implement existing time series forecasting models to evaluate performance and propose new methods; artificial intelligence, machine learning models, computer modeling and creation of process flow in order to meet the scope of this project.

It is also expected that the consultant's team be formed by professionals at the junior, full, senior and expert levels. In addition, if the consultant identifies any need of having a professional with a profile which is different from those described before on the team, they must define and quantify the profile of such a professional. In addition, the number of professionals who must make up the key team will be defined by the consultant, according to project needs.

8.4 Required Consultant Profile

For this subproject, the consultant must have a minimum experience of 5 years in the following requirements:

(i) Experience with studies, development and application of numerical weather prediction models, analysis of meteorological data, and methodologies for forecasting meteorological variables;

(ii) Experience with studies, development and application of satellite data, cloud identification and cloud motion forecasting techniques;

(iii) Experience in technological solutions and technical consulting services in the electric power sector and intermittent sources, especially in solar photovoltaic generation, with Brazilian and/or international competence;

(iv) Experience in analyzing, processing and feeding in meteorological, solarimetric and solar photovoltaic generation data, as well as experience in storing and structuring large volumes of data;

(v) Experience in studies and development of methodologies for forecasting generation from intermittent sources (especially solar photovoltaic sources), including proven knowledge of applications with artificial intelligence and machine learning techniques;

(vi) Experience in project management on topics related to such subproject.

In order to prove the aforementioned requirements, the consultant must present, in their technical proposal, only the latest services (last 10 years) which are somewhat associated with the requirements and services requested in this TOR. It should be emphasized that the services presented must only be provided by the consultant as a company, not by their experts, either working privately or for other companies.

9 FORM OF PRESENTATION OF PRODUCTS

The products and results must be delivered in Portuguese, in digital format, as follows:

(i) Compositions: MS Word® 2013 or later version, with delivery of the file in ".doc"/".docx" format;

(ii) Spreadsheets, Charts and Tables: MS Excel® 2013 or later version;

(iii) Pictures in general: JPG, PNG, TIFF, GIF or BMP;

(iv) Presentations: MS PowerPoint® 2013 or later version;

(v) Products in the form of Reports must display the appropriate logos, to be inserted in the following order: ONS, META Project, World Bank and MME/Federal Government. A template file will be provided to the consultant in a ".doc"/".docx" format;

(vi) Any digital spreadsheets or other documents developed must be delivered unlocked and with no editing restrictions;

(vii) Software, mathematical models, forecasting models developed or evaluated to make up this project must be delivered with the documented source code, technical notes and user manual, also containing installation and execution instructions.

At first, the computer tools used in this work must be those currently used by the ONS. If the use of any tool that requires the acquisition of a license by the ONS is needed, then such a need must be informed and discussed in advance.

Products resulting from this project will be the sole property of the ONS, and may, in due time, be made available to society.

In addition to said logos, the following information must be informed in the products/reports: Research/Product/Work performed with funds from Loan Agreement No. 9074-BR, formalized between the Federative Republic of Brazil and the International Bank for Reconstruction and Development – IBRD, on July 21st, 2021.

10 PAYMENT METHODS

The estimated percentage of the total value of the Agreement for each product is provided in section 7 herein. Payment methods, as well as deadlines for delivery, validation, review by the consultant and approval of products, will be linked to the Agreement Draft, an instrument that is part of the Invitation to Bid.

11 SUPERVISION

The beginning of the work which is the subject matter of this TOR, as well as the presentation of the expected products, must be preceded by a meeting with the technical team of the ONS for the general orientation of the process and follow-up of the consultancy.

Given that the ONS will take active part in the project's development steps, ideally, the construction should be made by following the steps described in section 7, with intermediate deliverables of the products described in each stage. The ONS will have up to fifteen (15) days from the delivery date to validate each product. After validation, the formal acceptance will be issued by the technical team designated by the ONS.

12 AVAILABLE SUPPLIES & ELEMENTS

The ONS will provide the consultant with information necessary for the development of the project, however, confidentiality agreements must be drawn up regarding the data to be used. It should be emphasized that not all data necessary for the project can be obtained with the ONS, therefore, it is up to the consultant to list the sources for obtaining such data.

The consultant should provide for the execution of online meetings throughout the execution of the project. In addition, at least a one-week on-site visit to the ONS is expected, for adjustments and training of the final forecasting model developed. However, this is the minimum specification, and it is the consultant's responsibility to point out any needs for in-person work meetings with the ONS, which must take place as agreed upon by both parties. In this case, the ONS will arrange the appropriate physical environment to allow such scheduled meetings between the parties at their office in Rio de Janeiro.

13 TRAINING NEEDS

Section 6 describes the scope of work and project boundaries, including the training sessions provided for each step/stage, which is reinforced in section 7.

14 WORLD BANK ENVIRONMENTAL AND SOCIAL FRAMEWORK

All activities supported by the project, including studies for the proposition of policies and regulations must be analyzed in accordance with the World Bank's Environmental and Social Standards, which establish guidelines for identifying, assessing, mitigating and managing potential risks and impacts associated with projects funded by the Bank.

The adoption of the Environmental and Social Standards aims to support borrowers in adopting international best practices related to environmental and social sustainability, fulfilling their national and international environmental and social obligations, as well as increasing non-discrimination, transparency, participation, accountability, governance and improvement of the sustainable development results of the projects through ongoing stakeholder engagement. In addition to the World Bank Environmental and Social Framework, the World Bank Group's Environment, Health and Safety Guidelines (IFC-EHSGs) shall be complied with, including specific guidelines for the mineral, electric, and oil and gas industries.

The preparation of the work should consider the World Bank's Environmental and Social Framework, which became effective on October 1st, 2018, assessing potential social and environmental impacts of subprojects, whenever necessary. The most relevant standard for the concerned Subproject 24 is Environmental and Social Standard 2 - Working Conditions and Workforce of the team that will perform the studies.

15 INSTITUTIONAL AND ORGANIZATIONAL ARRANGEMENTS

Subproject 24 shall be managed by organizational structures linked to the Brazilian Ministry of Mines and Energy (MME) and to the Brazilian National Electric System Operator (ONS), as determined by the Operational Manual for the Project – MOP, available online at the MME website (www.mme.gov.br).

At the MME, the project will be managed by the Project Management Committee (CGP) and the Central Project Management Unit (UGP/C).

At the ONS, it will be managed by the Sectorial Project Management Unit (UGP/S), as schematically presented in

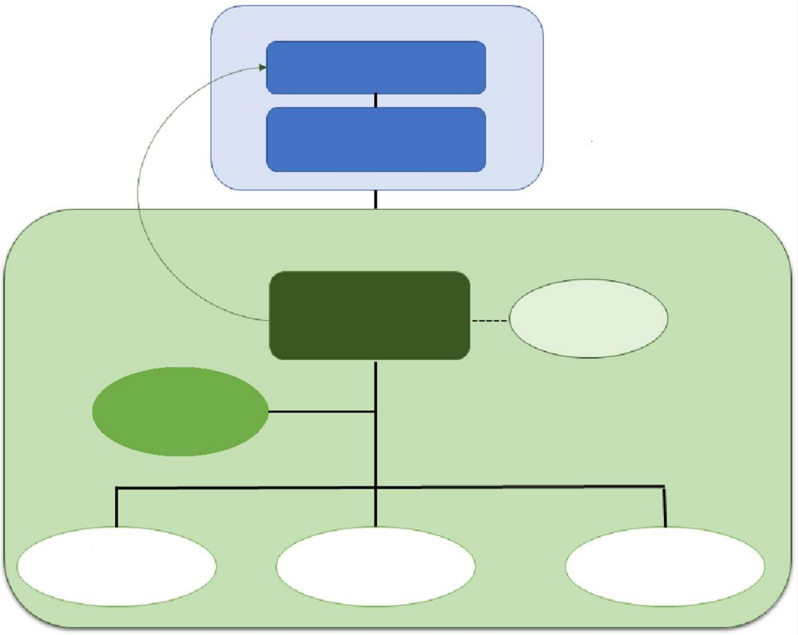

Figure 2.

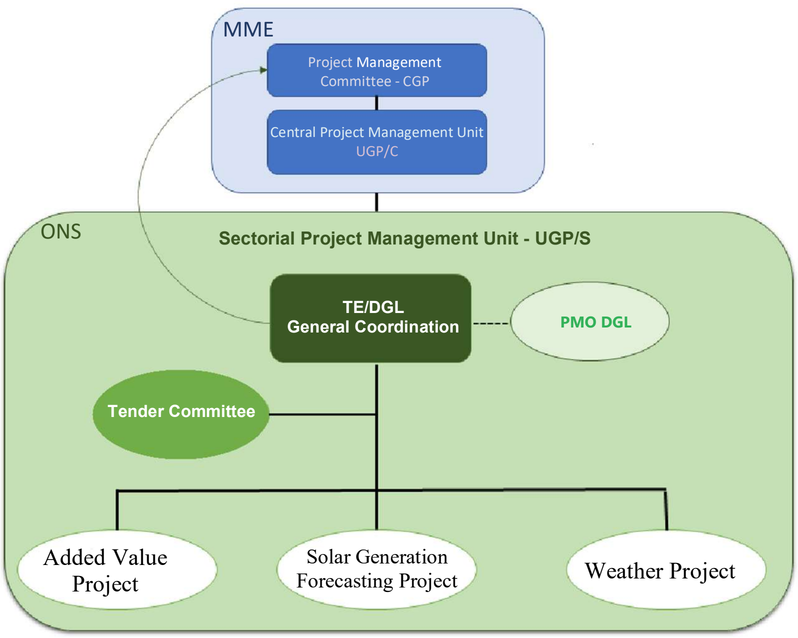

Figure 2 Functional structure of ONS' Sectorial Project Management Unit – UGP/S

Table 7 UGP/S Formation in ONS

UGP/S	Managements
General Coordination	Strategic Transformation Executive Management
DGL Projects Office	Strategic Transformation Executive Management
Tender Committee	Financial Executive Management
	Legal Executive Management
	Water Resources and Meteorology Management
	Methodology and Energy Model Management
	Calculation, Analysis and Operation Costs Executive Management
	Executive Supply Management
Solar Project 1(*)	Methodology and Energy Model Management

(*) Solar Project 1 is the short name for ONS's Subproject 24

16 LIST OF REIMBURSABLE EXPENSES

Reimbursable expenses corresponding to travel and per diem expenses may be applied to products that justify their presence in the ONS, such as implementation of models in the ONS's environment if remote implementation is not possible, training of the technical team of the ONS, etc.

17 LEGAL PROHIBITION

The contractor may not directly or indirectly hire, in any capacity, active servants of the Federal, State, Federal District or Municipal Government or employees of its subsidiaries and controlled companies, within the scope of international technical cooperation projects. *Art. 7 of Dec. 5,151 from 07/22/2004*.

18 TECHNICAL STAFF IN CHARGE
Name: Paulo Sergio De Castro Nascimento
Agency: Methodology and Energy Model Management – Operation Planning Board
Signature:
Name: William Cossich Marcial de Farias
Agency: Methodology and Energy Model Management – Operation Planning Board
Signature:

19 APPROVAL
Name: Maria Aparecida Martinez
Position: Executive Energy Planning Manager
Signature: