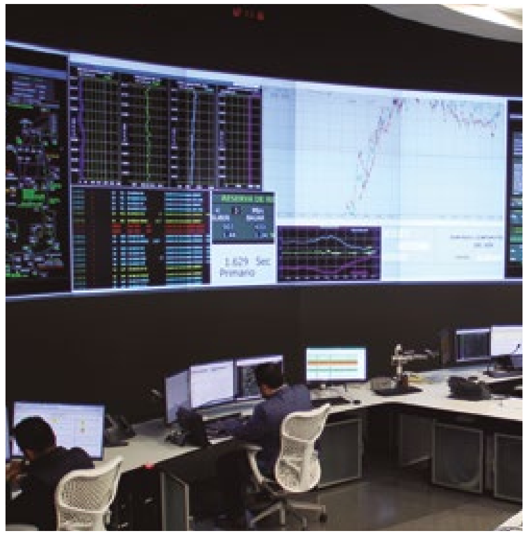
INTEGRATING VARIABLE RENEWABLE ENERGIES INTO THE MEXICAN GRID VIA RELIABLE WIND AND SOLAR POWER FORECASTS

Results of a Successful DeveloPPP.de Project



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energy & meteo systems

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1 Introduction

How can the rapidly growing share of fluctuating solar and wind power generation in Mexico be successfully integrated into the energy system and the energy market?

That was the key question that united the company energy & meteo systems, the German International Cooperation Agency (GIZ) and the National Energy Control Center (CENACE) of Mexico in a Public Private Partnership (develoPPP.de) to exchange theoretical and practical know-how on forecasting solar and wind energy and recommendations on regulatory issues.

1.1 DeveloPPP.de Program

The develoPPP.de program was set up by the German Federal Ministry for Economic Cooperation and Development (BMZ as per its German acronym) to foster private sector engagement in areas where business opportunities and the need for development action overlap. Through the program, BMZ supports companies with innovative projects and commercial investments in developing and emerging countries that have long-term benefits for the local population. Specifically, the develoPPP.de program:

- Provides companies with financial and professional support.
- Contributes with up to 200,000 EUR to the project, with the company funding at least half of the total costs.
- Requires the company to work closely with one of the three official partners appointed by BMZ to implement the program on its behalf: DEG Deutsche Investitions- und Entwicklungsgesellschaft mbH, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH or sequa gGmbH.

The projects include a wide range of sectors addressing a wide range of topics. Furthermore, they include the training of local experts, the use of climate-friendly technologies and product certification, as well as the improvement of eco- and social standards in manufacturing facilities.

Since the program's inception almost 20 years ago, the private sector and development cooperation agencies have joined forces and together have invested over EUR 1.1 billion in sustainable economic development in sectors such as energy, agriculture, education and health in over 100 countries. They have brought about long-term improvements to the quality and living standards in the partner countries.

The present project is within the framework of a regional develoPPP.de project in Mexico, El Salvador and Honduras, that includes energy & meteo systems GmbH as the company providing the forecasts, and GIZ as the implementing program. Specifically, **the present document exclusively describes and presents the project's results for the 3-phase collaboration in Mexico** between the Mexican independent system operator (CENACE), GIZ Mexico through its Large-Scale Solar Energy in Mexico program (DKTI Solar) and energy & meteo systems.

Figure 1.- DeveloPPP.de framework

1.2 Stakeholders

1.2.1 Centro Nacional de Control de Energía (CENACE)

The National Energy Control Center (CENACE) is a Mexican public entity with the legal mandate to exert operational control of the National Electric System (SEN), manage the wholesale electricity market (WEM) and grant impartial access to the national transmission and distribution grids. CENACE was established in the process of structural reforms that led to a liberalization of the Mexican energy market.

As the independent system operator, it performs its functions under the principles of efficiency, transparency and objectivity, fulfilling the criteria of quality, reliability, continuity, safety and sustainability in the operation and control of the SEN. CENACE is also responsible for formulating the expansion and modernization programs of the National Transmission Network (RNT) and the General Distribution Network (RGD), which, if authorized by the Ministry of Energy (SENER), are incorporated into the Development Program of the National Electric System (PRODESEN).

Short-term power forecasts would allow CENACE to fulfil more adequately and efficiently its mandate and attributions to operate both the SEN and the WEM.

1.2.2 Large-Scale Solar Energy in Mexico program (DKTI Solar)

In 2015 BMZ commissioned GIZ to implement the program “Large-Scale Solar Energy in Mexico” (DKTI Solar), within the framework of the German Initiative on Climate Protection Technologies (DKTI), in order to improve the technological, financial and organizational conditions for the application of large-scale solar energy in Mexico. DKTI Solar focuses on the following areas of intervention:

- **Politics, strategies and regulations:** support the design and implementation of policies and strategies in order to achieve and meet the energy transition goals.
- **Technology and innovation:** align the capacity for innovation and the development of value chains to adequately respond to the demand of the solar market.
- **Promote the development of the solar market:** promote the development of the market to take advantage of the solar photovoltaic potential in the generation of electricity and the use of solar thermal energy in industrial processes.
- **Strengthening institutional capacities in the area of financing RE projects:** support the financial sector to respond to the future demand for financing solar energy projects due to the growth of the solar energy sector.

1.2.3 energy & meteo systems GmbH

energy & meteo systems GmbH (energy & meteo systems) is a German-based, internationally leading provider of both short-term power forecasts (for wind and solar PV), and virtual power plants (vpp). Furthermore, since 2004, energy & meteo systems has engaged in research and development projects in power predictions, grid operations, energy trading and load management.

The company currently forecasts 280 GW of wind power (circa 47%[1] of total installed capacity worldwide) and 130 GW of solar power (circa 31%[2] of the worldwide total). The company's services are employed by independent-, transmission- and distribution system operators (ISO, TSO, and DSO respectively), as well as plant operators, and energy traders from Europe, North and South America, Asia, Africa and Australia.

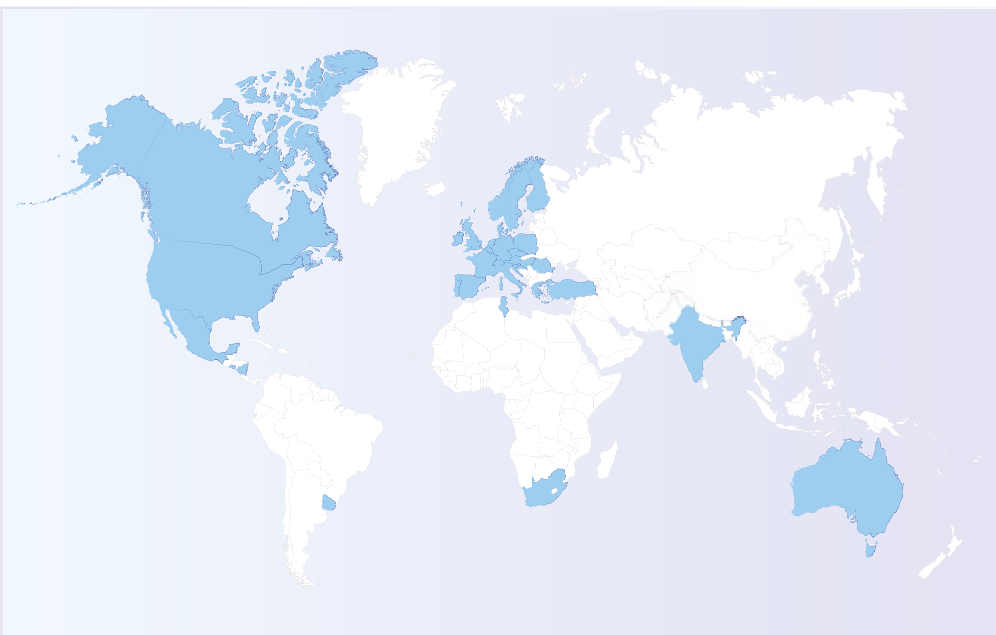


Figure 2.- energy & meteo system´s international presence

1.3 Special Considerations

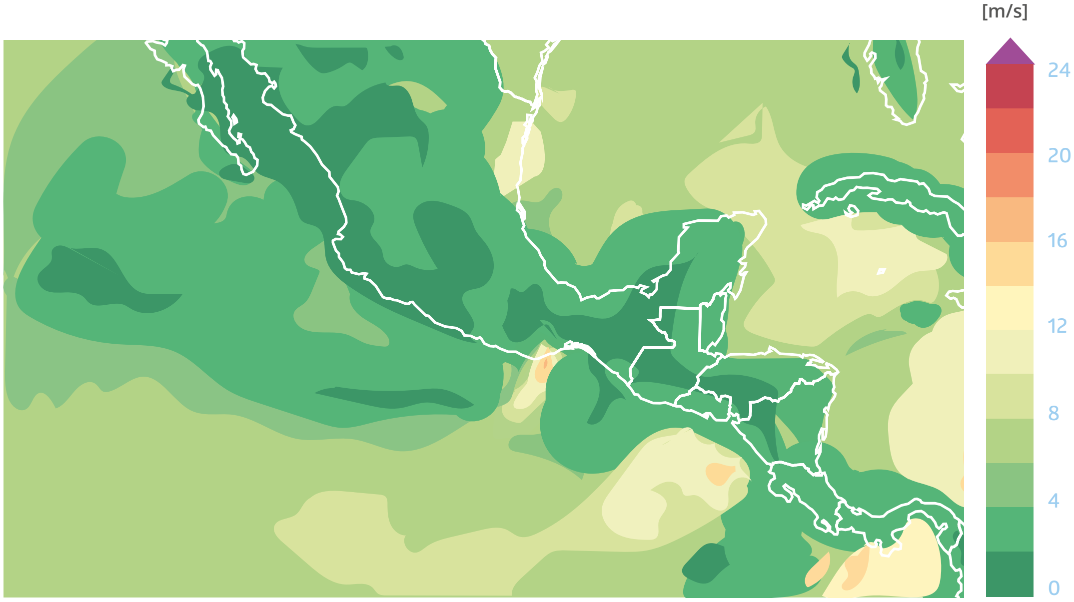
Given that the information provided by CENACE to energy & meteo systems is confidential in nature and that a Non-Disclosure Agreement was signed between the parties involved, the results presented in this document are not comprehensive, and are only shown for illustrative purposes. Furthermore, any and all information that directly identifies a specific plant, wind or solar PV, has been redacted and eliminated. The only parties privy to the entirety of results generated through the project are CENACE and energy & meteo systems.

[1]According to a recent press release from the World Wind Energy Association, 2018 closed with 600 GW of installed capacity.
http://wwindea.org/blog/2019/02/25/wind-power-capacity-worldwide-reaches-600-gw-539-gw-added-in-2018/

[2] Information from 2017. Retrieved from Bloomberg New Energy Finance

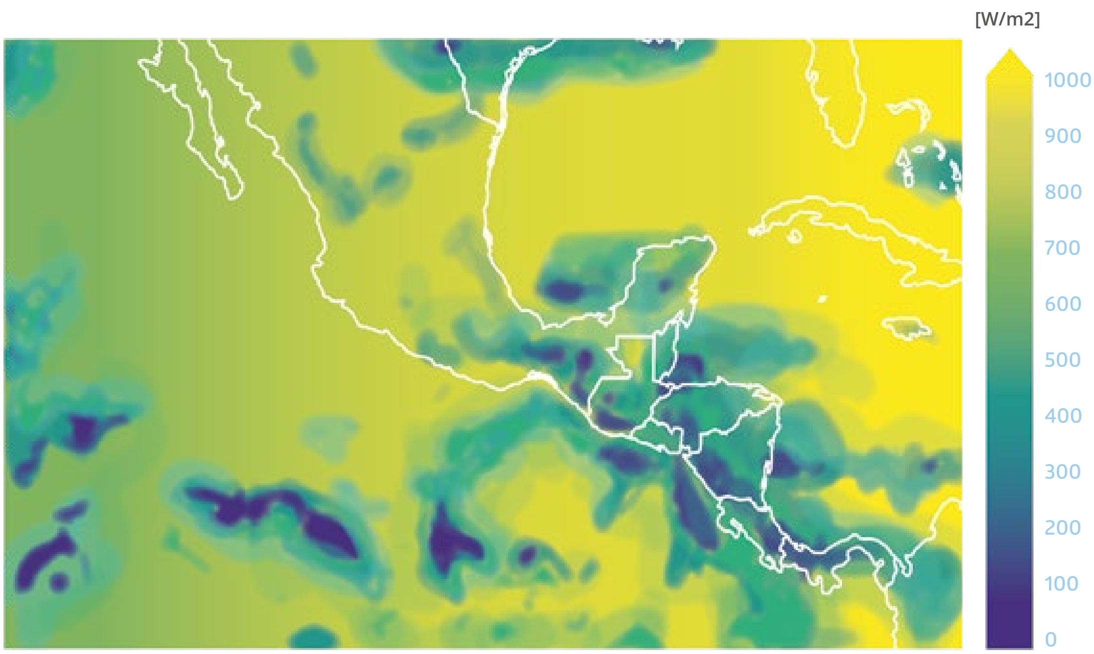
2 Short-term power forecasts

The power forecasts' goal is to convert and transfer meteorological variables into power output predictions of solar PV and wind plants. The meteorological variables are obtained through a combination of different numerical weather prediction (NWP) models provided by different weather services.



Source.- energy & meteo systems

Figure 3.- Example of a wind speed model at 10m above surface



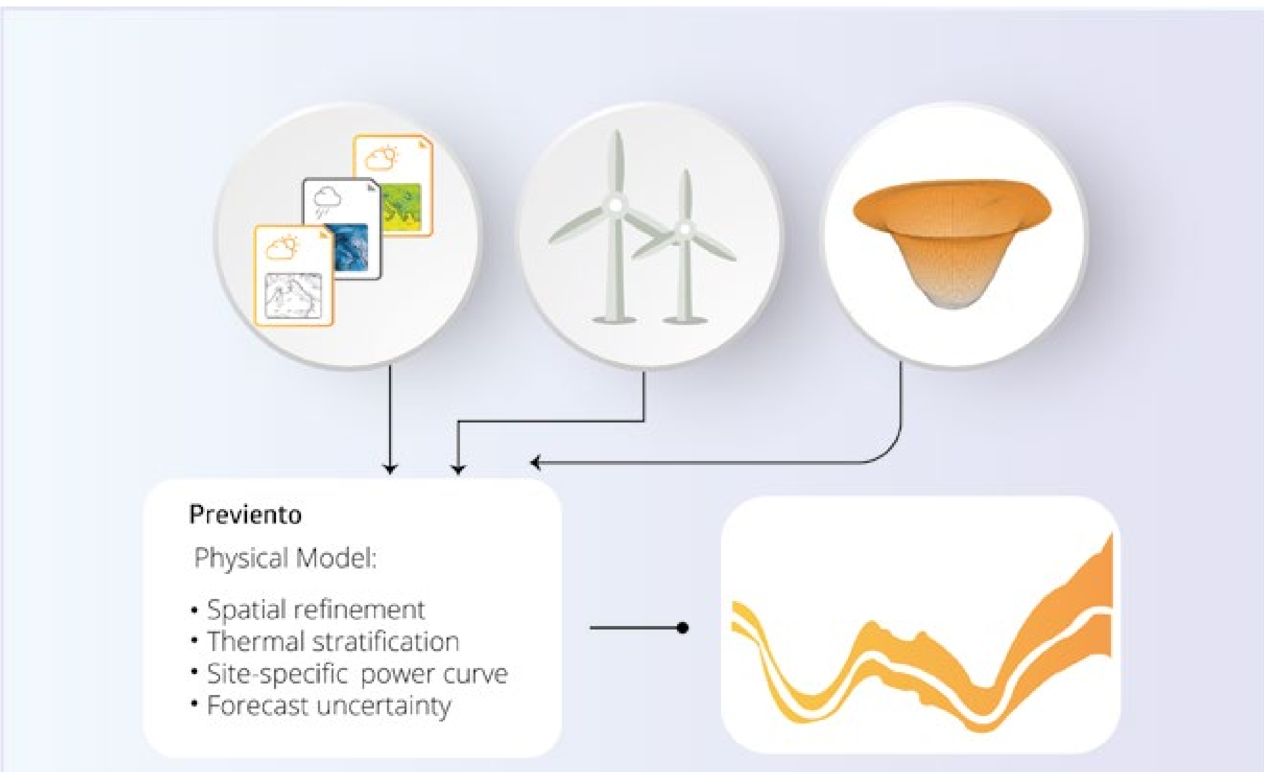
Source.- energy & meteo systems

Figure 4.- Example of a solar irradiation model

There are two main forcasting approaches: a) a statistical system which identifies statistical relations between NWP and measured power output; and b) a physical system based on equations that simulate different conditions such as boundary layer meteorology, thermal stratification and irradiance transfer schemes, conditions that affect power output for wind and solar PV plants.

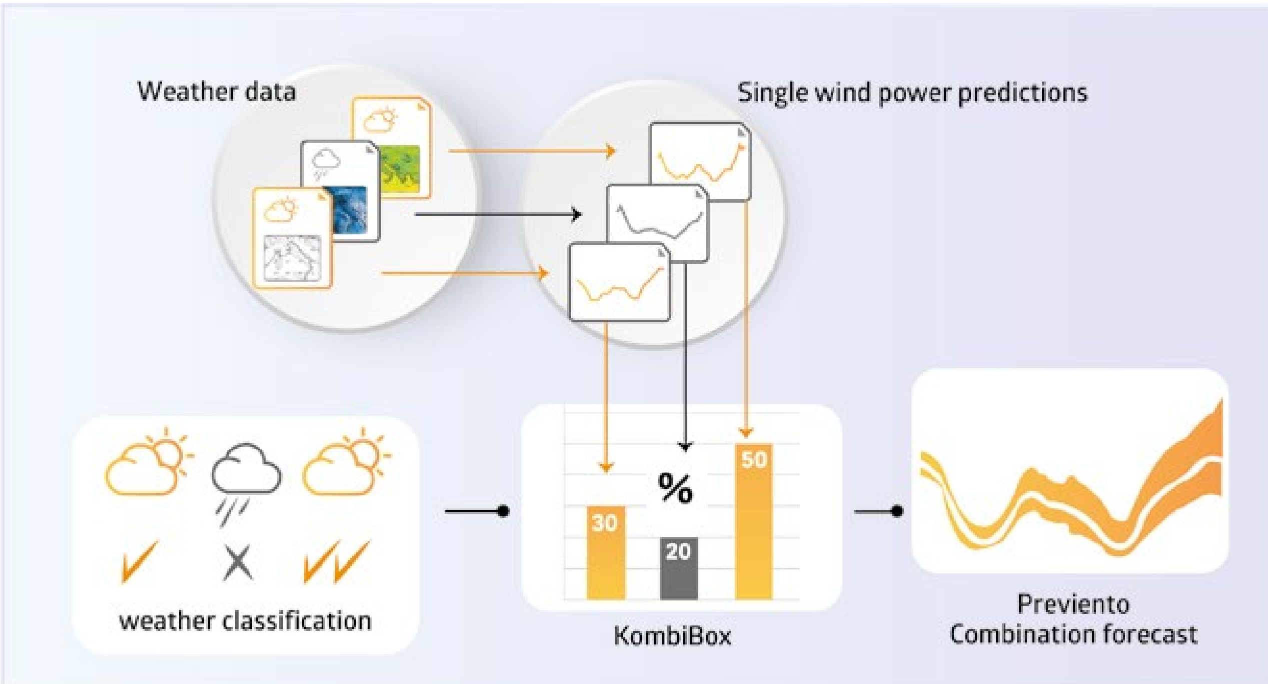
Specifically, energy & meteo systems' wind (Previento) and solar PV (Suncast) prediction system is based on an optimal combination of various weather models, numerical forecasts, and the integration of local on-site and power-plant specific conditions.

For a wind plant Previento's physical model takes into account detailed knowledge of the plant's orientation, geographical coordinates, number of wind turbines, their hub height, rotor diameter, capacity and specific power curve. Previento additionally calculates the appropriate uncertainty of the individual forecast situation along with the actual prediction value. This is because the forecast accuracy varies with weather conditions.



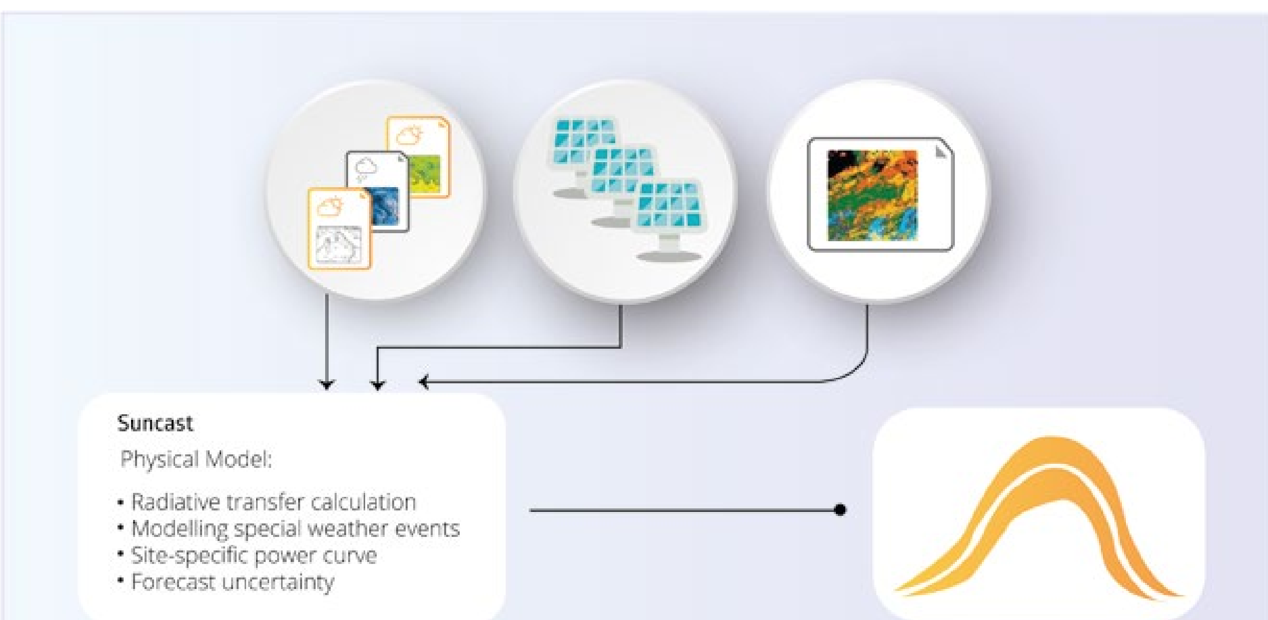
Source.- energy & meteo systems
Figure 5.- Previento model

A complex calculation model gives Previento the ability to predict with a high degree of accuracy. The basis of the calculation is numerical weather data from various weather services. From these, Previento calculates an initial wind power prediction which, in a second step, is then optimized by the so-called KombiBox. The KombiBox procedure allots a higher weight to those predictions which show the least prediction error in the corresponding weather situation. The result is a new, significantly improved wind power prediction.



Source.- energy & meteo systems
Figure 6.- KombiBox

The foundation of Suncast's solar power prediction stems from the irradiation data and numerical weather predictions of various weather services. From these parameters, a power prediction is determined for farm aggregations, individual grid areas, entire regions or countries. Moreover, these power predictions are continuously optimized for difficult weather conditions including extreme events such as fog, snow or Sahara dust. Additionally, Suncast considers the plant's capacity, orientation, tilt angle, type of rack mounting (fixed or with a tracking system), type and power curve of both the PV cells and inverters.

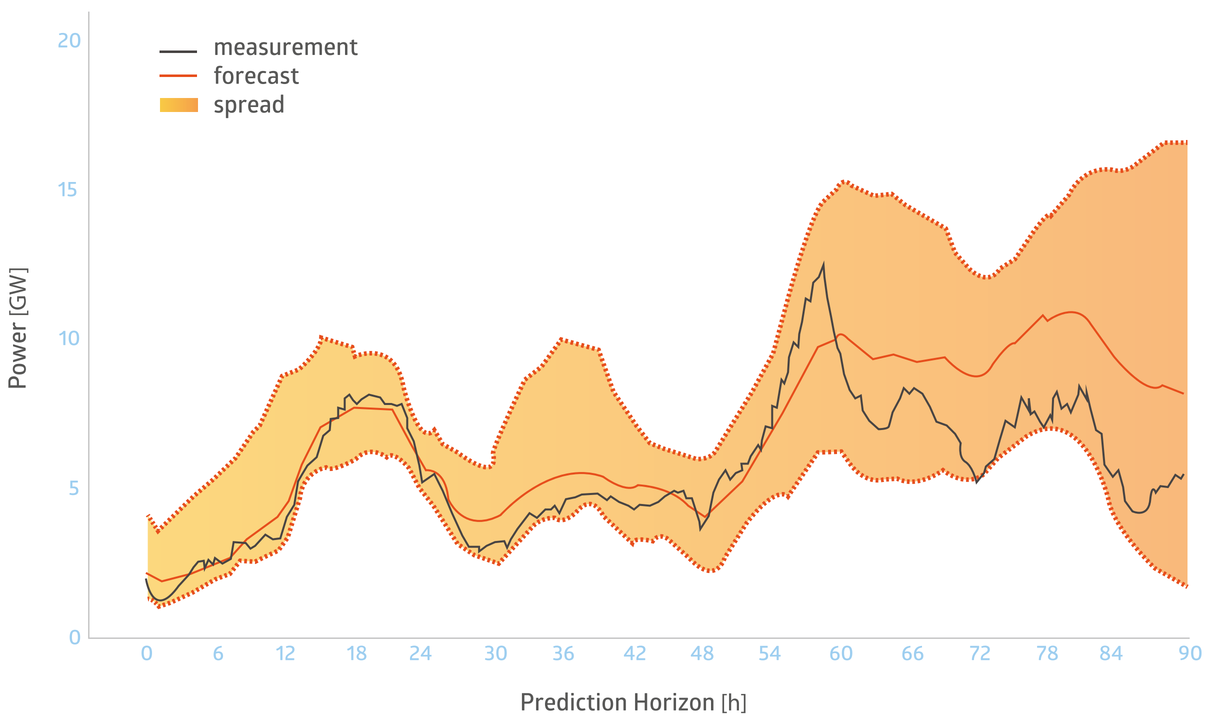


Source.- energy & meteo systems
Figure 7.- Suncast model

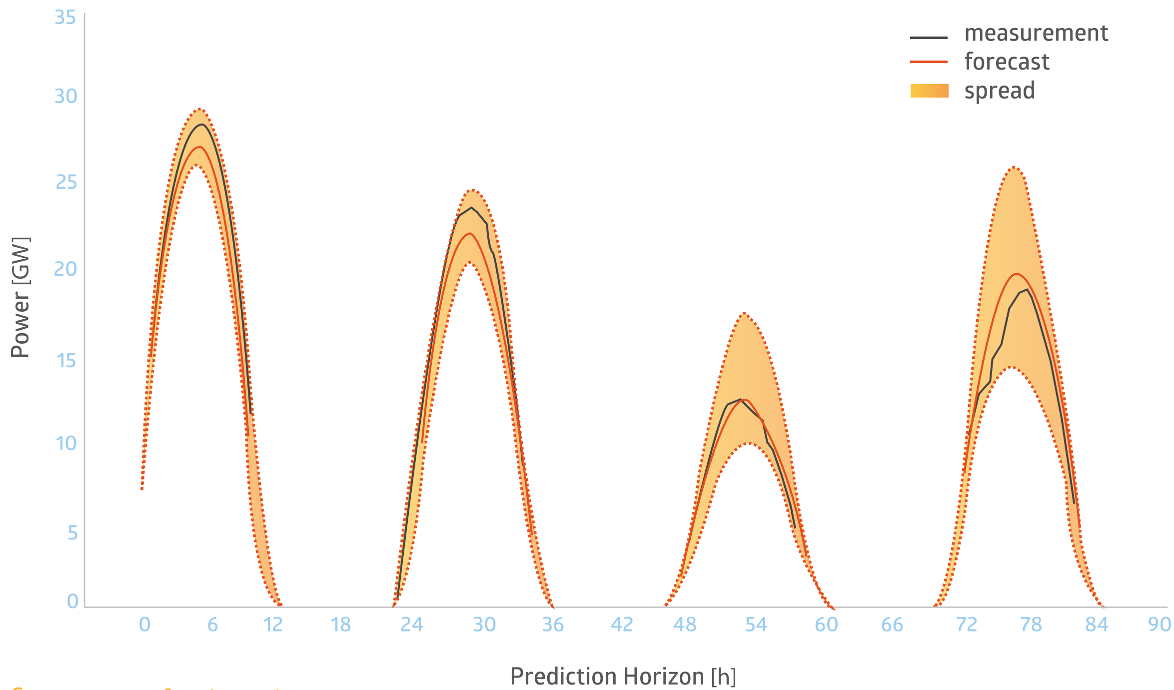
Previento and Suncast Facts:

- predict wind and solar PV power for
    - entire countries
    - designated balancing areas
    - individual states and counties
    - individual wind and PV farms
- time interval: 0 to 15 days
- time resolution: 5 min. to 1 hour
- shortest-term-prediction: 0 to 6 hours
- optimal combination of different weather models
- ramp event prediction: point in time, duration, amplitude and rate of increase
- multiple daily updates of the prediction
- prediction uncertainty considers weather situation
- electronic transmission in all major formats
- optional: integration of online measurement data to optimize the prediction
- Prediction of the actual or theoretical power supply including taking limitations into account imposed by the grid operator

The following two Figures, represent an example of a Wind and a Solar PV power forecast.



Source.- energy & meteo systems
Figure 8.- Wind power forecast example



Source.- energy & meteo systems

Figure 9.- Solar PV power forecast example

As can be observed in the previous Figures:

- The accuracy of forecasts is greater when the time horizon is smallest and diminishes as the prediction horizon increases.
- To reflect the previous point, the spread also increases as the prediction horizon increases, meaning that the model's level of confidence diminishes.

2.1 Uses of power forecasts

Time scale of forecast	Area of application	Stakeholder
Shortest-term (0-6 h)	Trading on intraday energy market Control of curtailment due to negative market price	Traders
	Influence of renewable production on market price	Speculators
	Balancing Unit re-dispatch Curtailment of power plants	Grid operators, load dispatch centers, independent system operators
Short-term (6-48 h)	Trading on day-ahead energy market Participation in regulation market Influence of renewables on market price	Traders
	Unit dispatch Load flow calculations DACF congestion forecast	Grid operators, load dispatch centers, independent system operators
	Day-ahead planning of maintenance	Plant operators
Medium-term (2-10 days)	Trading on long-term markets	Traders
	2DACF congestions forecast Week-ahead planning	Grid operators, load dispatch centers, independent system operators
	Medium-term planning of maintenance	Plant operators

Table 1.- Use cases

3 Project Description

The project's main goal and objective was to strengthen CENACE's short-term wind and solar PV forecasting capabilities through:

- The provision of best-practices in wind and solar PV forecasting.
- Capacity building on how forecasts can be implemented into CENACE's day-to-day processes: for example, in the day-ahead and real-time energy markets, and in grid management maneuvers.
- Executing a pilot project in which CENACE received daily short-term power forecasts for 25 wind and solar PV plants in the country, thus providing them with experience in handling these forecasts.
- Constant two-way feedback between CENACE and energy & meteo system allowing the latter to correct and fine-tune their forecasting models in order to better represent local wind and solar conditions in Mexico.

In order to reach the aforementioned goal, the project consisted of three phases, as described in the following sections and in the following figure.

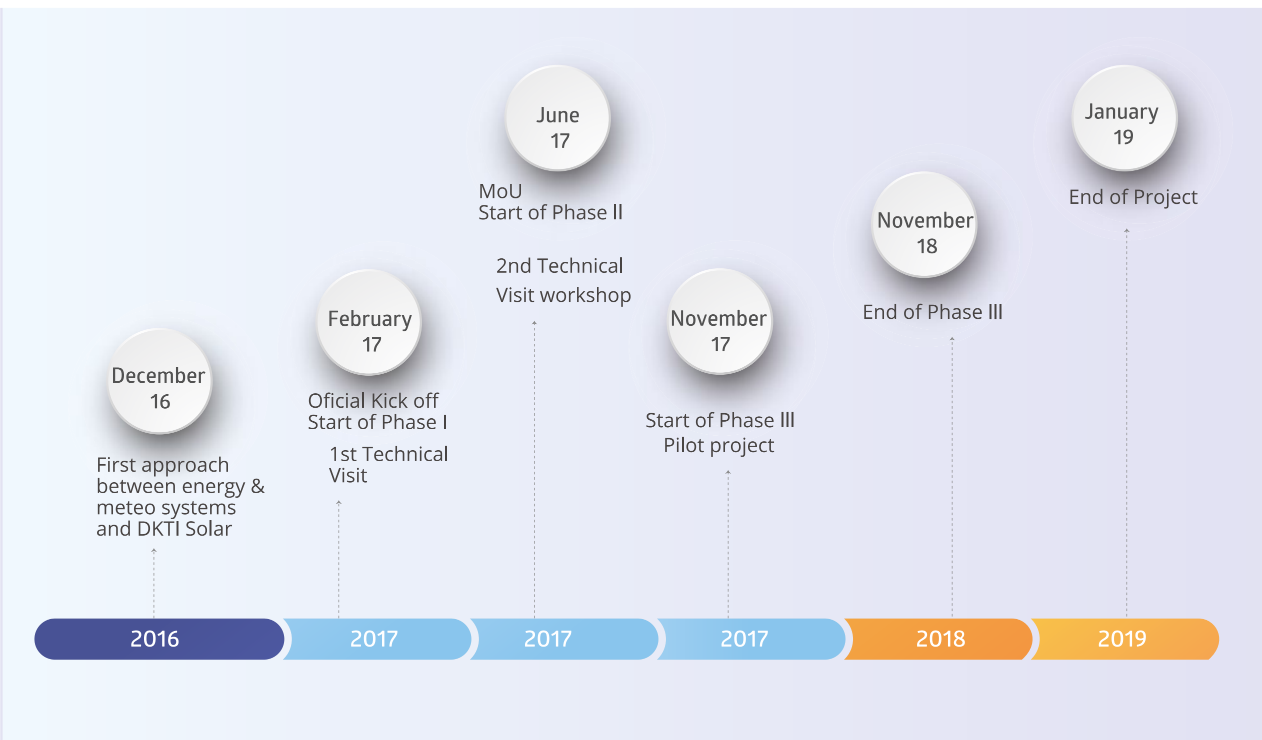


Figure 10.- Project Timeline

3.1 Phase I - Fact Finding:

Objective: Analyze the legal, regulatory, technological and procedural conditions in Mexico for the integration of renewable energies into the electricity system and into the energy market, with an emphasis on how short-term generation forecasts are employed by CENACE.

Support mechanism:

- Visits and meetings with CENACE, SENER (Ministry of Energy) and CRE (Energy Regulatory Commission).
- Analysis of the current state of the electricity market and procedures for the integration of variable renewable energies (wind and solar).

3.2 Phase II - Capacity Building:

Objective: Verify and share with CENACE, CRE, SENER, academia and the private industry the results of the first phase; and improve the capacities, through a series of workshops, of the implementation of short-term energy forecasts in the country.

Support mechanism:

- Workshops in Mexico City

3.3 Phase III - Pilot Project:

Objective: Provide CENACE with practical experience handling and introducing short-term generation forecasts for 25 solar and wind power plants into their market operation processes.

Support mechanism:

- Energy & meteo systems provided CENACE, for a period of one year, with daily short-term energy forecasting service for **25 wind and solar PV power plants.**
- Forecast service: Electronic delivery according to CENACE specifications.
- Continuous and constant dialogue between energy & meteo and the partners in Mexico to discuss the quality of the forecasts and their integration to CENACE's processes.
- Constant review, re-calibration and fine-tuning of the quality and certainty of the forecasts

3.3.1 Selection Criteria

CENACE and energy & meteo system decided on the 25 PV and wind power plants based on the following criteria.

By variable Renewable Energy (vRE) technology:

Both wind and solar PV plants were considered for the pilot phase.

By Installed Capacity:

In order to better represent Mexico's wind and solar PV installed capacity, both small and large-scale plants were considered for the pilot phase. Solar PV ranged in size from 14 to 330MW, while wind plants ranged from 10 to 250MW.

By Status:

Plants already commissioned as well as plants that were to be commissioned during the pilot phase (and that were a product of Long-Term Auctions) were included as part of the forecasted plants. The reason behind including these latter plants was to allow for a wider and broader representation of PV and Wind plants (as mentioned in this section - Selection Criteria).

By Geographical Location:

The PV and wind power plants were selected based on two further geographical considerations:

- Each of the country's 3 interconnected systems (Baja California Interconnected System – BCIS; Baja California Sur Interconnected System – BCSIS; and the National Interconnected System – SEN) should have at least 1 plant (PV or wind). **This would allow CENACE and all regional control centers to gain experience in dealing with and incorporating the power forecasts provided by energy & meteo system.**

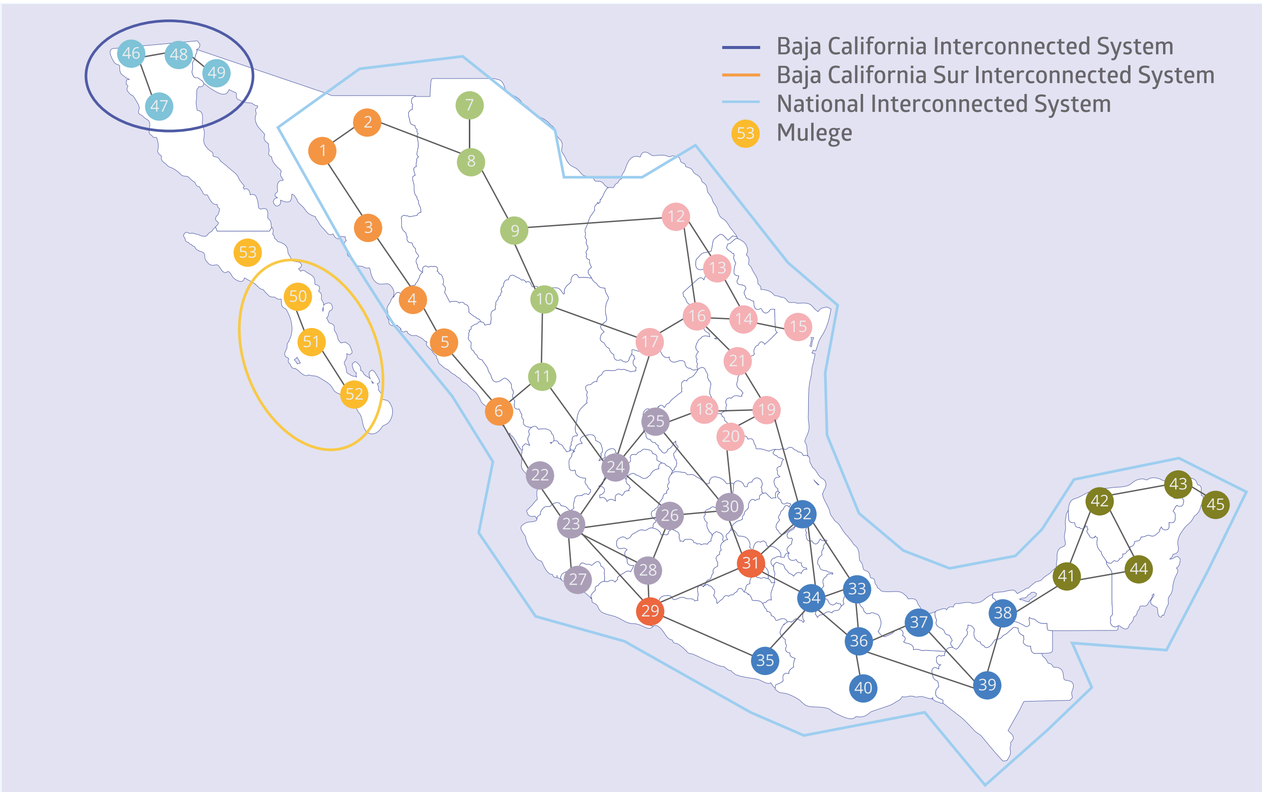


Figure 11.- Mexico´s 3 Interconnected Systems

- The plants should be scattered all throughout Mexico in as many different states, regions and topographies. This given the following reasons:
  - Having dispersed and topographically diverse regions allows for a smoothing effect of the aggregated forecasts (for wind and PV); in other words, very local wind and cloud conditions that might negatively affect a specific power plant's forecast would be offset by other plants in other regions, such that an aggregated forecast would not suffer high deviations with regards to the actual production.
  - It allowed energy & meteo system to better train and finetune their forecast model for different regions in Mexico.
  - Also allowed CENACE's regional control centers to gain experience in dealing with the forecasts.

3.3.2 Forecasted Power Plants

In total, 17 wind plants (1.88 GW) and 8 solar PV plants (0.98 GW) for a total of 2.86 GW were forecasted during the year-long pilot phase. This amount represents 34.4% of wind and solar PV's installed capacity in Mexico[3].

Figure 12.- Forecasted Solar PV and wind plants

3.3.3 Time Resolution

In order to attend to CENACE's procedural needs, the provision of short-term power forecasts included two time-horizons, as described below:

I) For the following **24 hours, with a time resolution of 5 minutes** (meaning that each forecast includes power predictions for 00:00, 00:05, 00:10 and up to 23:55 hours in advance), and **updated every 5 minutes via a secure data connection.**

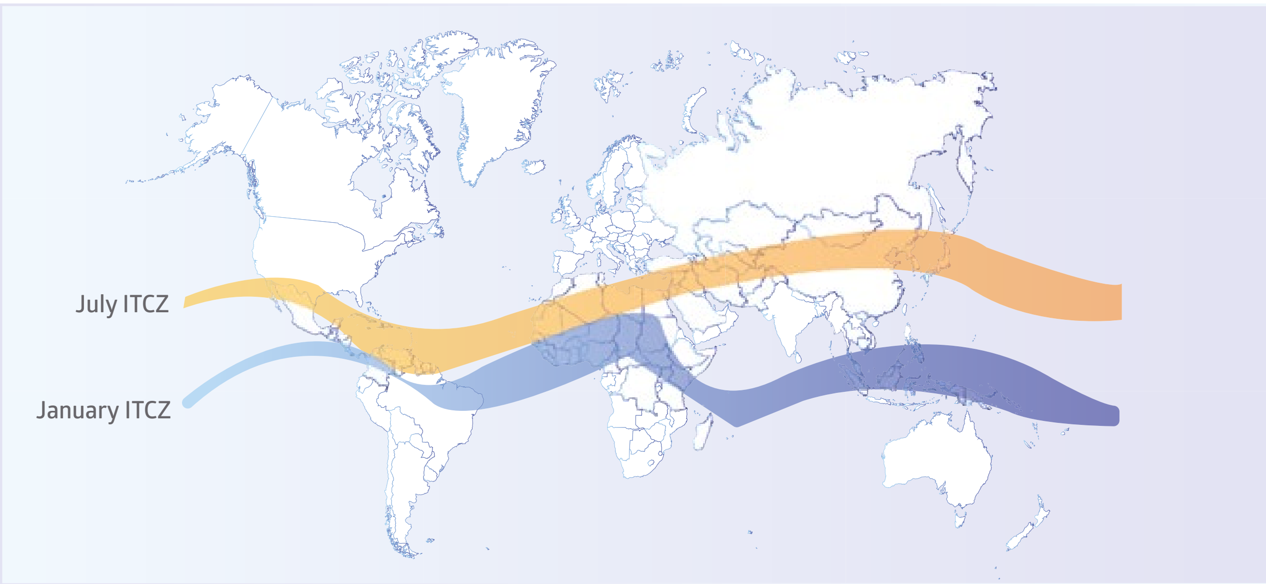
II) For the following 8 days, with a time resolution of 15 minutes (00:00, 00:15, 00:30 ...... 23:45 for the first day and up to hour 192 for day 8), and updated twice per day at 09:00 and 16:00 hours local time in Mexico City.

[3]According to information provided by CENACE.

3.3.4 General weather conditions in the region:

Intertropical Convergence Zone

The Intertropical Convergence Zone (ITCZ) has a strong impact on weather conditions in the region. Furthermore, the annual variation in the ITCZ causes the region's dry and rainy seasons. The dry season, which corresponds predominantly with winter, produces strong trade winds with low variations. Wet season, during spring and summer, produces a high variation of wind speed due to local effects such as thunderstorms and convective clouds.



Source.- Mats Halldin. The file is licensed under the Creative Commons Attribution

Figure 15.- ITCZ

Convection

In the convection process, the sun-warmed ground acts as an enormous radiator producing moist air that rises. These convection currents are known as thermals that produce certain types of clouds. However, convection may also produce clouds when the sun is not shining, for example, when cold air from the poles (north and south) collides with warmer air present in the tropics. When this happens, some of the colder air can ride up over the warmer, resulting in an unstable region of the atmosphere that produces large convection clouds.

Since they tend to form rapidly in the rising columns of air, convection clouds are 'optically dense', that is, they contain a lot of very small droplets, the surfaces of which scatter the sunlight more than in clouds made of fewer, larger droplets or ice crystals. For this reason, convection clouds often look bright white on the sides facing the Sun and dark grey on the sides away from it. These types of clouds block solar radiation and thus preventing solar PV plants from delivering their full installed capacity.

The maximum convective activity happens between May and November.

4 Project Results

This section presents the main findings and results of the one-year pilot project. It is divided into two parts, the first deals with Solar PV results, while the second with the results of the wind forecasts.

In order to determine the error measurement, the Mean Absolute Percent Error (MAPE) was used as the defining metric. The MAPE measures the size of the error in percentage terms, calculated as the average of the unsigned percentage error as shown by the following formula:

For the pilot-phase results, the MAPE employed by CENACE is the following:

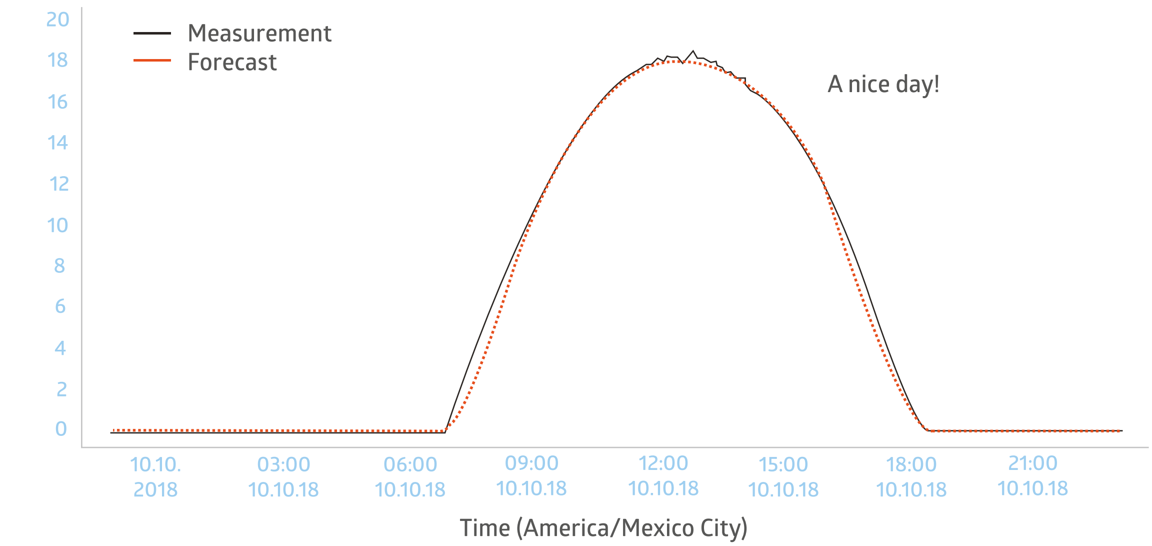
$$\mathbf{MAPE} = \frac{1}{h} \sum_{t=1}^{h} \left| \frac{Dr_t - DP_t}{DR_t} \right| *100$$

Where h represents the number of hours for a given month, DRt is the integrated real power output for hour "t", and DPt is the integrated forecasted power output for hour "t".

CENACE receives power forecasts from each individual solar PV and wind power plant and thus the results shown in this section compare the MAPE from energy & meteo systems forecasts in addition to the MAPE from each individual plant operator's forecast.

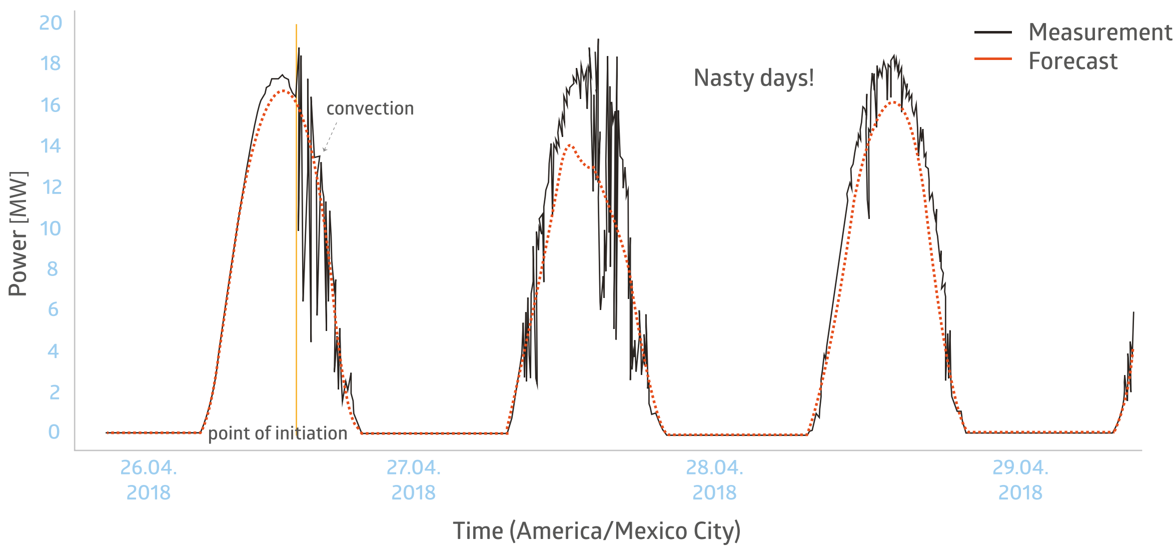
4.1 Solar PV Results

Figure 16.- Forecasted Solar PV plants



Source.- energy & meteo systems
Figure 17.- Solar PV Forecast and Real Output

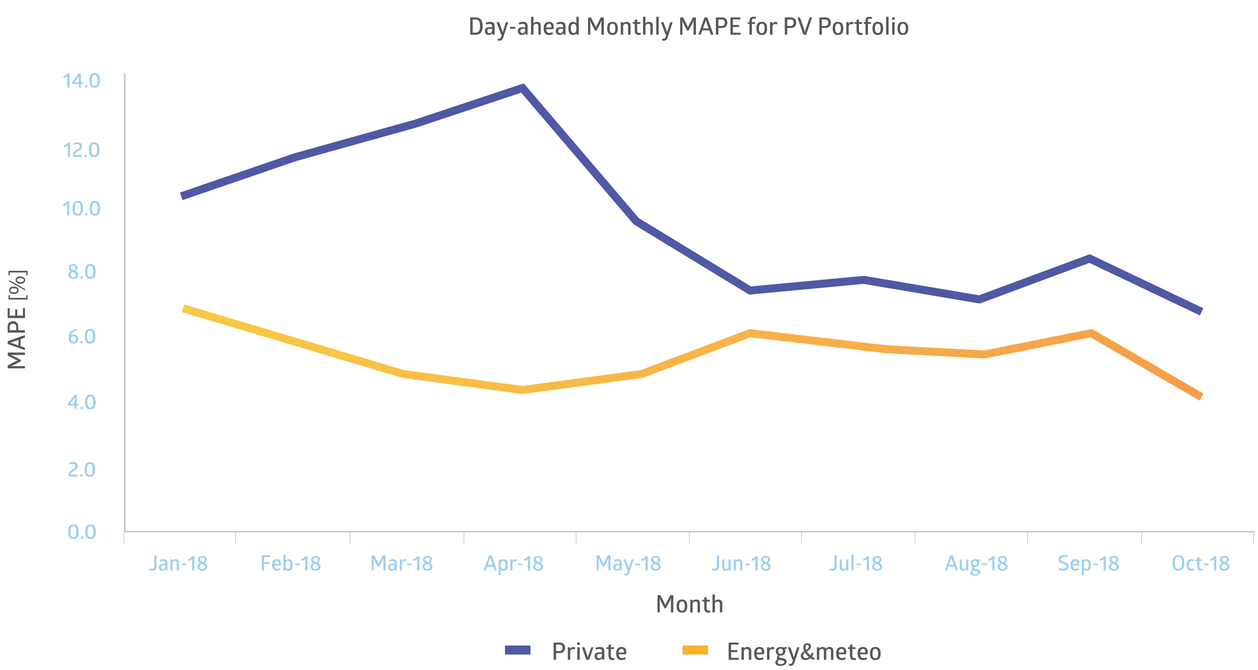
Figure 17 shows a 24-hour ahead prediction for one of the 8 solar PV plants. As can be seen from the figure, the forecast followed and predicted with an extremely high level of accuracy the expected output for that specific plant.



Source.- energy & meteo systems
Figure 18.- 3-day sample of an 8-day ahead PV forecast

Figure 18 shows a 3-day sample of an 8-day ahead forecast, upon close examination one can conclude that convection clouds passing over the PV plant greatly altered the real production, generating quick, sudden and abrupt changes in output. The forecast model was not well equipped to predict these very local events.

Figure 19.- Visual representation of convection clouds



Source.- CENACE

Figure 20.- MAPE for the PV Portfolio

The previous figure shows the day-ahead monthly MAPE for the whole portfolio comparing the individual plant operators' forecasts and those from energy & meteo system. To be clear, each PV plant operator submitted to CENACE their own day-ahead forecast; it is unclear however, if the power plants have a forecasting service from a third-party provider or if the forecast is generated in-house.

As a portfolio, the forecasts provided by energy & meteo system are more accurate than the aggregate forecasts provided by plant operators. However, it should be mentioned, that given the small sample size of 8 plants, a particularly bad forecast from as little as one plant operator can heavily distort and alter the entire portfolio's MAPE.

4.2 Wind Results

Given that more wind than solar plants were forecasted and that these had a larger geographic spread, the results are shown for three specific regions, representing 15 of the 17 power plants forecasted.

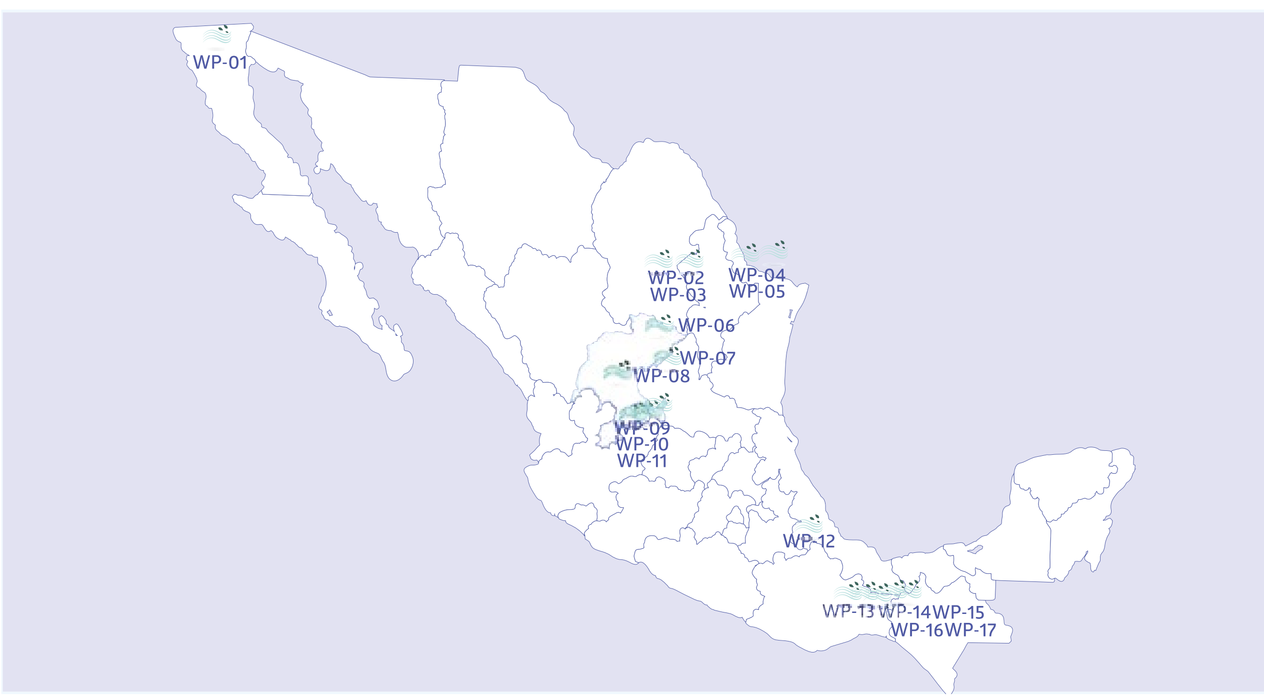


Figure 21.- Forecasted Wind Power Plants

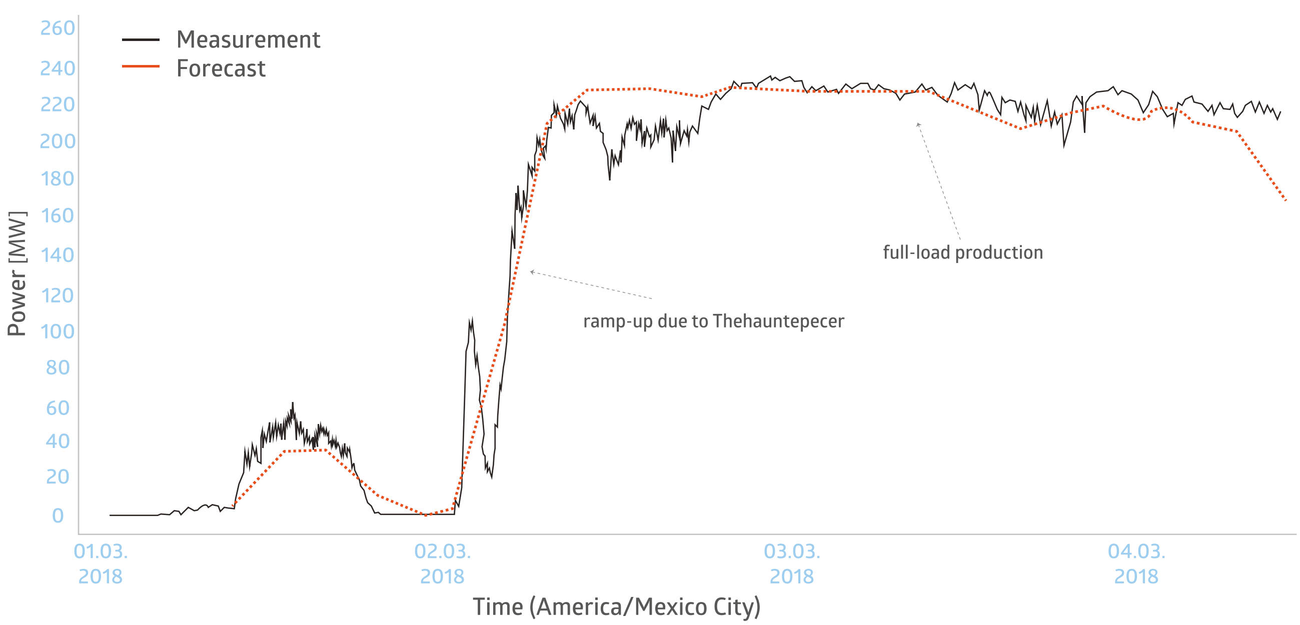
4.2.1 Regional Results

Oaxaca

The 5 plants located in the state of Oaxaca and more specifically in the Isthmus of Tehuantepec are situated at an average altitude of only 23 meters above sea level (m.a.s.l.), with an average installed capacity of 149 MW, and ranging in sizes from 27 to 250 MW.

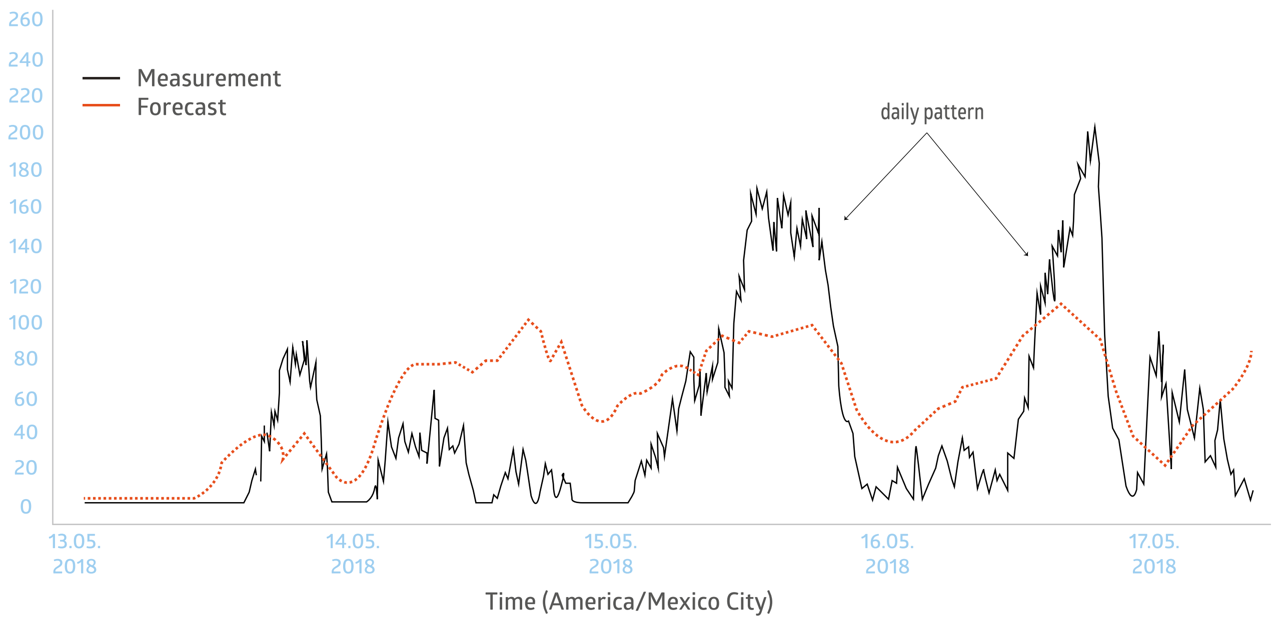
In the case of Oaxaca, the forecasts provided by energy & meteo system proved to be very accurate in autumn - winter and somewhat erratic in spring – summer; the reasons behind this as explained in section 3.3.4.

Autumn - Winter



Source.- energy & meteo systems
Figure 23.- Winter Forecast Example

Spring - Summer

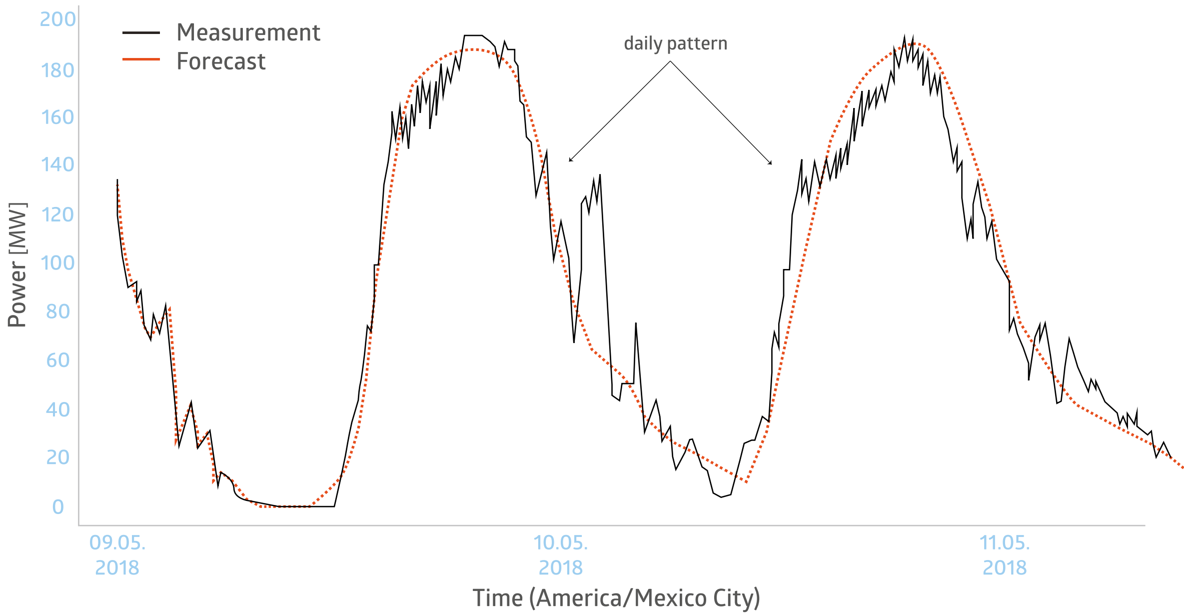


Source.- energy & meteo systems
Figure 24.- Spring - Summer Forecast Example

As previously mentioned, spring-summer months represented quite the challenge for the wind forecasts, given the high and sudden variation of wind speed due to local effects such as thunderstorms and convective clouds. Although not as accurate as forecasts from other seasons, CENACE was still able to make use of the information contained in these forecasts, specially since these more or less predicted the output trend. In other words, although the quantity of power was not very well predicted, the forecasts in general terms predicted if the plants were going to ramp up or down.

Central Highlands

The 6 plants located in what was termed as the Central Highlands are located at an average altitude of 2300 m.a.s.l., with an average installed capacity of 150 MW, and ranging in sizes from 55 to 250 MW.

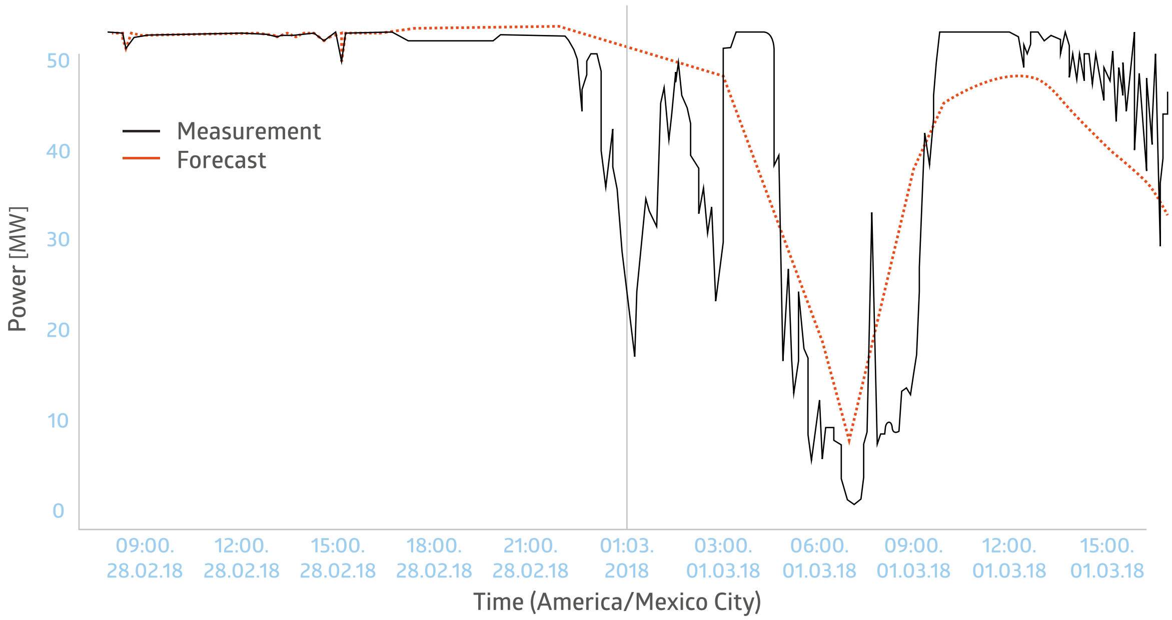


Source.- energy & meteo systems

Figure 26.- Central Highlands Forecast Example

North-east

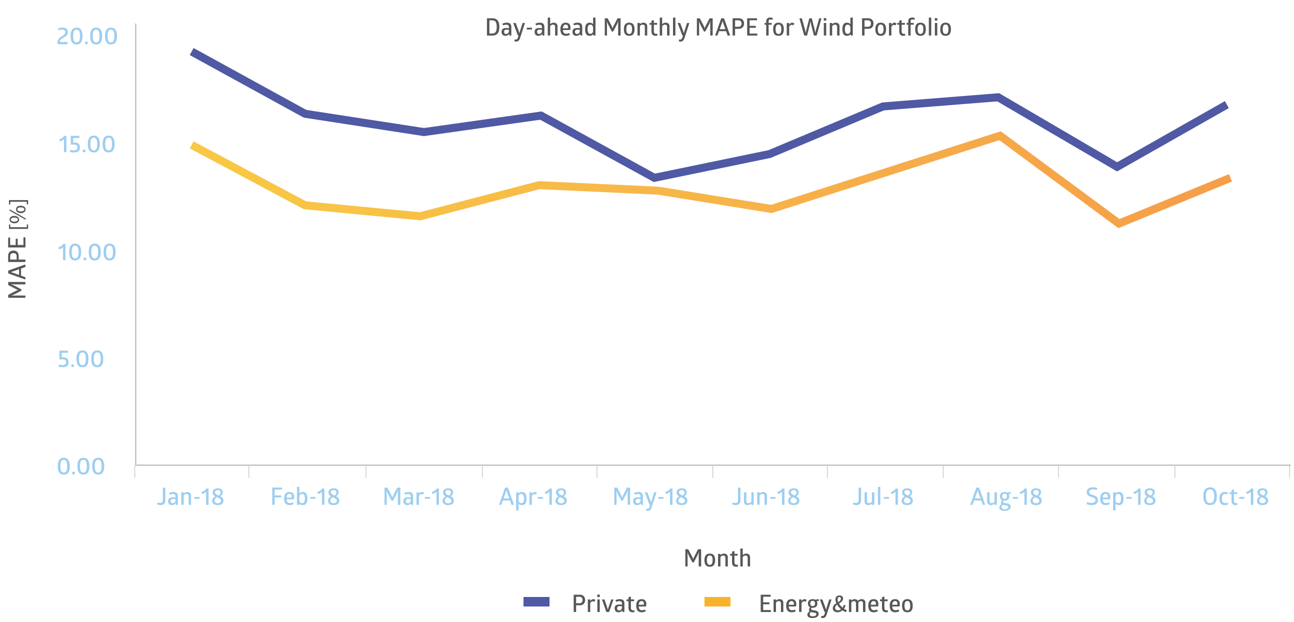
The 4 plants located in the North-east region are situated at an average altitude of 665 m.a.s.l., although unlike the other 2 regions, with a wide range of altitudes between 40 and 1260 m.a.s.l. The average installed capacity of the plants of 100 MW and ranging in sizes from 22 to 200 MW.



Source.- energy & meteo systems

Figure 28.- North-east Forecast Example

4.2.2 Portfolio Results



Source.- CENACE

Figure 29.- Wind Portfolio Monthly MAPE

As with the solar PV portfolio, for the wind portfolio the forecasts provided by energy & meteo system are more accurate than the aggregate forecasts provided by plant operators.

5 Conclusions

The year-long pilot project provided CENACE with practical and real-time experience handling and introducing short-term power forecast into their market and grid operation processes. Specifically, the pilot allowed CENACE to:

I) determine Unit Assignment, i.e. which power plants to dispatch, as part of the day-ahead and real-time energy markets and the Extended Horizon;
II) more accurately determine the price of energy as part of the Locational Marginal Pricing within the day-ahead Market and thus have lower deviations with regards to real-time Market;
III) predict variations of intermittent generation in the real-time market, allowing better administration and application of resources and operational strategies;
IV) better manage the electric grid in general, and the transmission lines in particular.

The forecasts sent by energy & meteo systems during the pilot phase of the project showed an overall higher accuracy compared to those provided by wind and solar plant operators. For the wind portfolio CENACE found an average error of the plant operators' forecasts of 17 % (MAPE) in comparison to 13% for energy & meteo systems'. The same was true for the solar portfolio where the forecasts of the plant operators showed an average error (MAPE) of 9 % while energy & meteo systems forecasting error of 6% which is considerably lower. CENACE concluded that a higher accuracy of renewable energy forecasts is essential for the energy system, reducing the need and the costs for correcting the deviation between prediction and real production.

As the forecasts from energy & meteo systems showed a higher accuracy they were used in the day-ahead process to suggest revisions of schedules to the plant operators and in the intra-day process to make corrections in the dispatch. These centralized forecasts provided in a professional manner were of great importance to CENACE due to several reasons, among them, having redundancy in case the plant operator fails to provide a forecast and having a high quality forecast in which they can rely and to which they can compare and evaluate the different forecast provided by the plant operators.

From the perspective from energy & meteo systems the forecasts performed very well in Mexico. A detailed evaluation was done and the results where compared to sites in similar conditions in other countries. Even though the conditions for some sites in Mexico seemed to be complicated due to local weather events, the forecasts performed well and had a high accuracy throughout the project.

INTEGRATING VARIABLE RENEWABLE ENERGIES

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Results of a Successful DeveloPPP.de Project