elia grid international

Support for the short term improvement of the current renewable energy forecasting in Chile

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Por encargo de:

Ministerio Federal de Medio Ambiente, Protección de la Naturaleza, Obras Públicas y Seguridad Nuclear

de la República Federal de Alemania

Ministerio de Energía

Gobierno de Chile

Edition:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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Titel:
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Declaration:
This publication has been prepared on request of the project "Promotion of Solar Energy" implemented by the Ministry of Energy of Chile and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in the framework of the intergovernmental cooperation between Chile and Germany. The project is funded by the German Climate and Technology Initiative (DKTI) of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). Anyhow, the conclusions and opinions of the authors do not necessarily reflect the position of the Government of Chile or GIZ. Furthermore, any reference to a company, product, brand, manufacturer or similar does not constitute in any way a recommendation by the Government of Chile or GIZ.

Santiago de Chile, 14.01.2016

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1 Introduction

Chile has great potential of fluctuating renewable energy resources such as wind and solar energy. Worldwide, the costs of many technologies for the use of these energy sources have fallen significantly in recent years. Against this background, Chile has the necessary conditions to shape the electrical and thermal energy conversion, which is still based on conventional energy sources by more than 60%, becoming more sustainable without elevating electricity prices and reducing the international competitiveness of Chilean exports.

Through expert advice on improving the legal framework, education and training, technology transfer and initiating innovative projects, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH supports the Chilean Ministry of Energy with the energy program 4e, commissioned by the (German) Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), on the implementation of measures to diversify the energy supply of the country. Promoting the development of solar energy is one of the tasks pursued. With this project the energy conversion and grid injection of large-scale solar systems, for which exist the world's best conditions particularly in the North of Chile, but also with other fluctuating renewable energies, are to be supported.

The general working areas include topics such as capacity building and training, advice on the grid integration of renewable energies, technology transfer and the dissemination of experiences gained in Chile on an international level. This technical cooperation project is part of an agreement between Chile and Germany and includes a financing component, which is covered by the German development bank KfW. The project funds from the Energy and Climate Fund of BMUB.

The market for large-scale solar systems in Chile is predicted to have good prospects and currently there are a large number of projects with several thousand MW (CSP and PV) under development.

The Chilean electricity transmission system is comprised of 2 main grids. The central grid and grid operator CDEC-SIC (Centro de Despacho Económico de Carga del Sistema Interconectado Central) cover more than 90 % of the Chilean population. The Northern grid operator, CDEC-SING (Centro de Despacho Económico de Carga del Sistema Interconectado del Norte Grande) mainly delivers electricity to big mining companies. Up to date both transmission systems are not interconnected and operate independently. The Northern interconnected System (SING) disposes of an interconnection line to Argentina, which currently is not being used for regular electricity exchange. Other than that there are no further interconnections with neighbouring countries.

During the year 2015 the construction of a transmission line between the Central Interconnected System (SIC) and the SING has begun and it has been decided to unite both CDECs to one national grid operator and dispatcher. The technical interconnection of the two systems as well as the unification of the two grid operators are planned for the beginning of 2018.

In August 2015 approx. 530 MW of utility scale PV and approx. 890 MW of wind capacity were connected to the Chilean grids and have been in operation. Thereof in the SIC approx. 1.237 MW installed capacity were PV and wind (of a total installed capacity of 15.433 MW and a peak load of 7.500 MW) and in the SING approx. 183 MW installed capacity were PV and wind (of a total of 4.793 MW and a peak load of 2.300 MW). Nevertheless, another 2.100 MW of PV and 112 MW of wind capacity are under construction and will be connected during the upcoming months (in both systems combined). Additionally, several GW of PV and wind capacity are in different planning stages.

Considering this rapid increase in shares of variable Renewable Energy (vRE) in the Chilean electricity grids, the need for adequate mechanisms for forecasting the injection of electricity generated by PV and wind power plants is obvious in order to aim at guaranteeing a stable operation of the electricity system and keeping costs resulting from generation reserves to a minimum.

When a significant share of the generation is generated by renewable sources, the balancing of load becomes more complex. Indeed, the availability of these resources fluctuates according to the weather conditions and the real production levels at each moment in time are therefore not really predictable a long time in advance. The renewable generation is uncertain because it depends on the variability of the weather conditions. Presently, one cannot predict perfectly how much wind will be blowing or how the sun will be radiating. This brings uncertain forecast errors in the balancing forecasts of the grid. One solution to manage forecast errors is to develop better forecasts of renewable generation by implementing new forecasting tools or challenging available external forecast providers.

Today in Chile, forecasting of fluctuating renewable energies is not performed in a centralized way. Rather every plant operator is committed by the grid code to deliver forecasts with intervals ranging between one and three hours, and with a horizon ranging from 12 hours to 7 days ahead to the CDECs. Almost all plant operators have contracted private service providers that regularly deliver the forecasts for the respective plants. Overall the currently used systems, models and processes for forecasting the grid injection of vRE appear to result in above-average errors, which in turn result in uncertainties in grid operation.

In recent months a discussion has begun whether a centralized forecasting system that covers the future combined transmission systems and operated by the future unified grid operator should be implemented. The debate indicates that such decision might be taken in the near future and that such a system may be developed.

Nevertheless, the implementation of a centralized forecasting system for vRE is a complex and time-intensive undertaking. Therefore, considering the vast increase in vRE in the upcoming months in Chile a quick interim solution is required to improve the currently applied systems and processes in order to be able to integrate the upcoming vRE plants using the existing, but improved forecasting models.

With this report, the currently applied system and processes for forecasting vRE in the Chilean electricity systems are analysed and possibilities identified that improve the prevailing forecasting systems and processes in the short term without having to implement a complete new system. Based on the expertise of the Elia group and especially on that of 50Hertz in Germany recommendations are elaborated for forecasting vRE in Chile.

2 Executive summary

In this report the current system used in Chile for forecasting the grid injection of solar (PV) and wind power plants is analysed. In addition, the actions taken by the CDECs resulting from the forecasting data is illustrated. Furthermore, the relevant sources of forecasting errors are identified based on extensive data processing and assessment. Finally, recommendations for short term improvements using the existing systems resulting in improvements of system operation are provided.

The report introduces the current situation in Chile and the ambitious plans to integrate renewables, and delivers a review of the current forecasting process. The current grid code prescriptions do not put quality requirements on forecasting, which should be added. The current forecasting process is based on (meteorological) models processed by the forecasting service providers. These forecasts are sent to the CDECs and are not challenged. The consultant is convinced that CDEC need to perform their own forecasting based on existing meteorological forecasting systems, as is the case in Germany where we take a weighted average of different forecasts based on the quality of each forecast. In the operation control we introduce additional processes which can be performed using improved forecasts.

The report elaborates on the results from the received data assessment and processing. Data consistency and systematic errors are investigated. Thereafter the most relevant error indices calculated over the received forecasts and real active power time series provided by the CDECs are elaborated. The main performance indices considered are the MAE (Mean Absolute Error), RECMN(normalized Root-Mean-Squared Error based of the standard deviation), nRMSE (normalized Root-Mean-Squared Error based of the installed capacity) and the Maximum and minimum Errors. The identification of the relevant forecasting error sources closes this chapter of the report.

The identification of the relevant error sources shows a potential for improvement. The main potential lies in the cooperation and communication between the CDECs, Forecast service providers and the Plant operators. The CDECs shall play an important role in the improvement of the quality of forecast through regular feedback to both the service providers and the plant owners. A direct cooperation between the service providers and the CDECs should be enabled in addition to the cooperation with the plant owners.

At the end of the report the consultant focuses on recommendations to improve the current forecasting system applied in the Chilean electricity system. It starts with recommendations on how to make a better use of the ongoing forecasting process. Afterwards recommendations on additional requirements, which could be realized in the short-Term, are elaborated. And finally, short- to medium-Term measures affecting the structure of the CDECs are explained.

To make a better use of the current forecasting process in Chile the following is recommended; it is recommended that the Plant operators should be responsible for providing and updating the measurements and planning data of the RES to the forecast service provider and to the CDECs. Additionally, plausibility checks and assessment of the forecast data should be performed by the CDECs and feedback should be given to the plant operators and the service providers. Furthermore, the grid code should put obligations on quality of forecasting.

The additional requirements are summarized as follows; it is recommended to increase the frequency of update for the short term forecast up to 15 minutes and use similar forecast horizons for both wind and Photovoltaic plants. In addition, indicators for weather events like storms or fogs should be provided by the service providers. Moreover, a direct link should be established between the CDECs and the RES forecast service provider. Besides, more than one forecast service provider should be involved.

In the advent of the planned unification of the two CDECs the following measures are advised; examine the feasibility of having forecasting of renewables centralized at the CDECs. Furthermore, adjacent RES plants should be grouped in clusters up to a regional level and additional forecasts for these clusters should be delivered to improve the overall forecast quality. Finally, a process for adapting power schedules of the different energy sources should be developed in an efficient way.

3 Review of the current forecasting process in Chile

The quality of forecasting becomes a critical component of system operation with the increase of renewable generation. Some measures are therefore required to make the best use of the current forecasting process and consequently improve it. A first measure is to assess the forecasting quality of the current process. In this chapter the state of the art of the forecasting system in Chile and a review of its practice are provided.

3.1 Grid code requirements for forecasting

The requirements for forecasting for wind and photovoltaic generation are defined in article 7-13 of the grid code (see [1]). The grid code prescribes the submission of 113 forecasts per day for each wind farm and only 3 forecasts for each photovoltaic farm (cf. Appendix A). The plant operators are responsible for providing the required forecasts to the CDECs. However, the assessment and improvement of the quality of forecasting is not regulated.

Furthermore, the regulation allows the CDEC to define and request other format or probabilities of occurrence for the short term, day ahead and week forecasts. The CDECs are already using this allowance and have defined their own requirements (cf. Appendix A).

3.2 Current forecasting process

A general overview of the current forecasting process is provided by Figure 1.

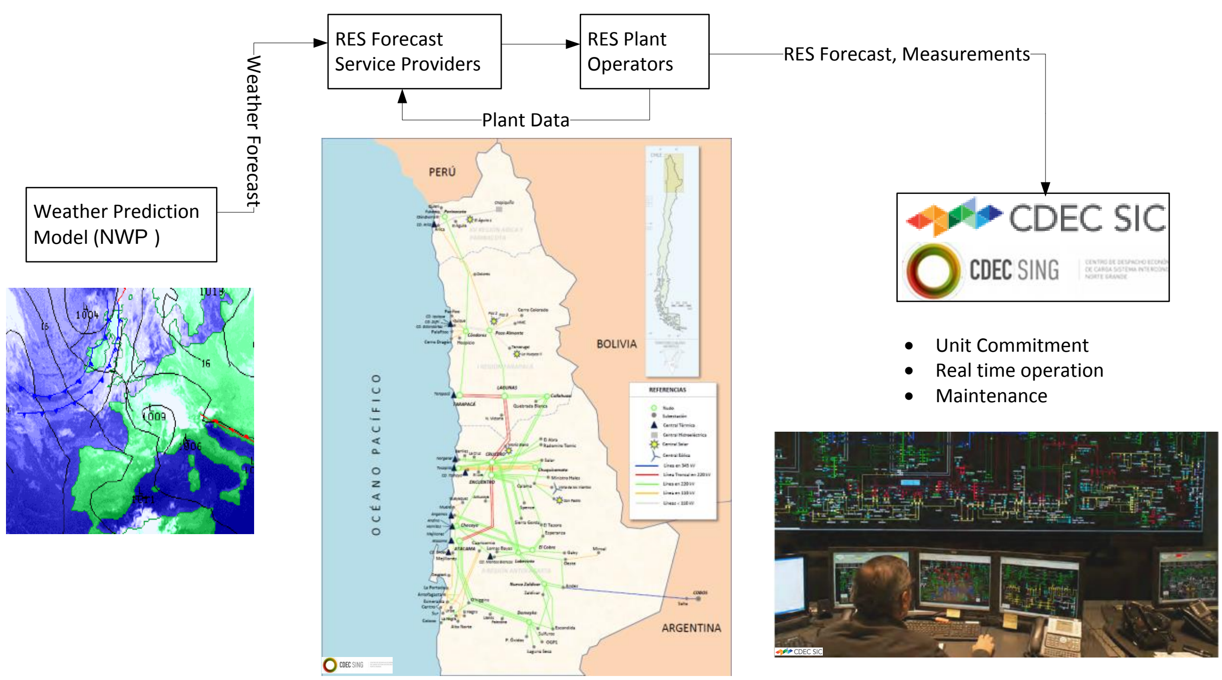

Figure 1 Current Forecasting and subsequent processes in Chile

Based on numerical weather prediction models (NWP) and available plant data the RES forecast service provider generates the required electrical power forecast. The basic data submitted to the service provider are the locations of the plants, coordinates of the wind turbines and power curves. In some cases, meteorological data is provided by giving the service provider access to meteorological in-site measurements. However, only few plant owners provide real active power generation with regular updates.

CDEC-SIC requests 75 forecasts per day for wind farms and 3 forecasts for Photovoltaic plants per day. On the other hand, CDEC-SING requests each wind and photovoltaic farm to deliver 9 forecasts per day (cf. Appendix A).

3.2.1 Weather prediction Model

Numerical Weather Prediction (NWP) models perform computed based simulations of the atmosphere's evolution for the incoming days. They are the essential and universal tools used in weather forecasting. Despite their sophistication, the forecasts generated by the NWP models of the surface's meteorological situation still have limitations. These limitations make it essential to implement a post-processing technique known as “reinterpretation” or “downscaling”.

Some of these models include physical laws that simulate relationships between variables, others are based on statistical relationships between input and output variables. All of them require a specialised calibration with observed data in order to provide maximum value to the user [2].

3.2.2 Forecast service providers

The majority of the companies consulted have contracted the services from the Spanish forecast provider Meteologica, which accounts for 451 MW of wind and 520 MW of photovoltaic installed capacity (SIC and SING). The option for this vendor most referred in big utilities is related to international agreements for the plants that they own, and for small power plants is related to recommendations made by other companies in the Chilean market. Just one wind farm has contracted the service from Vestas, and one PV has developed its own software [3].

The input data for running the forecast model comes from two sources:

- Numeric weather prediction models (NWP) of the two most used entities [4]: the European model ECMWF [5] and the US model GFS [6]. The information of the first is paid and is updated twice a day (0:00 and 12:00) with a horizon of 168 hours ahead. The GFS model updates 4 times a day (0:00 6:00 12:00 18:00), is free and forecast to 180 hours ahead.
- Information from the wind and PV farms: electric power, availability of the power plant, meteorological variables.

Because NWP generally calculate with the help of meshes with 15-50 km spatial resolution, it may be useful to apply a mesoscale model to achieve 5 km resolution. The company mentions that for Chile apparently there are no mesoscale models available. Nevertheless, it is considered that this issue does not represent a disadvantage for the service provided.

The model uses directly the output of the NWP and to transform them into electric power, it is used a model output statistic (MOS) that correlates the meteorological variables of interest with the measured output. For this reason, a learning process is expected in wind and PVs with no history measurements. The learning is completed usually with 1 year of meteorological and electrical power measurements. For shortest term forecasts, it is also used the active power measurements provided by the client, which are effective in reducing error in a range of 1 to 6 hours. No forecasts are made in an intra-hour basis. NWP models provide ensemble forecasts, which allow Meteológica to provide probabilities of occurrence for each hour [3].

Utilities that request the services to Meteológica, must submit in first place the installed capacity, power plant location and generation historian. The historic must contain turbine availability or grid limitations for the correct training of the MOS. This information is the basis for the tuning of the model [3].

3.2.3 Processes between the CDECs, the RE plant operators and the forecasting service providers

CDEC-SIC receives forecasts in csv format, via ftp and are stored in a local hard drive. The forecasts are also submitted via e-mail as a back-up. Short term forecasts are submitted every hour, Long term forecasts are submitted at 6:00 AM and 6:00 PM and Week forecasts are delivered at 9:00 each day.

The CDEC-SING receives both types of forecasts in xml format through a web application developed in-house named SGER (Renewable Energy Management System, acronym in Spanish). Long term forecasts may be received until 1:00 PM of the previous day, while short term predictions will be received every 3 hours starting at Midnight [3].

3.2.4 Subsequent processes in the operational control

Forecast data is mainly used in 2 internal processes of the CDECs; unit commitment and real time operation. For the unit commitment schedule the CDEC-SIC uses Long term forecasts, uploading them from the local hard drive to the program that optimizes the unit commitment. The schedule for the next day is published no later than 4:00 PM. For real time operation short term forecasts for wind, and Long term forecasts for Photovoltaics will be used. The dispatchers calculate an update of the schedule with the latest information received by renewables on a daily basis at 7:00 AM. In case of risk of transmission congestion calculated with 50% probability of occurrence, CDEC-SIC will ask wind and photovoltaic involved to reduce generation in those hours proportional according their installed capacity. In order to reduce real time overflow in these lines, wind and PVs are enforced to use ramp up control, limited to a 10% maximum ramp up according to their nominal power [3].

In the southern area of the CDEC-SIC system the penetration of renewables is not yet affecting the operation. This region is mainly backed up by large hydro power plants with sufficient power reserves. In the northern part of the system however, the area is characterized by a 220 kV long and unmeshed transmission system, with low power transport capability and high installed capacity of renewables.

The main application of forecast data up till now is to decide on the dispatch of the Guacolda coal power plant in the northern part. The decision of the dispatch of these coal units is taken in advance and because their high start-up/shut-down duration, once dispatched no other measures can be taken until the next set-point is set based on the schedule. For system stability reasons 3 coal units shall always be in operation. In case of high penetration of renewables, 3 coal units are reduced down to the technical minimum and one unit is shut down if required.

It is important to mention that the Guacolda units cannot be stopped and started every day. The renewable forecast is used for programming in advance the ramp up or down of these units. It must be considered that in one of them, the power set-point cannot be changed until 8 hours have passed before the last set point, and for the others this parameter is 2 hours. The constraint is defined in the CDEC-SIC as “stabilization time”.

CDEC-SING uses the forecast data for 3 internal processes of the CDEC which are unit commitment, real time operation and Facilities maintenance programming.

Long term forecasts will be downloaded from the SGER and uploaded to the unit commitment software around 9:30 – 10:00 a.m. of the previous day. The deterministic daily dispatch schedule is published no later than 17:00 hrs. The only adjustments made to received forecasts applies to photovoltaic farms, where sometimes the forecast may be delayed/advanced in one hour because of manual errors in the power plant control centre before the upload to the SGER. Reserve requirements for upward (70 MW) and downward (116 MW) secondary control are fixed for all the year, and the actual calculation methodology only involves load forecast deviations, as stated in article 6-48 of the grid code. The recalculation of reserves is done once per year. The preliminary results of this year are expected to be available on 18/12/2015 and it is expected that this time it will involve requirements regarding RES forecast deviations [3].

Short term forecasts are displayed in real time in the control room, contrasted to actual generation for each wind and photovoltaic farm. The personnel uses this information to be aware of wind and PVs startup/shut down, the maximum power that they will provide in the next hours and the ramps that may occur (in an hourly basis). The data provided by the companies is used and trusted for every power plant. In case of deviations, SGER will be the first source of information to understand the differences between the scheduled generation and real time operation. In case of large programming deviations - rule of thumb described is 80 MW difference regarding the schedule for more than 8 hours , the personnel may run a redispatch, using Plexos including the actual conditions experienced in the system and the last update of long term renewables forecasts -if there are significant changes regarding the last forecast used in the program i.e. due to the outage of a wind or photovoltaic farm. The calculation usually takes 20 to 30 minutes, and the implementation of the new schedule may take 1 hour due to administrative work. Every dispatcher in the control room is capable of running the unit commitment software and has received training in the usage of the SGER program and its capabilities, but hasn't received formal training about renewables forecasting issues [3].

Main concerns about forecasting in real time relates to photovoltaic farms and cloud covering, because the actual forecasts submitted to the CDEC doesn't represent this phenomena. For this reason, the biggest photovoltaic park (68 MW) included an in-site watchman, who alerts the control room – via phone call – if clouds are watched nearby. Nevertheless, the warning won't allow the CDEC personnel assess the impact that the cloud covering will produce, both in active power reduction (and increase after cloud passage) and timing of the event. Because of this issue, curtailment is done via local active power reduction, to a "safe" set point decided by the power plant operator. The limit is released when no clouds are spotted nearby, with a controlled upward ramp. No problems regarding transmission constraints have been observed so far in wind or photovoltaic [3].

4 Data assessment and identification of error sources

4.1 Data assessment

Because of low performance detected in forecasts, for some wind farms dispatchers adjust the forecasts to previous day behaviour or to persistence forecast for the next hour.
The actual forecast performance of wind it is perceived as very low. In some of them, 1-2 hour ahead foreseen generation have higher errors than forecasts submitted 12 hours before. Because of this, for some wind parks is necessary to consider persistence as the best forecast for the next hour. In other cases, hourly updated forecasts remain the same with no actualization according to the real generation of the wind farm. Also, delays in the submission have been detected [3].

On the other hand, PVs forecast are perceived to be accurate. Nevertheless, as metrics have been calculated for few months, there isn't a benchmarking of what is considered to be "good" or "bad" performance, neither for PV or wind.

4.1.1 Data provision

1 year of data for power plants operational since 9/2014 (from 9/2014 to 11/2015) were provided by the CDECs to GIZ and used in the assessment in this report. For power plants connected recently to the grid only data from the beginning of operation date to 11/2015 shall be available. In total 23 power plants are involved. 20 integrated in the system of CDEC-SIC and 3 in CDEC-SING (cf. APPENDIX B– Plant data and forecast availability).

The data provided from the CDECs to GIZ includes the following:

- Characteristics of wind and photovoltaic plants with installed capacity above 9 MW.
- Real active power generation measured at the connection point to the grid, with the associated time stamp for each value, in an hourly basis.
- Forecasts provided to the CDECs for each power plant with the time stamp including day and hour.
- Events that represent limitations to active power injection into the grid of wind and photovoltaic farms (forced operation below maximum active power available), with the date and hour of the beginning/end of the restriction, for each power plant.
- Maintenance (Programmed disconnections) or trip events (Failure)

The 2 CDECs have organized the data differently. CDEC-SIC provides 3 different folders for forecasts, measured active power and limitations of active power. CDEC-SING on the other hand provides only one folder for each power plant. The same applies for the data. While CDEC-SING gathers all the data in one file for each plant, CDEC-SIC provides 3 different files for that;

1. Transmission constraints or limitations for each power plant are given in binary format (1: transmission restriction active, 0: no restriction) and the value of curtailment is not specified.
2. The short-Term forecast is provided either every 1, 3, 6 or 12 hours. This organization is due to a modification in the grid code, which changed the requirement for updates between 3 hours to an hourly update for wind farms. For photovoltaic the update requirement was reduced from a 3 hours basis to two times a day. Each folder contains individual files that represent each forecast provided. Inside the file the date and hour at which the forecast was generated is specified. Whereas the long-Term forecast is provided only once a day.
3. Real active power generation measured at the connection point to the grid

4.2 Performance metrics for short-Term, day ahead and long-Term forecast

As the main performance metric the Root Mean Square Error (RMSE) normalized by standard deviation (σ) is by CDEC-SIC. This metric (RECMN) is defined with the following equation:

$$RECMN = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i - x_{pi}\right)^2}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \cdot \frac{N-1}{N}} = \frac{RMSE}{\sigma_i}$$

Where x_i corresponds to real generation in hour i, x_{pi} corresponds to forecasted power for the hour, N is the number of hours of the horizon considered to the calculation and $\bar{x}$ is the averaged real generation during the hours investigated. For PVs the metric is calculated only for sun hours. The usage of this metric is justified as the one that best represents the performance of individual power plants seen by the dispatchers of CDEC-SIC. RECMN stands for the Spanish abbreviation.

For CDEC-SING the main performance metric used is the Mean Absolute Error (MAE) normalized by the installed capacity of the Wind or PV plant calculated according to the following equation:

$$nMAE = \sqrt{\frac{\sum_{i=1}^{N}\left|x_i - x_{pi}\right|}{N \cdot P_n}}$$

Where x_i corresponds to real generation in hour i, x_{pi} corresponds to the forecast of generation for the hour, N is the number of hours involved in the calculation (horizon) and corresponds to the installed capacity. The metric is also calculated for sun hours only for photovoltaic farms.

To be able to benchmark the results, an additional metric is added. This metric is based on the Root Mean Square Error based on the bias and standard deviation of the error normalized by the installed capacity of the Wind or PV plant (nRMSE). The German TSO 50Hertz made positive experience with this metric as an indicator of forecasting quality.

$$nRMSE = \frac{\sqrt{\left(\frac{\sum_{i=1}^{N}\left(x_i - x_{pi}\right)}{N}\right)^2 + \left(\frac{\sum_{i=1}^{N}\left(x_i - x_{pi}\right)^2}{N-1}\right)}}{P_n} = \frac{\sqrt{Bias^2 + \sigma_{E_i}^2}}{P_n}$$

The symbols and subscripts of this equation correspond to the other equations. Similarly N is calculated for sun hours only for photovoltaic plants. The following reasons are given by the German TSO 50Hertz on why it is preferred to use this metric:

- It does not only assess the bias but also the variance of each error. In addition, the biggest errors are strongly weighed through building of the square value.
- This metric gives normally a better representation of the forecast error than the non-quadratic MAE. Statistical methods e.g. neural networks also minimize the sum of the quadratic errors and not the non-quadratic sums.

To be able to calculate the metrics the real power values, the forecasts and the limits were gathered for every plant for three different horizons; 12, 48 and 240 for CDEC-SIC and 24 for CDEC-SING. The horizon predefined by each file is used for the calculation for the CDEC-SIC data and for CDEC-SING a constant horizon of 24 hours is used.

Firstly the files were separated in three categories to be able to calculate the metrics for each horizon. This enables the assessment of both the short and long term forecast. The calculation of every horizon aims at showing a general overview of the quality of each forecast supplied. For every available file in each horizon the metrics are calculated to give an overview of the performance of the forecast along the whole duration under investigation. The duration is mainly determined by the available data provided by the CDECs. At the end the metrics for the whole period available is calculated to give a final performance indicator about each plant. The non-consistent data was not included in the calculation. Therefore, in order to track the results, the corresponding dates used for calculation are mentioned in each graph.

In the calculations of the final performance indicator the forecast values with 50% probability of occurrence are used. This is the only forecast probability, which is available for all the plants in the three horizons. CDEC-SIC provided additional probabilities of 25 and 75% of occurrence.

4.2.1 Example for a wind power plant

The following figures illustrate the calculated RECMN, nRMSE, nMAE, maximum and minimum error values for the duration between June and November 2015 for the wind park Canela I of 18.2 MW installed capacity. The values are calculated for the short-Term (12 hours), day-ahead (48 hours) and long-Term (240 hours).

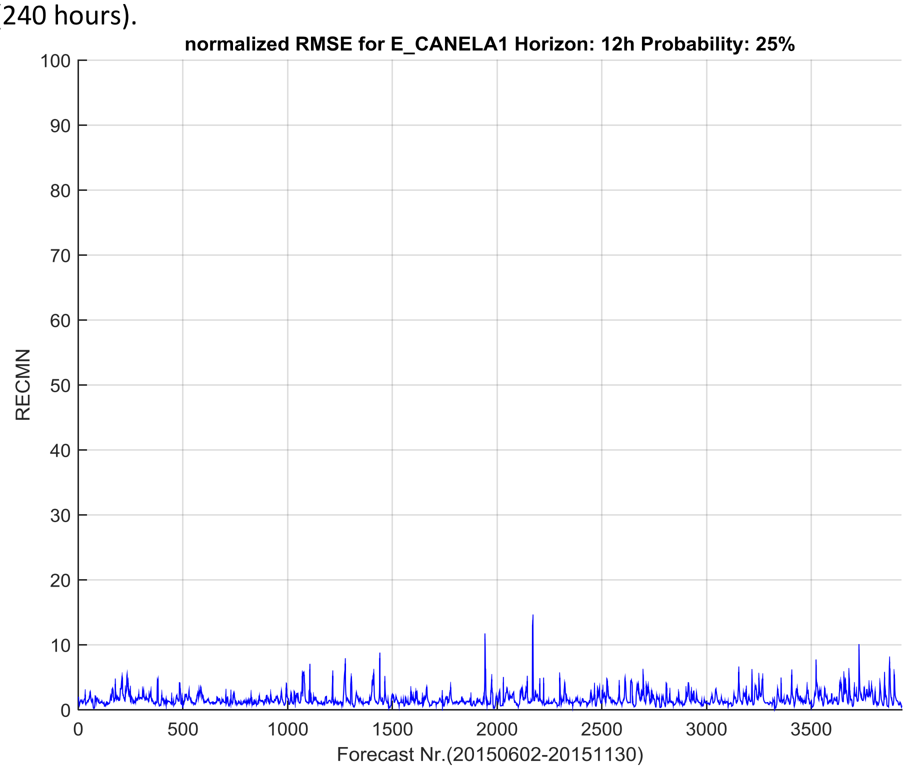

Figure 2 RMSE Normalized based on standard deviation for the short-Term forecast 25% probability between June and November 2015 for the wind farm Canela I

Figure 2 shows the RECMN calculated for the data available from 02-06-2015 till 30-11-2015 for a forecasting probability of 25%. The results are calculated for the horizon of 12 hours and have a minimum of 0.72 and a maximum of 13.8. The x-axis represents the forecast Number, which is the number of files or hourly forecasts available between June and November. Excluding the non-consistent data and missing files only 3932 forecasts are included i.e. 164 days out of a total of 182.

Non consistent files are e.g. the ones having a different format as showed in the APPENDIX D– Data consistency in Figure 32. Another reason of why files are not included in the calculation is if the measurements are missing for a certain date. In comparison to the 25% probability of occurrence Figure 3 shows relatively higher RECMN peaks for a 50% probability of occurrence reaching values of up to 24. This trend continues for the 75% probability as illustrated in Figure 4, where the values of RECMN reach almost 40.

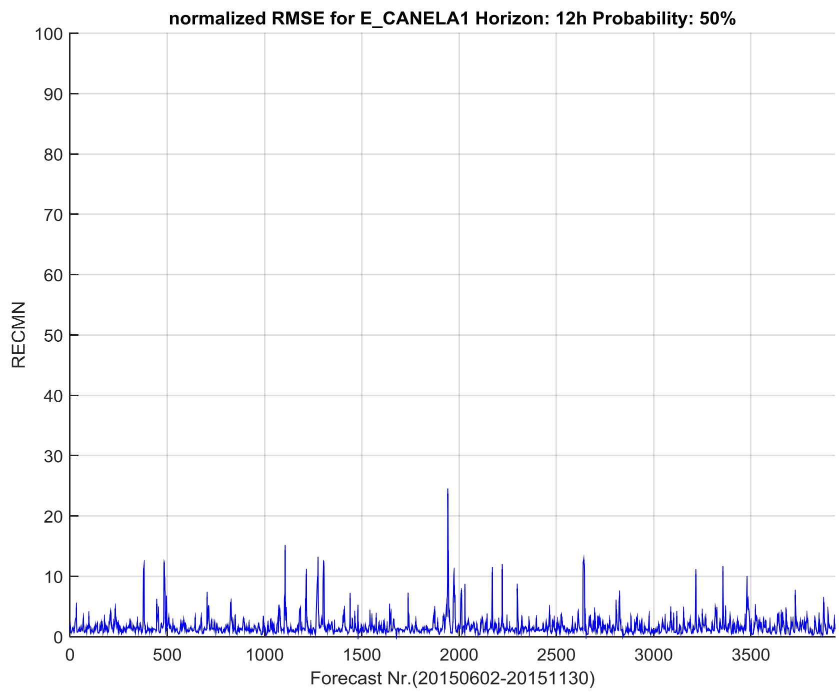

Figure 3 RMSE Normalized based on standard deviation for the short-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

To evaluate the overall performance of the plant based on this metric the results for the whole investigated period are used to calculate the RECMN. For the wind plant CANELA1 the RECMN for the whole period is 0.96, 0.8 and 0.7 for a probability of 25, 50 and 75% respectively. In this case the overall performance corresponds to the intuition, that a forecast with 75% probability provides better quality than one with 25%. Nevertheless the individual errors could reach higher values than those of a 25%. The performances based on the 50% probability are summarized in APPENDIX C– Performance metrics. This shows that the intuition is not always correct. Based on the forecasted data provided by the CDECs, a 75% probability represents the 75% upper case (overestimation) of – if wind forecast is considered - wind speed and a 25% the lower case (underestimation). This means that if the forecast - measured over a long period of time - is biased, one would expect that any one of the three forecasts (25, 50 or 75%) would show a better quality of forecast than the other two.

To get more insight about the performance for each hourly forecast, the forecast errors were calculated for the different probabilities of occurrence as shown in Figure 5, Figure 6 and Figure 7. Hereby the error is calculated as the measured active power minus the forecasted value. This means that a positive error resembles an underestimation and a negative an overestimation by the forecast for the real power. To show the worst case estimations, the maximum and minimum errors of each horizon are chosen and illustrated in the figures. The errors are calculated as a percentage of the rated power capacity of the plant.

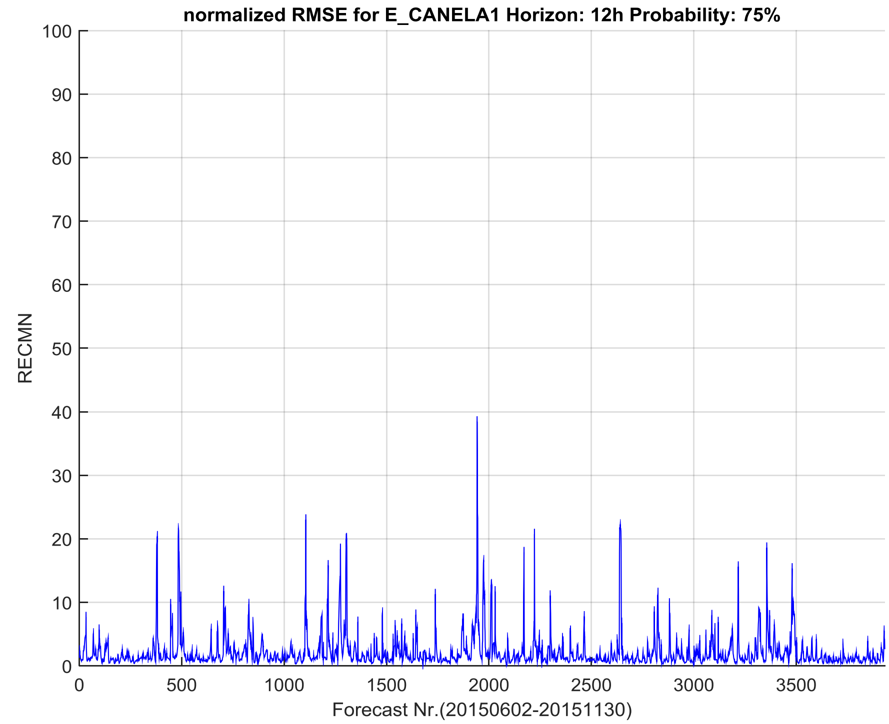

Figure 4 RMSE Normalized based on standard deviation for the short-Term forecast with 75% probability between June and November 2015 for the wind farm Canela I

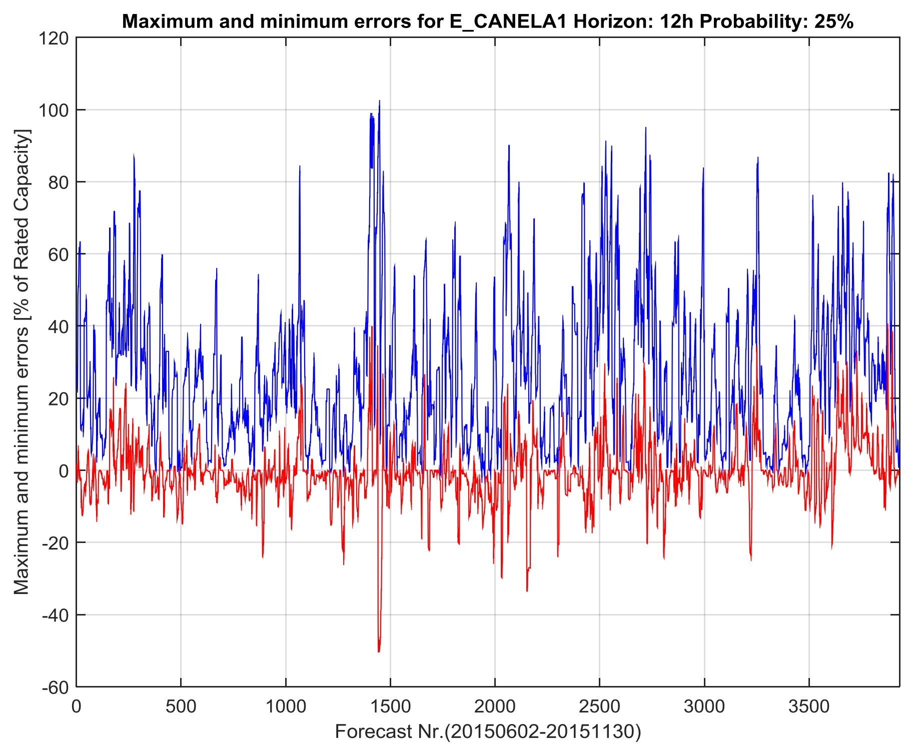

Figure 5 maximum and minimum forecasting errors for the short-Term forecast with 25% probability between June and November 2015 for the wind farm Canela I

The increasing trend recognised by the RECMN calculation is also trackable in the errors; in general the maximum and minimum errors are relatively lower in the case of 25% probability compared to 50 and 75% probability.

Nevertheless, the global maximum of all probabilities occurs in the case of 25% probability with a value of even more than 100%. In this case the forecast indeed underestimates the active power. However, the measurements surprisingly exceed the rated power of the plant. This happened on the 07th of August 2015 at 9 PM, where the measured value reached 18.6 MW for an 18.2 MW of rated power. This shows how important it is to perform a plausibility check on the measured data.

In other scenarios the forecast and not the measurements delivered non plausible values. This is the case of the wind plant Totoral on the 8th of August 2015, where an overestimation of 124% occurred (not shown here but in the summary in APPENDIX C– Performance metrics and illustrated in Figure 35 of APPENDIX D– Data consistency). Similarly a plausibility check should be performed to avoid using forecasts which are larger than the rated power. In general the maximum and minimum errors for the wind plant Canela1 starting at 1% up to 100% show that the forecasts delivered have a wide span of performance.

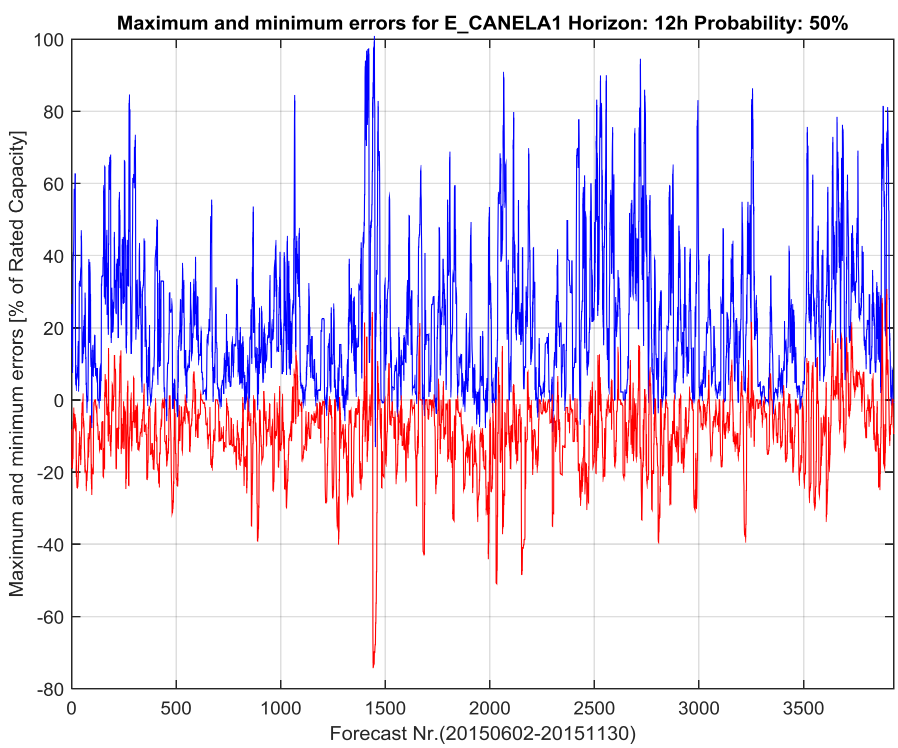

Figure 6 maximum and minimum forecasting errors for the short-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

Another interesting point is to try to relate the global peak of the RECMN calculation with the maximum and minimum error peaks. The global peak for RECMN occurs for the forecast Nr. 2169, but this does not correlate with the global peak of the maximum errors happening around the forecast Nr. 1480. This indicates that the RECMN does not emphasis the maximum individual errors. It even misinterprets the forecast quality in this case as the maximum error is only at 20% for forecast Nr. 2169 i.e. it is below the average.

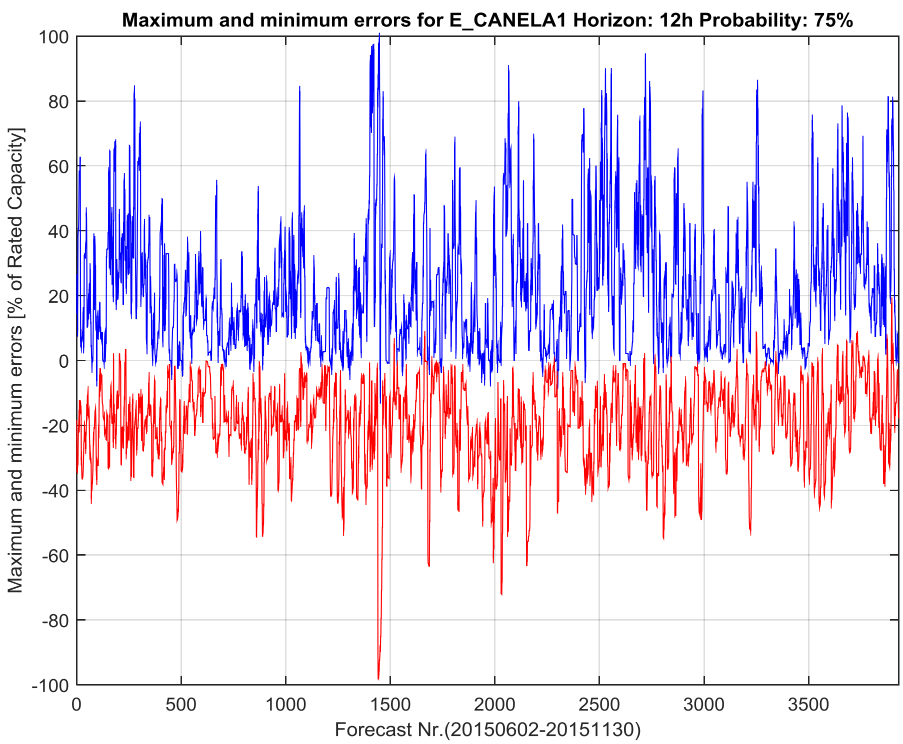

Figure 7 maximum and minimum forecasting errors for the short-Term forecast with 75% probability between June and November 2015 for the wind farm Canela I

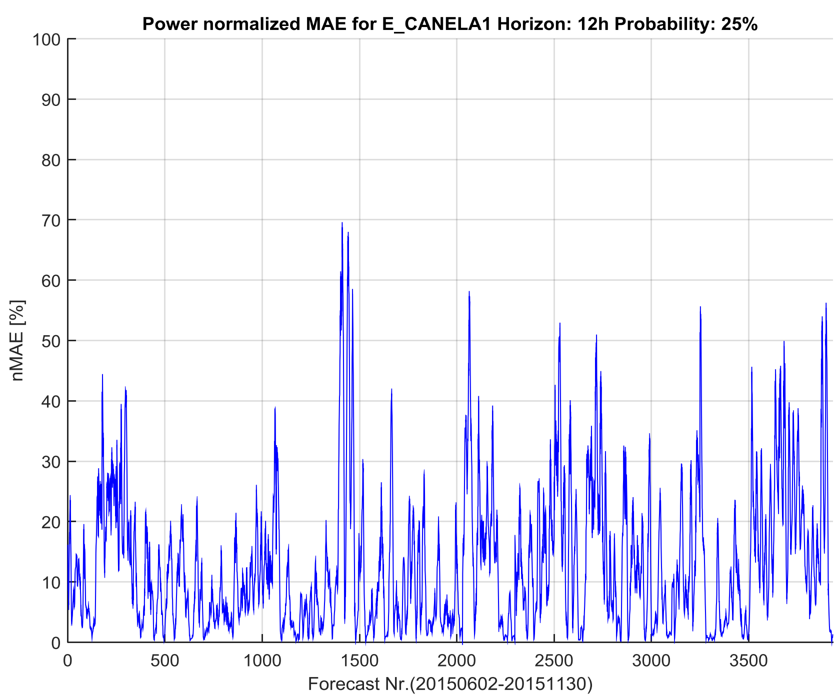

Figure 8 MAE Normalized based on installed capacity for the short-Term forecast with 25% probability between June and November 2015 for the wind farm Canela I

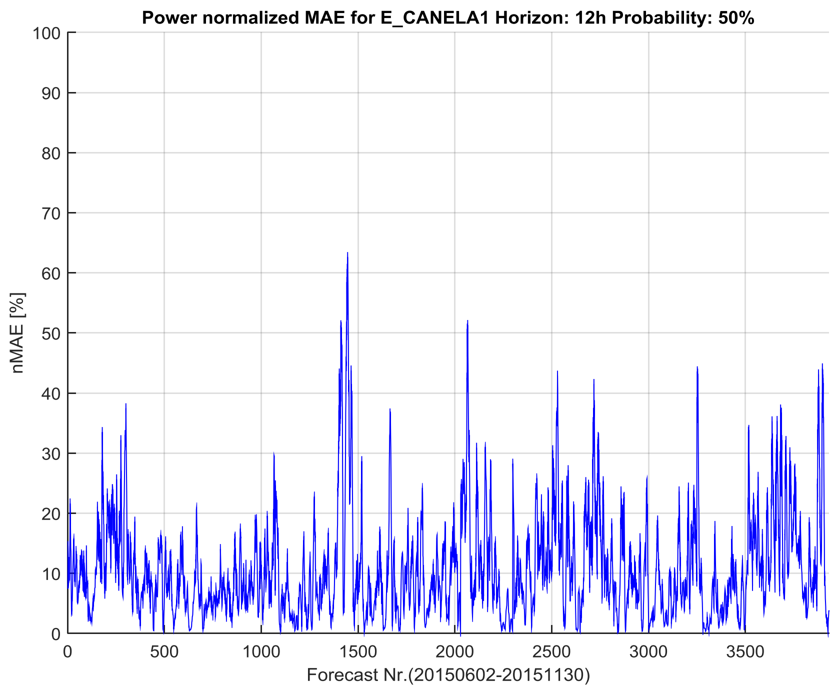

Figure 9 MAE Normalized based on installed capacity for the short-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

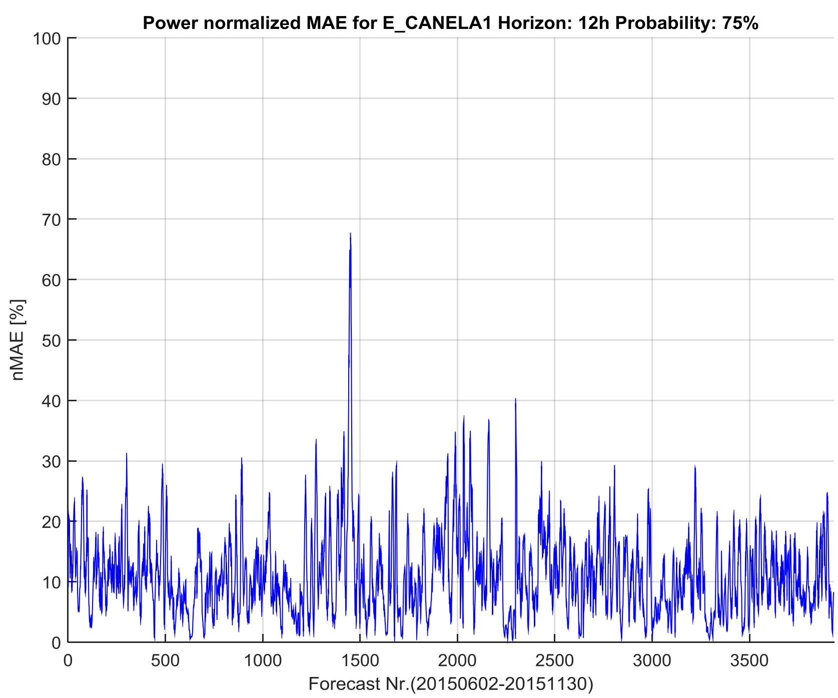

Figure 10 MAE Normalized based on installed capacity for the short-Term forecast with 75% probability between June and November 2015 for the wind farm Canela I

Compared to the RECMN the nMAE correlates better with the maximum errors. As shown in Figure 8 the maximum nMAE is reached at the Forecast Nr. 1411, which is exactly the same forecast Nr. of the second highest error of 97.5 %. The first maximum error happens at 1448 is an outlier, where the active power measured is larger than the rated power, and is much higher than the other forecast errors in the same horizon.

In contrast to the RECMN calculations for the different probabilities, both the individual nMAE and the overall nMAE over the whole period show an almost decreasing trend with increasing the probability of forecast. The overall nMAE is 12.9, 10.7 and 11.1 for a probability of 25, 50 and 75% respectively. In this case a minimum is reached at 50% and the trend is interrupted. Nevertheless, compared to the 25% probability the other probabilities has a lower overall nMAE in this case.

For the forecast Nr. 2169, where the maximum RECMN occurs, the value of nMAE is only 11.4%. This means that both metrics are not correlated. The correlation of the different metrics appears only between nMAE and nRMSE. nRMSE emphasis the maximum error at forecast Nr. 1411 even more than nMAE does. In the case of a 25% probability nRMSE reaches 100%, whereas it reaches 69% in the case of nMAE. It is not absolutely correct to compare the two metrics but the values indicate that nRMSE overweighs the global maximum error. This is an advantage of nRMSE as already mentioned in the introduction of this chapter.

Similar to nMAE the calculations for the different probabilities, both the individual nRMSE and the overall nRMSE over the whole period show a decreasing trend with increasing the probability of forecast. Figure 11, Figure 12 and Figure 13 show this trend for the individual nRMSE. The overall nRMSE is 22.8, 17.1 and 16.2 for a probability of 25, 50 and 75% respectively.

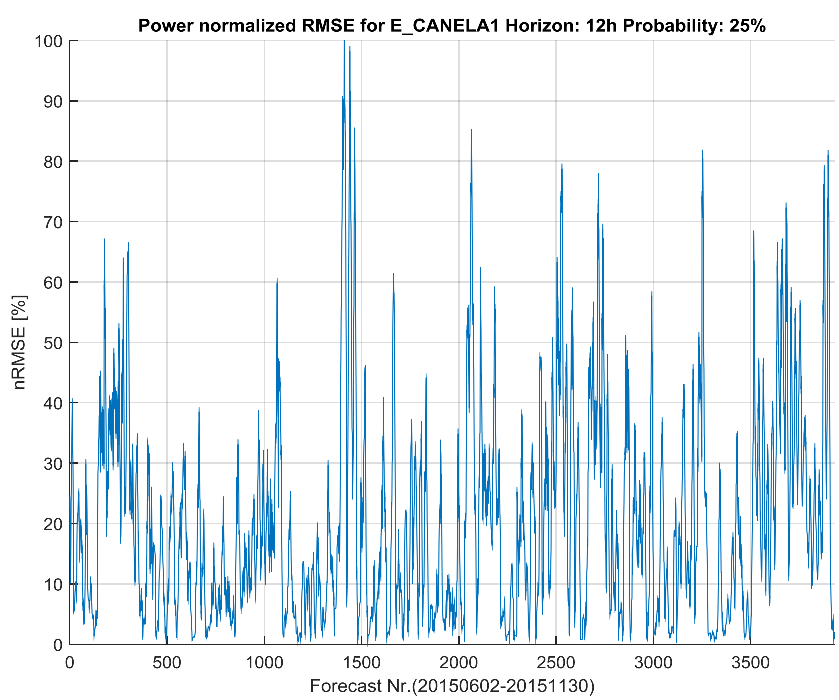

Figure 11 RMSE Normalized based on installed capacity for the short-Term forecast with 25% probability between June and November 2015 for the wind farm Canela I

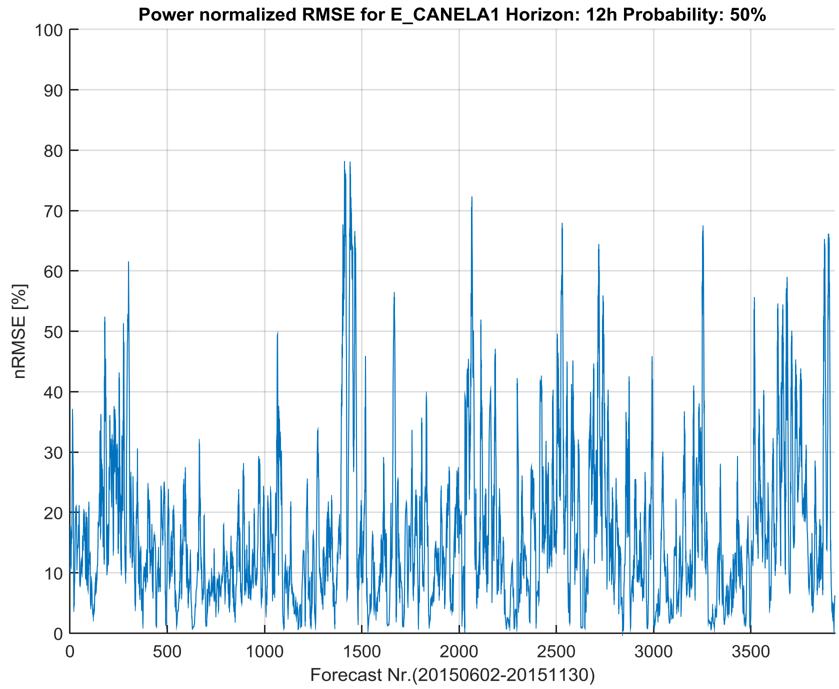

Figure 12 RMSE Normalized based on installed capacity for the short-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

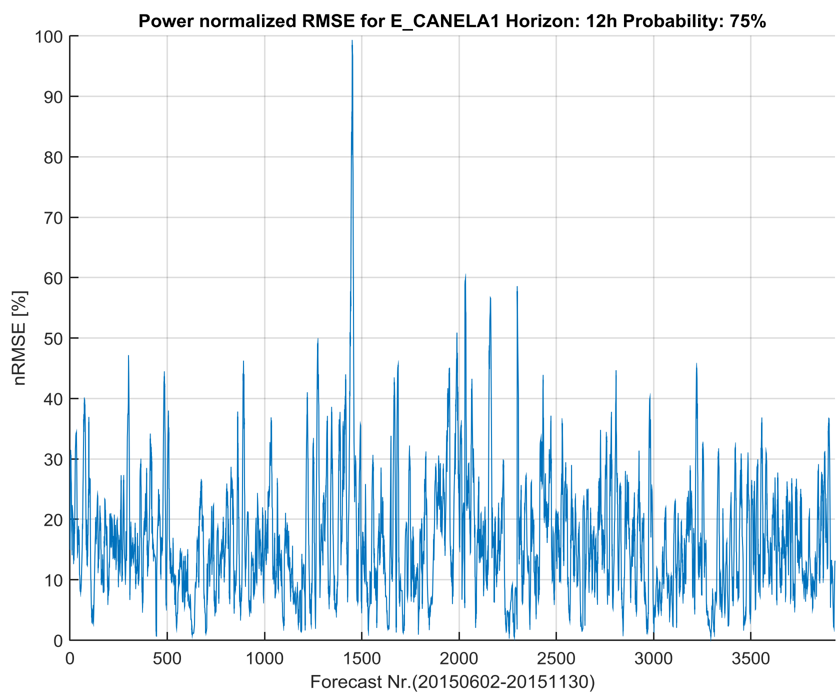

Figure 13 RMSE Normalized based on installed capacity for the short-Term forecast with 75% probability between June and November 2015 for the wind farm Canela I

For the day ahead (48h) and the long-Term (240h) forecasts the only probability of forecast available is 50%. Dislike the short-Term forecast only one figure for each metrics is present in this case. Nevertheless, some files unexpectedly include forecasts for 25 and 75% probability of occurrence (cf. Figure 36 in APPENDIX D– Data consistency).

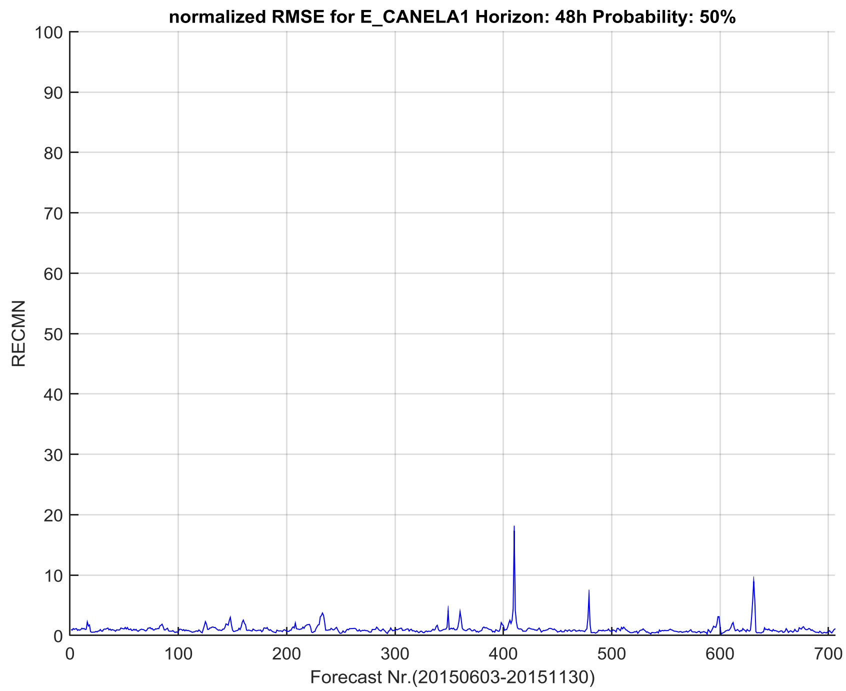

Figure 14 RMSE Normalized based on standard deviation for the day-ahead forecast between June and August 2015 for the wind farm Canela I

Furthermore, fewer forecasts exist as the frequency of update is lower in line with the requirements. The calculated RECMN for the day ahead forecast is lower than that of the short-Term (cf. Figure 14 and Figure 3). One should be cautions with this comparison as the metrics are calculated based on a different horizon in each case.

A more clear comparison can be made based on the maximum and minimum errors occurring in the different forecasts (cf. Figure 6 and Figure 15). The figures show that the short-Term forecasts exhibit higher values of underestimated forecasts (positive errors), whereas the day-ahead show higher values of overestimated forecasts (negative errors). A short-Term forecast should deliver less errors (in number and magnitude) compared to day ahead and long-Term forecasts. However, the maximum and minimum errors for the long-Term forecast show a different trend. The global maximum error in case of long-Term is around 70% (see Figure 16), whereas it is almost 90% in case of the day ahead forecast. A more extensive investigation in cooperation with the forecast service provider is needed to check this issue.

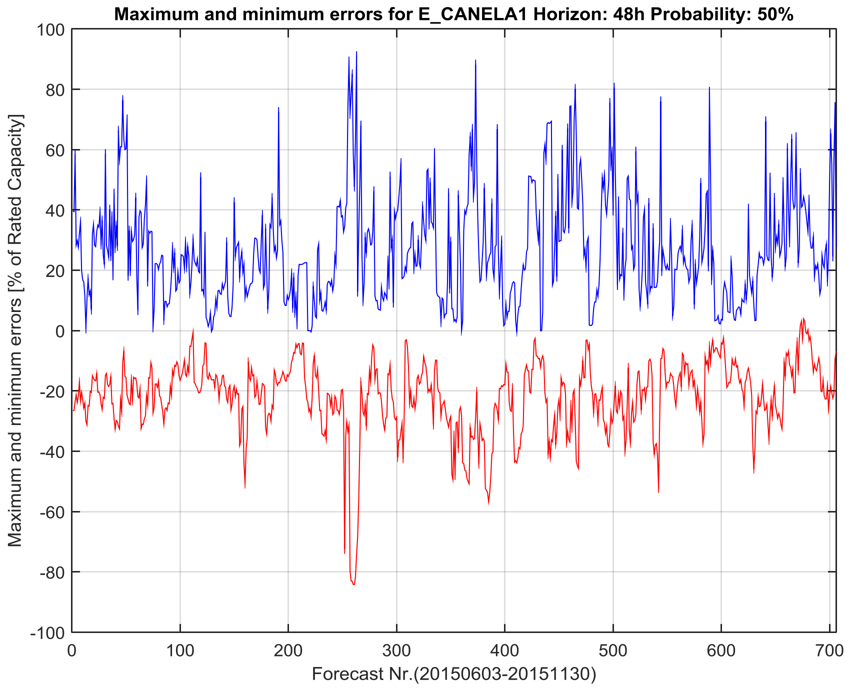

Figure 15 maximum and minimum forecasting errors for the day ahead forecast with 50% probability between June and November 2015 for the wind farm Canela I

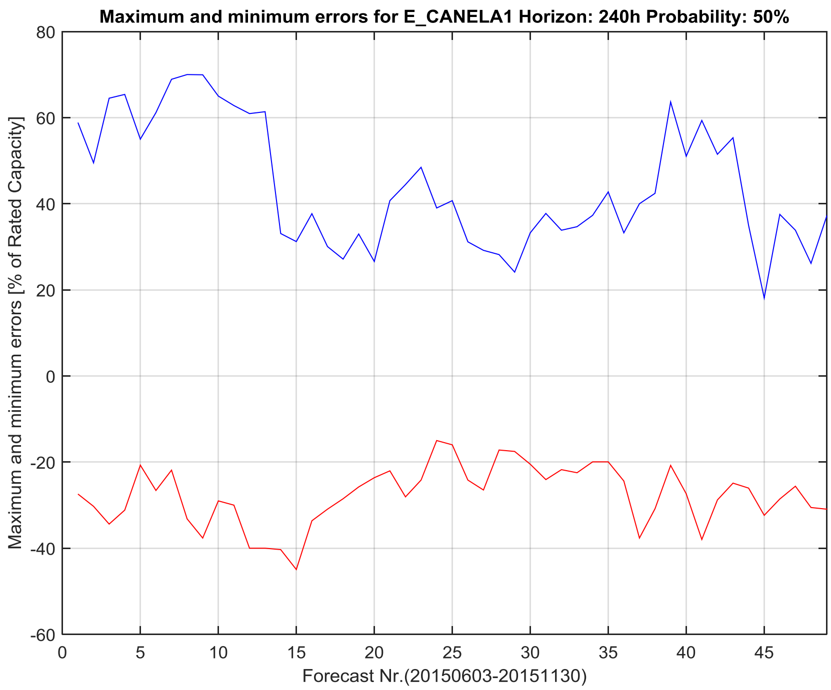

Figure 16 maximum and minimum forecasting errors for the long-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

Alike the short-Term results the RECMN does not correlate with the maximum errors. The maximum RECMN appears near the forecast Nr. 400, whereas the maximum error appears near the forecast Nr. 250. In contrast the nMAE shows this correlation as well as the nRMSE (cf. Figure 17 and Figure 18).

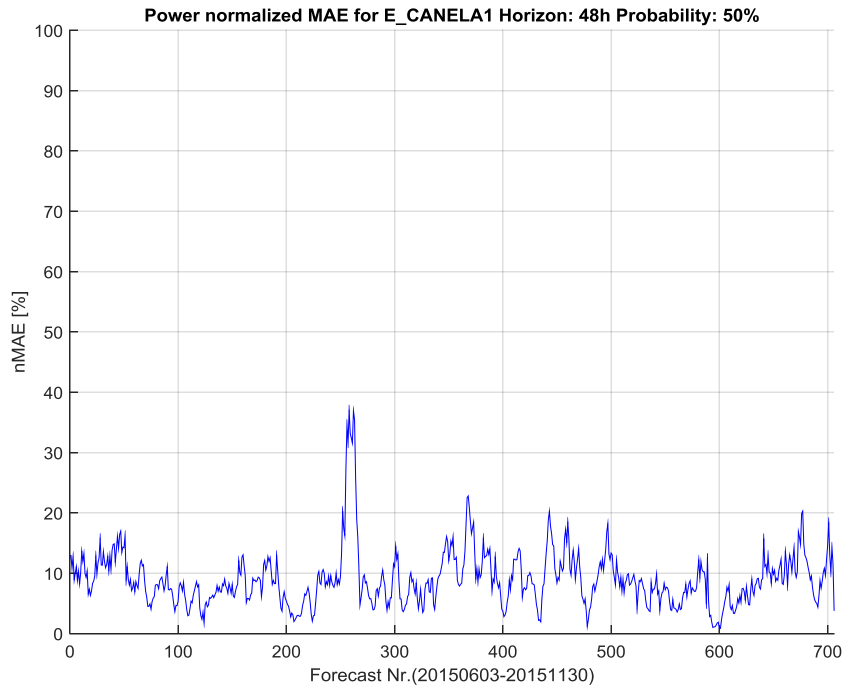

Figure 17 MAE Normalized based on installed capacity for the day ahead forecast with 50% probability between June and November 2015 for the wind farm Canela I

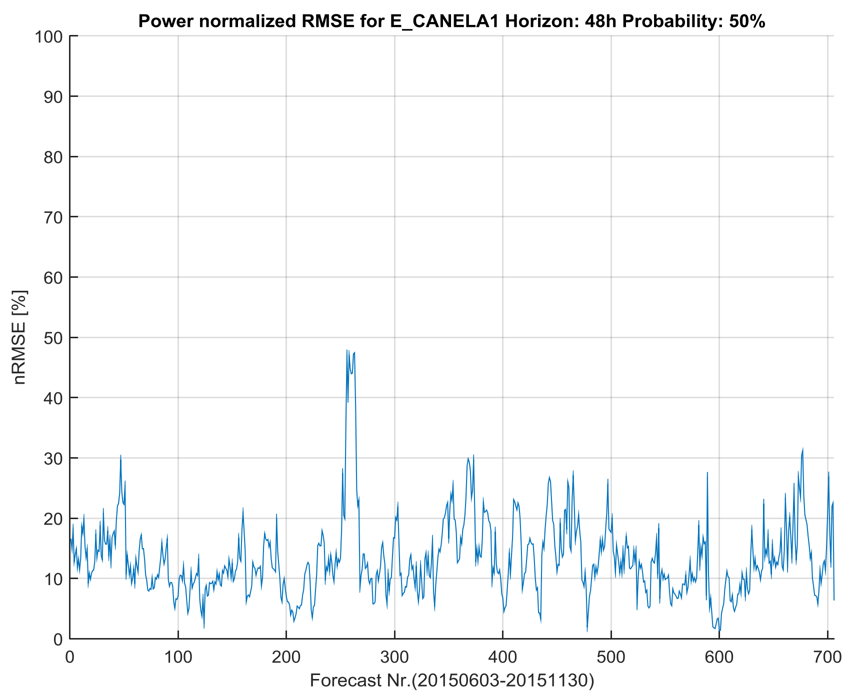

Figure 18 RMSE Normalized based on installed capacity for the day ahead forecast with 50% probability between June and November 2015 for the wind farm Canela I

For the long-Term forecast the RECMN shows up to be not a good indicator of the changes and errors taking place throughout the period as shown in Figure 19. Again the other metrics nMAE and nRMSE show a better indication for the errors in this period (cf. Figure 20 and Figure 21).

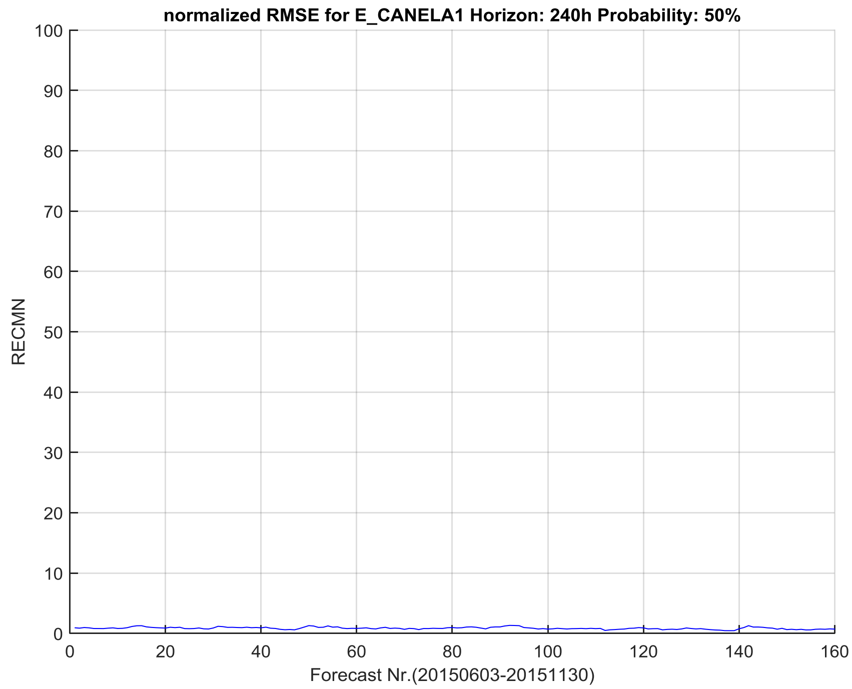

Figure 19 RMSE Normalized based on standard deviation for the day-ahead forecast between June and August 2015 for the wind farm Canela I

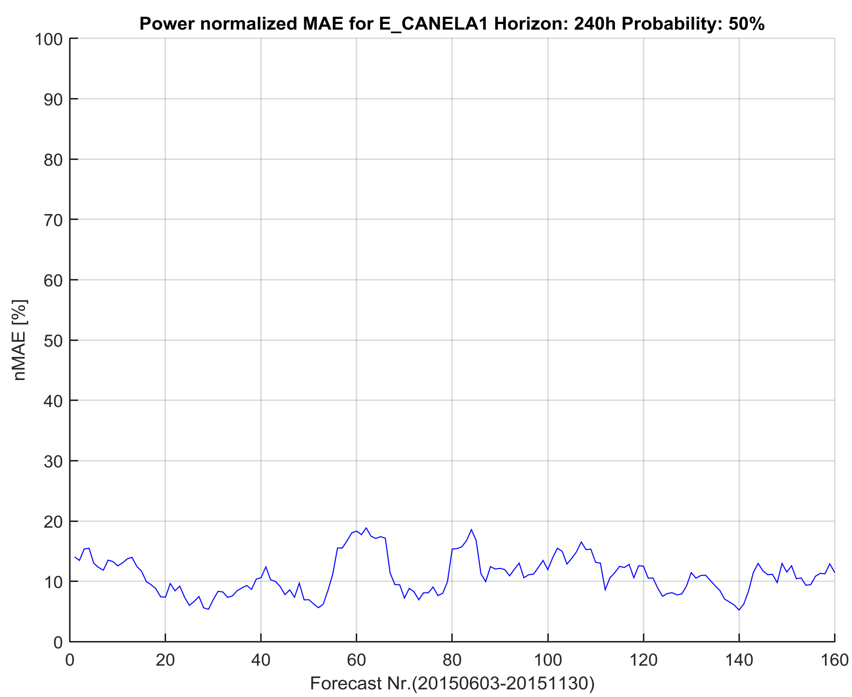

Figure 20 MAE Normalized based on installed capacity for the long-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

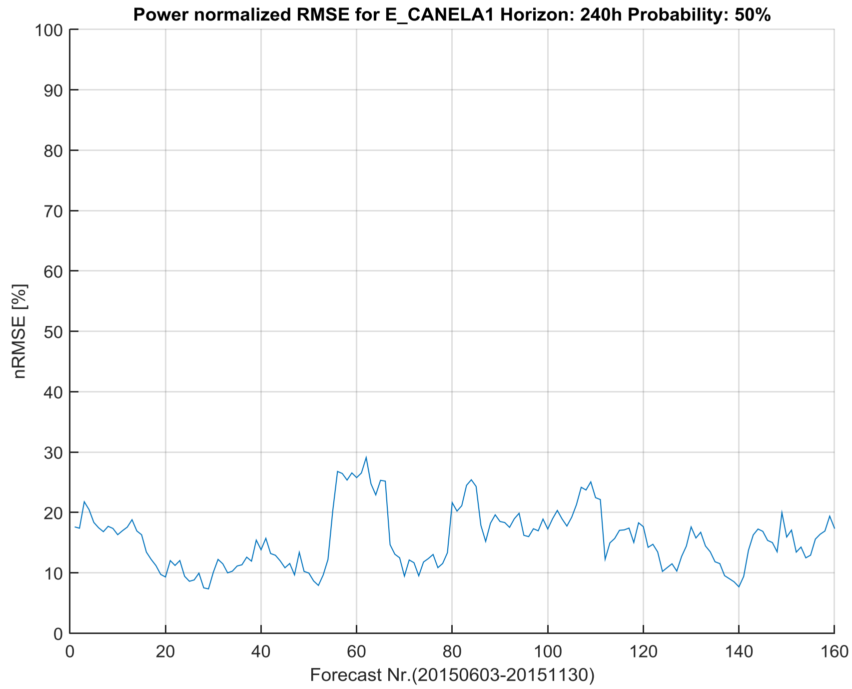

Figure 21 RMSE Normalized based on installed capacity for the long-Term forecast with 50% probability between June and November 2015 for the wind farm Canela I

4.2.2 Example for a photovoltaic power plant

The following figures illustrate the calculated RECMN, nRMSE, nMAE, maximum and minimum error values for the duration between June and November 2015 for the photovoltaic plant "Llano De Llampos" of 101 MW installed capacity. The values are calculated for the day-ahead (48 hours) and long-Term (240 hours) forecasts.

Figure 22 shows the RECMN calculated for the data available from 30-06-2015 till 30-11-2015 for a forecasting probability of 50%. The results are calculated for the horizon of 48 hours and have a minimum of 0.2 and a maximum of 0.7. The x-axis represents the forecast Number, which is the number of files or hourly forecasts available between June and November. Compared to the day ahead forecasting the RECMN for the long-Term ranges between 0.3 and 0.55 (not illustrated).

Excluding the non-consistent data and missing files only 293 forecasts are included i.e. 146 days out of a total of 154. Non consistent files are e.g. the ones having a different format as showed in the APPENDIX D– Data consistency in Figure 32. Another reason of why files are not included in the calculation is if the measurements are missing for a certain date.

Similar to Canela1 nMAE and nRMSE are more directly related to the errors than RECMN. Despite that the maximum values of the metrics are lower in case of Llano De Llampos (compare Figure 17, Figure 18, Figure 23, and Figure 24), the overall value is higher (cf. APPENDIX C– Performance metrics). In contrast to Canela1 the maximum and minimum long-Term errors are larger than those of the day ahead forecasts in case of Llano De Llampos. This has an impact on the nRMSE and nMAE as shown in the following figures. The maximum values of the metrics are lower in case of the day ahead forecasts. But again one should recall that a different horizon was used to calculate the metrics.

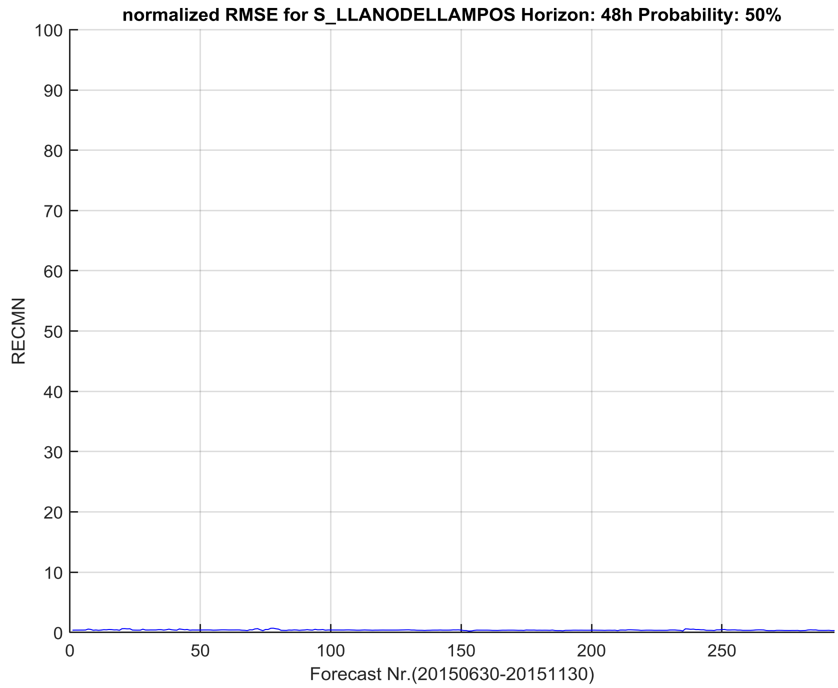

Figure 22 RMSE Normalized based on standard deviation for the day ahead forecast 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

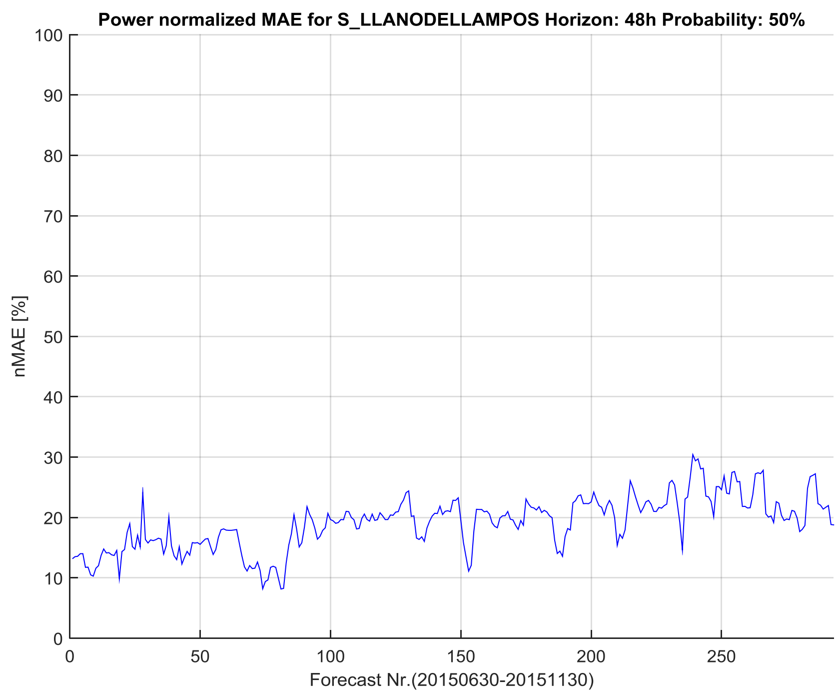

Figure 23 MAE Normalized based on installed capacity for the day ahead forecast with 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

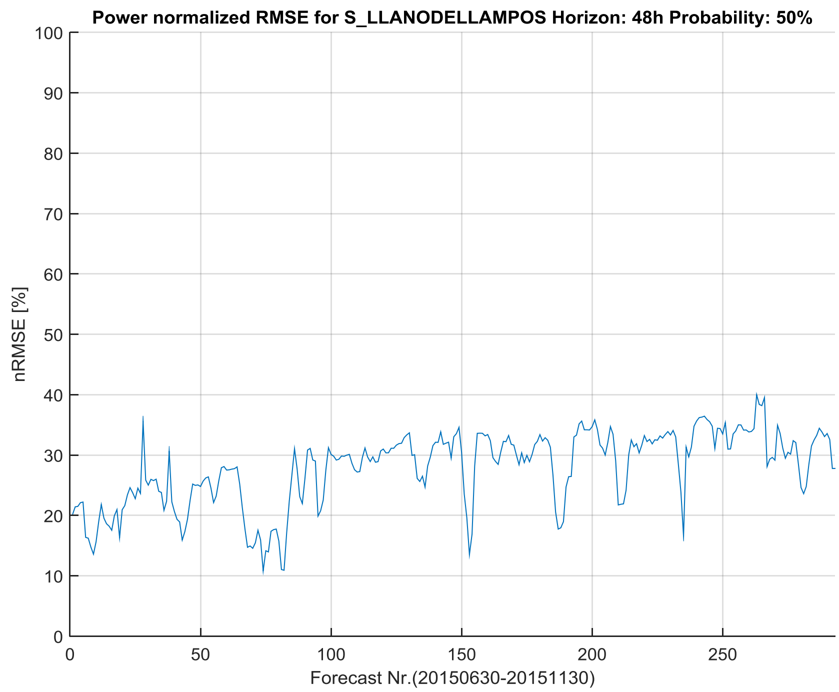

Figure 24 RMSE Normalized based on installed capacity for the day ahead forecast 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

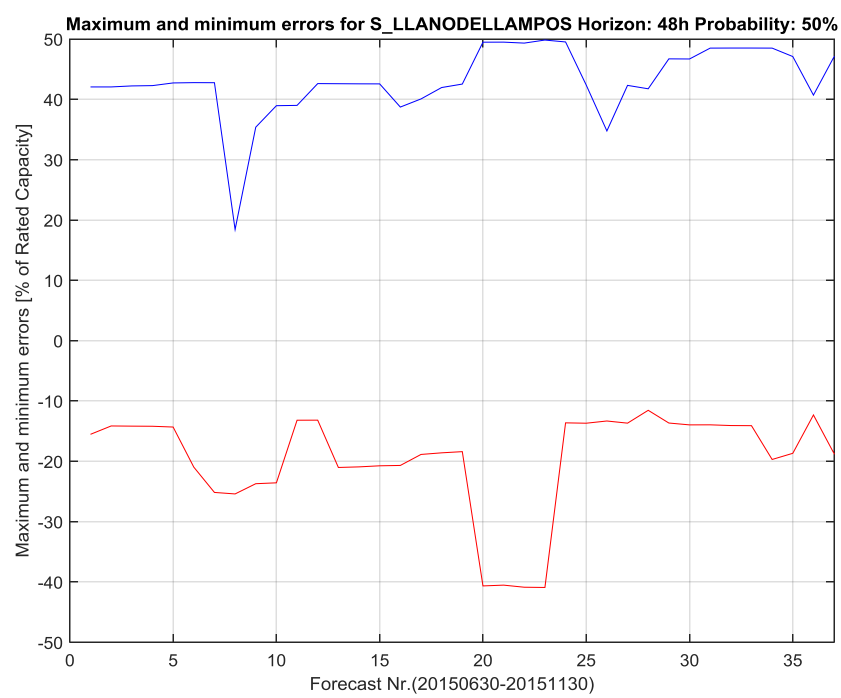

Figure 25 maximum and minimum forecasting errors for the day ahead forecast with 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

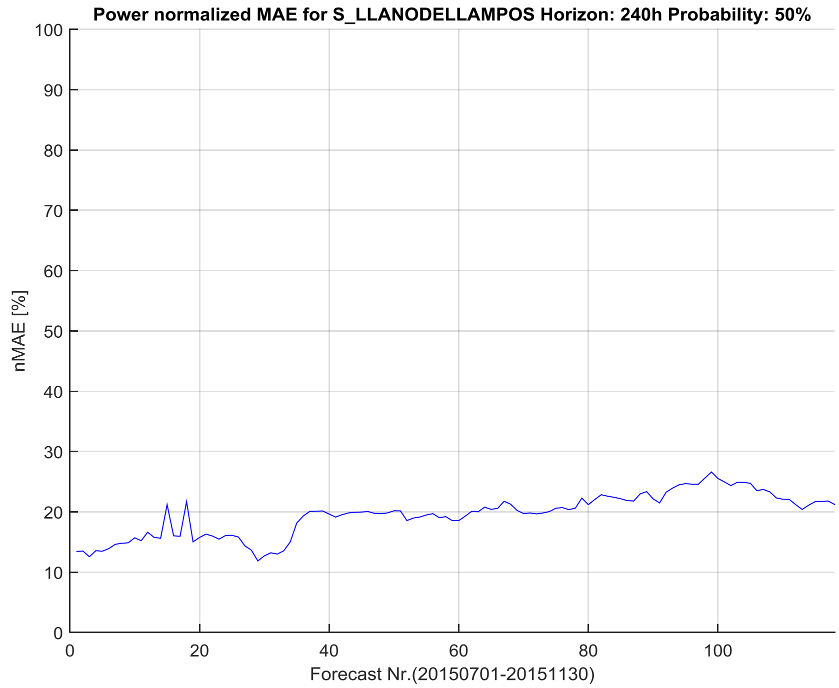

Figure 26 MAE Normalized based on installed capacity for the long-Term forecast with 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

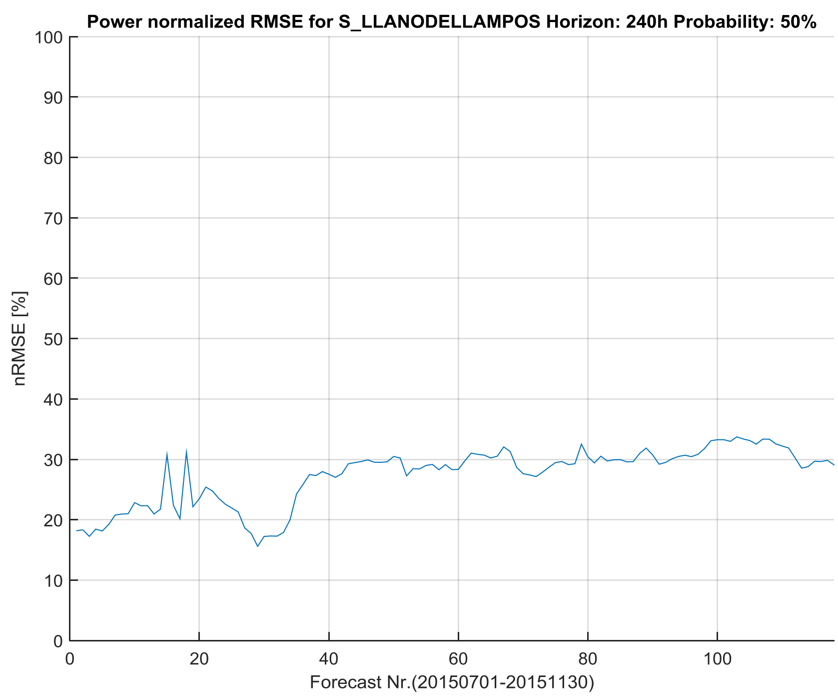

Figure 27 RMSE Normalized based on installed capacity for the long-Term forecast 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

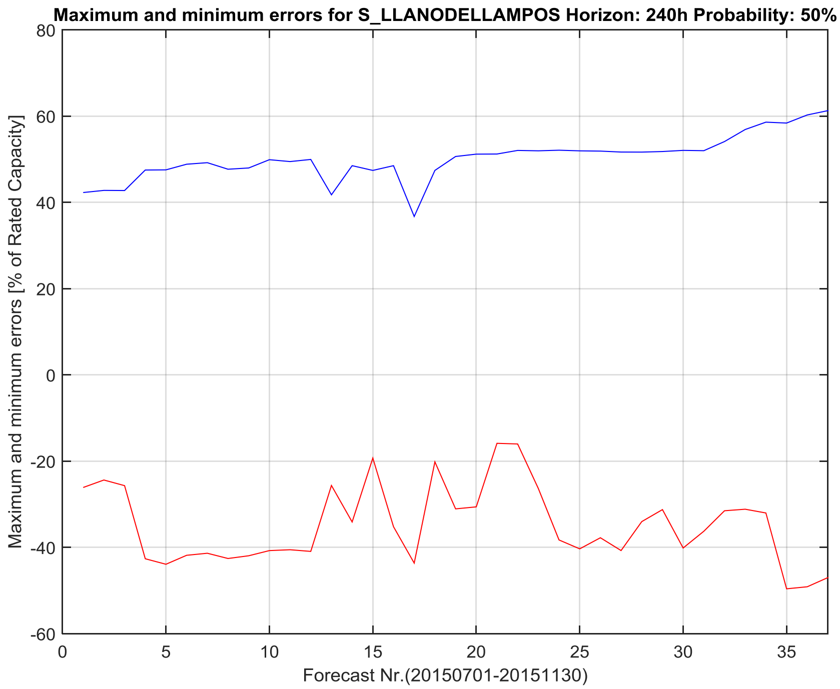

Figure 28 maximum and minimum forecasting errors for the long-Term forecast with 50% probability between June and November 2015 for the photovoltaic plant Llano De Llampos

4.3 Identification of forecasting error sources

Data consistency and plausibility Check

The investigation of the results in chapter 4.2 showed that data plausibility affects the quality of the forecast. In one case it was shown that the forecast indeed underestimates the active power. However, after a detailed look it was found out that the measurements unexpectedly exceeds the rated power of the plant. This happened for the wind plant Canela1 on the 7^{th} of August 2015 at 9 PM, where the measured value reached 18.6 MW for an 18.2 MW of rated power. This shows how important it is to perform a plausibility check on the measured data.

In other scenarios the forecasted values were non plausible. This is the case of the wind plant Totoral, where an overestimation of 124% occurred. Similarly a plausibility check should be performed to avoid using forecasts which are larger than the rated power.

Performance metrics

It was also shown chapter 4.2 that the RECMN does not emphasis the maximum individual errors. It even misinterprets the forecast quality in some cases. On the other hand, the other metrics do that. Furthermore, nRMSE overweighs the global maximum error. This is an advantage of nRMSE as already mentioned in the introduction of this chapter. Finally, it was shown that RECMN is not correlated with the other metrics.

In a preliminary analysis of the forecast outliers were detected for RECMN as shown in Figure 29. To identify the error sources the available information regarding outages and curtailment were checked. For major outliers the cause was not curtailment or outages. It turned out that such outliers are caused by the very low values of active power impacting the metric. As shown in the beginning of chapter 4.2, the calculation of RECMN depends on the standard deviation of the active power. If the deviation is very low, which is the case for most of the outliers, the value of RECMN becomes unrealistic. One should track such effects before assessing the final results.

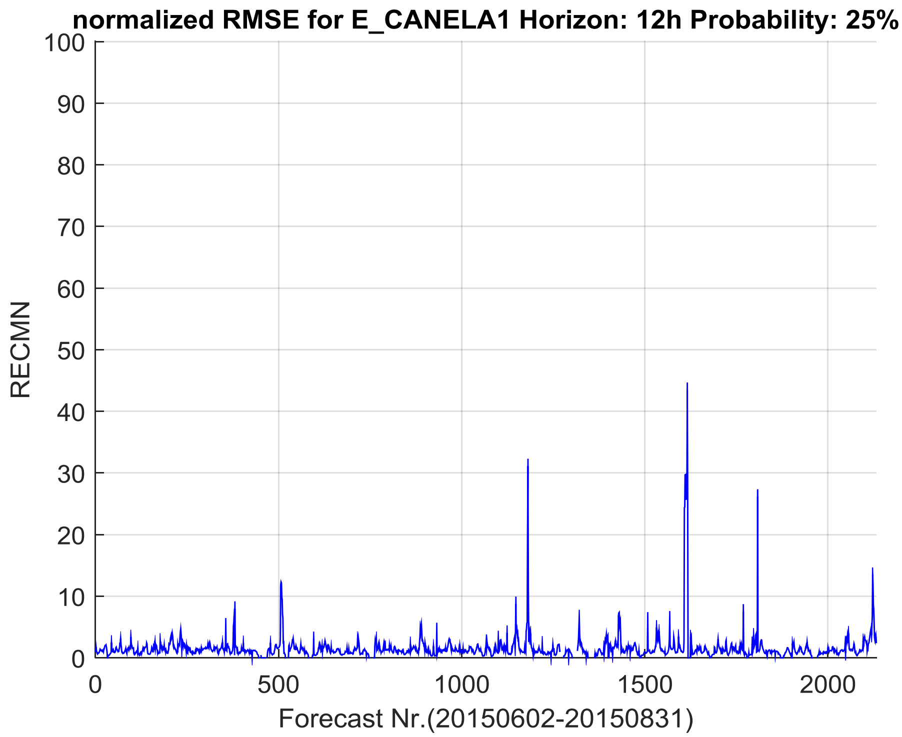

Figure 29 RMSE Normalized based on standard deviation for the short-Term forecast between June and August 2015 for the wind farm Canela I

Communication between plant operators and service providers to provide information on curtailment and metts

After reviewing the current practice for forecasting in Chile it was noticed that the plant operators do not supply the measured active power values to the forecasting service provider on regular basis. The data analysis even showed that sometimes the limits are given in text form (SI-Non: Spanish for Yes-No) form (cf. Figure 33 in Appendix D). This occurs as curtailment is manually registered by CDEC personnel.

Furthermore, the curtailment values are not provided as power values but rather in a binary format (0, 1). It is of course important to know if a limitation occurs. However, if the power values are also available the FSP can improve their models by providing more detailed training sets based on the real measurements and limitations. The experience of the 50Hertz system in Germany showed that this feedback is crucial in improving the forecasting. The plant owner or even the CDECs should deliver the curtailed power values in MW to support the Forecasting service provider in improving their models.

5 Recommendations for the short term improvement of the forecasting system and procedures

The renewable generation is uncertain because it depends on the variability of the weather conditions. Presently, one cannot predict perfectly how much wind will be blowing or how the sun will be radiating. This brings uncertain forecast errors in the balancing forecasts of the grid. One solution to manage forecast errors is to develop better forecasts of renewable generation by implementing new forecasting tools or challenging available external forecast providers. After reviewing the prevailing forecasting process of renewables in Chile and identifying the relevant error sources a potential for improvement was detected.

A general overview of the recommended process is depicted in Figure 30. This is an adapted process of the current one, which was already explained in chapter 3.2. The main adaptations, highlighted in blue, are the cooperation and communication between the CDECs, Forecast service providers and the Plant operators. In this recommended process the CDECs shall play an important role in the improvement of the quality of forecast through regular feedback to both the service providers and the plant owners. A direct cooperation between the service providers and the CDECs should be enabled in addition to the cooperation with the plant owners.

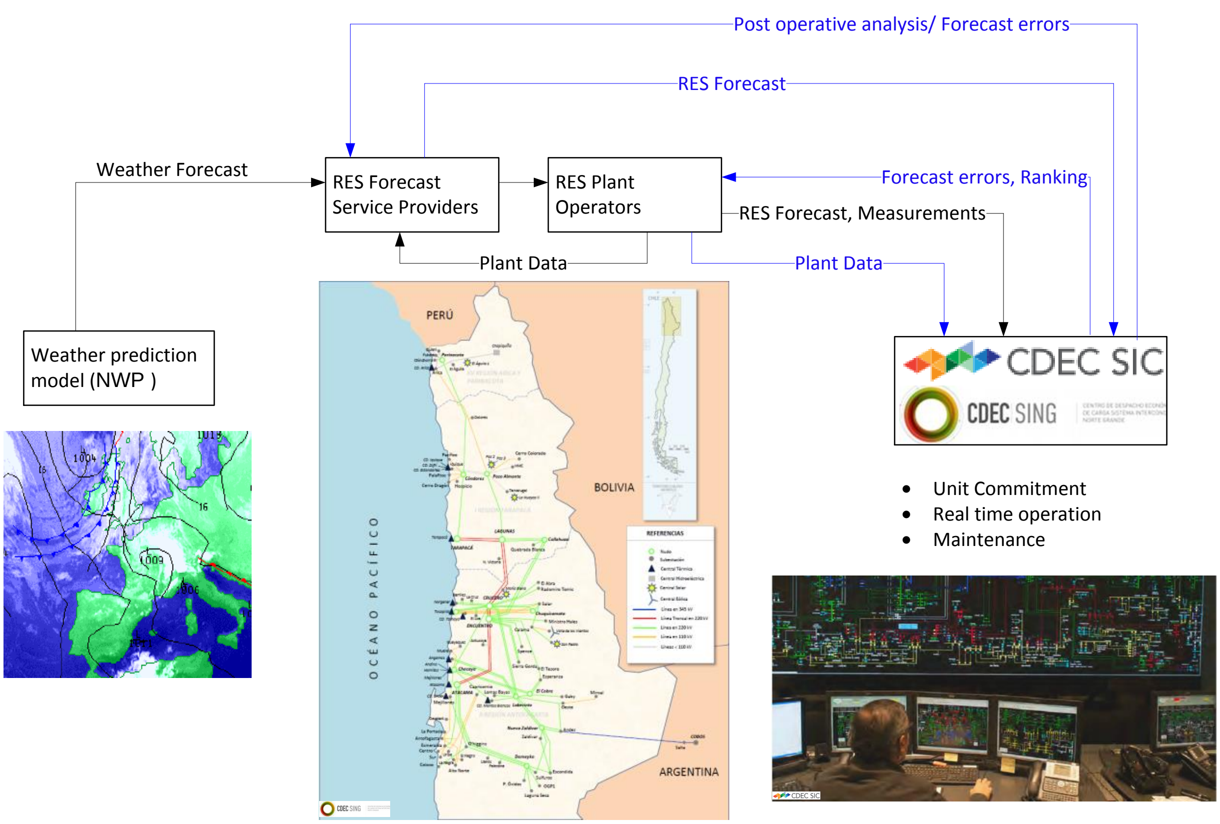

Figure 30 Recommended forecasting and subsequent processes for Chile

Based on the gathered information and performed analysis for Chile the consultant formulated the following recommendations:

1. **An inventory which contains the data of the installed capacity of renewable sources, their specifications, their localisation and the availability should be updated regularly by plant operators**

   The accuracy of the meteorological forecast is critical in forecasting power generation. The generation forecast is the product of weather prediction and plant characteristics. The inventory should therefore contain a referential of all the characteristics that can be useful to the forecast service provider. Based on the needs of the service provider this could include the geographic location, manufacturer power curves, type of unit, height (of wind turbines), installation owner, etc. This inventory is used as a reference for database sizing of the forecasts and measurements. A detailed inventory allows the forecasting supplier to provide more precise estimates in order to take into account effects like inclination, orientation, etc.

   This inventory should be updated regularly according to the introduction of new renewables in the grid and changes in the actual generation portfolio. The file and its content have a certain validity period; the plant operator has to send an update of the inventory to the forecasting supplier as often as needed. Whenever a new file is sent, this will then be the new reference file for which forecast estimations are needed. It is also not ruled out that extra interesting information could be added to the inventory to improve forecasting quality. The inventory should then be managed by the CDECs based on the provided information by the plant operators.

2. **The Plant operators should provide the measurements and planning data to the RES forecast service provider and to the CDECs**

   From international practice, the following data is usually asked and delivered:

   - Actual power for forecast service providers
   - For wind, nominal speed of rotation of the blades; for solar, orientation of the panels.
   - Maintenance schedules for the plant or site
   - Forced outages and curtailment should be immediately communicated and automatically registered

3. **The curtailment values should be provided in MW and not only in binary format as it is the case in the status quo**

   The forecast of power injected from renewables based on meteorological data assume full availability of a wind or solar plant. However, the availability of the plants can be lost temporarily or permanently due to e.g. maintenance. In addition the output power could be curtailed to mitigate grid congestions. Therefore, forecasting has to consider real-time availability, scheduled outages, planned curtailments of renewables in calculating the power predictions.

   In the current practice in Chile, the curtailment values are not provided as power values in MW but rather in a binary format (0, 1). It is of course important to know if a limitation occurs. However, if the power values are also available, the Forecast service provider can improve their models by providing more detailed training sets based on the real measurements and limitations.

4. **The characteristics and format of the measured data and the forecast should be standardized based on the needs of the CDECS**

   The investigation of the results in chapter 4.2 showed that data consistency (cf. APPENDIX D– Data consistency) affects the quality of the forecast. The file format is usually chosen according to the most used format by the system operator applications. In the case of the CDECs as mentioned in chapter 3.2.3 files with .xml or .csv/.xls formats are provided. It is crucial to standardize the format and the contents of the files. Furthermore these formats should not change without immediately informing all the stakeholders to avoid unnecessary errors. In this case the files with different or new formats should be archived correspondingly to prevent faults while post-processing the data.

5. **The CDECs should perform a plausibility check on measurements and the forecast data provided and give feedback**

   The investigation of the results in chapter 4.2 also showed that data plausibility affects the quality of the forecast. The consultant recommends that all forecasts of the service providers must be initially inspected by the CDECs. The following can be automatically performed after importing the data:

   <u>Plausibility check of forecasts:</u>

   - Completeness check: Are all values of the investigated period available?
   - Status check: Check the error status of the different communication links of all the participants (SCADA, Plant measurements, ftp server…etc.)
   - Limit or threshold check: based on the absolute limits (upper and lower) e.g. the plant capacity and the expected duration of a time series
   - For the plausibility checks a time-domain (e.g. 10 PM till 6AM 10AM to 2PM, PV must be at night always zero) should be defined, in which the tests are to be carried out.

   <u>Plausibility check of measurements:</u>

   - Measured value is too high: It is necessary to examine whether the value exceeds the installed capacity or non-realistic.
   - Measured value is too low: It is necessary to examine whether the value is negative or non-realistic.
   - Measured value rise and fall: It should be checked if the measured value rises or falls more than 50% of the installed capacity of the reference plant in one time step.
   - Hanging signal: Check if the measured value is constant for more than 60 minutes and the constant power value is above 10% of installed capacity of the reference plant. It is necessary to examine, whether the value actually hangs or the Reference plant just feeds-in constant power.
   - Non plausible zero: The reference measurement is zero, although the no maintenance or curtailment is planned. Here is necessary to examine whether there is a weather event or a fault causing the zero.

Data-quality indicators should be implemented

The data-quality indicator indicates whether the forecast and the real-time estimated measurement values in MW are based on sufficient data. If, on the contrary, accurate data is insufficient and other sources of data or extrapolation techniques are needed, this binary indicator indicates that the measurement is of lower quality. The indicator is based on the number of missing data at any moment in time

Drawbacks of the performance indicators should be considered

As shown in chapter 4.3 the performance indicators could indicate an outlier in the forecast, which is not caused by bad forecast but rather by the way the indicator itself is calculated

6. **The CDECs should assess the forecast data provided by the plant operators and give feedback**

A quality check of forecasts should take place monthly. All forecasts have to be compared with actual measured data and a post-operative analysis should be performed. This information shall be fed back to the plant operators in order to allow them to improve their forecasts. The information from the CDECs should contain the calculated data generated in the post-processing and not only as overview charts. Ranking of the plant operators in terms of forecasting quality could help to motivate them to provide better quality forecasts. A ranking on a monthly basis would fluctuate and change continuously as the metrics order and the forecast quality of each plant could vary. It is possible to issue the ranking every month based on the annually calculated metrics with additional information on the monthly data quality. The monthly data quality can assess the plausibility, the consistency and format of the data as mentioned in the previous recommendations. In addition, the maximum, minimum and average errors normalized to the plant installed capacity could be incorporated in the monthly assessment.

7. **The grid code should put obligations on quality of forecasting**

The renewable forecast providers should put reasonable effort in producing forecasts of sufficient quality for the needs of the CDEC to control the security of the grid and the quality of system frequency. The German TSO 50Hertz reached values for yearly nRMSE of 5-7% for Photovoltaic excluding night hours and 2-4% for Wind power plants. However, these values are for the aggregated forecast for the whole control area. Therefore, on the renewables plant level the consultant recommends a value of 6 to 10% for nMAE and 7 to 14% for nRMSE based on the day ahead forecast (48h). It is recommended to calculate the performance indicators based on the day ahead forecasts with a probability of 50%. This is estimated based on the status Quo in Chile (cf. APPENDIX C– Performance metrics) and the experience made at the 50Hertz area for individual plants. The CDECs should adapt these ranges based on their own needs and experience in their control area.

If the CDECs find it feasible, the merit order of the corresponding plant could even be affected by the quality of the forecast provided. Plants with relatively bad quality are more likely to be shut down in case of grid congestions. An alternative would be to introduce a bonus/Malus system as an incentive to increase the forecast quality.

8. **Increase the frequency of update for the short term forecast up to 15 minutes and use similar forecast horizons for both wind and Photovoltaic plants**

The forecast horizon is defined as the period for which forecasts need to be delivered by the forecasting supplier. The forecasting horizon has to be determined according to, on the one hand, the possibility to have an accurate forecasting and, on the other hand, the need to have information about the generation for a longer period. The degree of uncertainty of the prediction increases when the time horizon becomes longer since it is more difficult to predict weather conditions several days in advance. The time horizon has to be short enough to give an acceptable degree of uncertainty.

The penetration of photovoltaic in Chile is relatively low, and correspondingly its impact on the system, is lower compared to that of wind. This explains the fact that the required horizon of photovoltaic forecasting is lower than that defined for wind (cf. APPENDIX A– Forecast Requirements). However, the market for large-scale solar systems in Chile is have good prospects and as mentioned in the introduction currently there are a large number of projects with several thousand MW under development. The CDECs should be prepared for future short-Term large scale fluctuations coming from photovoltaics and improve the forecasting quality. It is therefore recommended to prescribe similar forecast horizons for wind and photovoltaic plants.

An additional factor that affects the forecast quality is the frequency of update. For the solar and wind forecasting, numerical global weather predictions are mostly used for the long-Term forecasts. Short-Term forecasts additionally use measured data and local indicators to obtain better forecasting results. In Chile the highest update frequency is 1 hour (cf. APPENDIX A– Forecast Requirements). This update frequency could be not sufficient to detect relevant weather effects like cloud passing or strong wind fronts. These weather events could lead to a rapid unplanned power reduction of the wind or photovoltaic power plants due to protection schemes of the wind turbines or sudden irradiation reduction for the PV plant.

According to the own experience in Chile this update frequency is apparently not sufficient. One of the main concerns about forecasting in real time relates to cloud covering as already mentioned in chapter 3.2.4. Instead an in-site watchman, who alerts the control room – via phone call – if clouds are watched nearby, is a work around for the problem. Furthermore, it seems that this method do not give the CDECs the possibility to act fast enough.

It is therefore recommended to increase the update frequency to 15 minutes instead of 1 hour in order to cover more real time effects. Moreover, for solar prediction, sky images should be utilized to help in predicting the impact of clouds. The experience of 50Hertz shows that with such technologies and with a higher update frequency the forecasting quality can be improved. The following table summarizes the forecast requirements for the German TSO 50Hertz. Ramp rates and weather information could be used for the plausibility check of the data.

Table 1: Forecast requirements for the German TSO 50Hertz

Type of forecast	Resolution	Horizon (Hr)	Frequency of update per day
Short-Term	15 min	8	96
Day ahead	15 min	Up to 192	Up to 4
Week	-	-	-

9. **Upscaling based on the available measurements should be performed by the CDECs in case measurements are missing for one or more plants**

   Besides forecasts, real-time estimations are also used to integrate vRE into grids and markets. These estimations can be used for grid operational information as well as for the shortest term improvement of intraday forecasts. The result of the upscaling gives an estimated real-time measured value of photovoltaic plants and of wind farms with missing measurements; this value is called the upscaled value. The upscaled measurement can then be compared to forecasting data for each electrical area or aggregated region

   Similarly, in this case the CDECs should contract different suppliers for the delivery of the upscaled measurements as is the case for the forecasts. The upscaled data would be independently compared to the multiple suppliers. Moreover, this will help to improve the quality of the upscaling algorithm and further to reduce the forecasting error.

10. **Indicators for weather events like storms or fogs should be provided by the service providers**

    Some extreme natural events could disturb the forecasting of the renewable power generation with the undesirable consequence that large deviations occur (in duration and/or power) between the forecasting data and the energy produced. The implementation of indicators for predicting these extreme events can provide warnings to the dispatcher in advance and give him the possibility to manage huge renewables forecasting errors. Infra-red scanning provides good information on fog based on the experience of 50Hertz.

11. **A direct link should be established between the CDECs and the RES forecast service provider**
    In case the plant operators do not deliver the required data to the CDECs due to technical or other reasons the CDECs will not be able to react proactively and effectively integrate the renewables in their system. Therefore a direct link between the RES forecast providers and the CDECs should be established to allow for redundancy.

12. **The CDECs should also assess the forecast data provided by the service providers and give feedback**

    A quality check of forecasts should take place regularly. All forecasts have to be compared with actual metered data. This data should be fed back to the forecast suppliers in order to allow them to potentially improve their forecasts. Post-operative analysis is important for the service providers in order to improve the forecasting process.

13. **Involve more than one forecast service provider**

    It is preferable to have multiple suppliers for the same location (power plant or region) and time for the forecasting. This would also increase redundancy and thus reduce the forecasting error. Indeed, by analysing the statistical values of the different suppliers (or models), and comparing them with the real production, the CDECs could give different weights to those who are closer to the measurements. Aside from Meteologica, Energy and Meteo Systems [7] is performing well in Europe based on the experience of 50Hertz. This service provider relies on the integration of online measurement data to optimize the prediction.

14. **Examine the feasibility of having forecasting of renewables centralized at the CDECs.**

    Based on the experience of the Consultant, and international practice, we propose that the CDECs perform the aggregation of the different sources of forecasting, and use the quality checks proposed above to attribute weight factors to the forecasts depending on the reliability of the different forecasts, thus creating a more reliable centralised forecast of renewable energy

15. **Adjacent power plants should be grouped in clusters and additional forecasts for these clusters should be delivered to improve the overall forecast quality.**

    Regional forecasts lead to better results than single plant forecasts. This is because of regional smoothing effects due to the spatial averaging. In addition, the local level forecasts encounter large uncertainty.

    The TSOs in Germany use forecasts not only for trading purposes, but also for grid information and security analysis. For these reasons, forecasts are calculated on a regional level. There are e.g. forecasts calculated for whole Germany, for the four control areas or for federal states. The German-wide forecasts, i.e. the aggregate wind and solar forecast, are also used by electricity traders, even if they do not have RES portfolios. The national wind and solar forecasts are used as a spot market price indicator as RES production strongly influences the spot market price. The forecast can be used for speculators who need to determine when energy is best bought or sold [4].

    Based on the needs of the CDECs applicable clusters should have an additional forecasts. An example would be to cluster the following power plants:

    - In the area of Diego de Almagro (Javiera, Chañares, Diego de Almagro and Salvador).
    - In the area of Mantos de Hornillos (Punta Palmeras, Canela1, Canela2, Totoral)

    It should be also examined if a regional forecast is feasible in the advent of the planed unity of the CDECs.

16. **Develop a process for adapting power schedules in an efficient way**

    Based on the forecasting updates the CDECs will perform rescheduling of the non-renewable power plants for the coming hours. This process performed in intraday must be optimised to obtain two distinct goals:

    - Have the final production programs as close as possible to the actual needs in real time which is forecasted load minus forecasted renewable production
    - Avoid updating the programs too often and with too much variability as this would render the operation of the power plants extremely difficult.

    German TSOs and 50 hertz in particular have extensive experience in dealing with regular updates in production programs and can assist the Chilean CDEC to develop this know-how.

To summarize and weigh out the different recommendations the following table illustrates the expected duration of implementation, the regulatory adjustment needed and the priority of each recommendation.

Table 2: Overview and analysis of the recommendations to improve the forecasting current system

Nr.	Recommendation	Duration of implementation	Regulatory adjustments	Priority
A-Better use of the ongoing forecasting process				
1	Plant inventory should be updated regularly by plant operators and managed by the CDECs	Short-Term	Simple adjustment	High
2	Plant operators should provide measurements and planning data to the RES forecast service provider and to the CDECs	Short-Term	Simple adjustment	High
3	Detailed information on curtailment	Short-Term	Not needed (Agreement between stakeholders)	Very high
4	Standardisation of data Formats	Short-Term	Not needed (Agreement between stakeholders)	High
5	Data consistency check by CDECs	Medium-Term	Not needed (Essential for CDECs)	High
6	Plausibility check by CDECs	Medium-Term	Not needed (Essential for CDECs)	High
B- Additional requirements				
7	Data assessment performed by CDECs (Feedback to plant operator)	Medium-Term	Few adjustments	High
8	Obligations on forecasting quality	Medium-Term	Few adjustments	High
9	Increase update frequency of forecasting	Medium-Term	Simple adjustment	Very high
10	Indicators for weather events	Medium-Term	Not Needed (Should be contracted)	Low
11	Cooperation between CDECs and service providers	Medium-Term	Not needed (Agreement between stakeholders)	High
12	Post-operative analysis performed by CDECs (Feedback service providers)	Medium-Term	Few adjustments	Very high
13	Redundancy of forecasts	Short-Term	Not Needed (Should be contracted)	Very high
C- Measures affecting the structure of the CDECs				
14	Forecasting of renewables centralized at the CDECs	Long-Term	Not needed (Important for CDECs)	Low
15	Clustering of power plants	Medium-Term	Not needed (advisable)	high
16	Develop a process for adapting power schedules in an efficient way	Medium-Term	Not needed (advisable)	High

APPENDIX A– Forecast Requirements

Forecast requirements for Wind and Photovoltaic plants in Chile

P_e: Electric power

ΔP_e: Electric power variation

v_v: Wind speed

d_v: Wind direction

T: Temperature

P: Atmospheric pressure

Table 3: Wind forecast requirements prescribed in the grid code

Type of Forecast	Variable	Resolution	Horizon (Hr)	Probability of occurrence (%)	Frequency of update (Hr)	Total per day
Short term	P_e	Hour	12	25, 50, 75	1	24(*3)
Day ahead	P_e	Hour	48	25, 50, 75	6	4(*3)
Week	P_e	Hour	168	50	24	1
Ramps	ΔP_e	Hour	12	-	1	24
Meteorological	v_v, d_v, T, P	Hour	48	-	6	4

Table 4: Photovoltaic forecast requirements prescribed in the grid code

Type of Forecast	Variable	Resolution	Horizon (Hr)	Probability of occurrence (%)	Frequency of update (Hr)	Total per day
Day ahead	P_e	Hour	48	50	12	2
Long-Term	P_e	Hour	168	50	24	1

Table 5: Wind forecast requirements defined by CDEC-SIC

Type of Forecast	Variable	Resolution	Horizon (Hr)	Probability of occurrence (%)	Frequency of update (Hr)	Total per day
Short-Term	P_e	Hour	12	25, 50, 75	1	24(*3)
Day ahead	P_e, v_v, d_v, T, P	Hour	48	50	12	2
Long-Term	P_e	Hour	240	50	24	1

Table 6: Photovoltaic forecast requirements defined by CDEC-SIC

Type of Forecast	Variable	Resolution	Horizon (Hr)	Probability of occurrence (%)	Frequency of update (Hr)	Total per day
Day ahead	Pe	Hour	48	50	12	2
Long-Term	Pe	Hour	240	50	24	1

Table 7: Wind forecast requirements defined by CDEC-SING

Type of Forecast	Variable	Resolution	Horizon (Hr)	Probability of occurrence (%)	Frequency of update (Hr)	Total per day
Short term	P_e	Hour	24	50	3	8
Long Term	P_e	Hour	168	50	24	1

Table 8: Photovoltaic forecast requirements defined by CDEC-SING

Type of Forecast	Variable	Resolution	Horizon (Hr)	Probability of occurrence (%)	Frequency of update (Hr)	Total per day
Short term	P_e	Hour	24	50	3	8
Long Term	P_e	Hour	168	50	24	1

APPENDIX B– Plant data and forecast availability

Power Plant	Operational since	Type	Location UTM (East, North, zone)	Installed Capacity (MW)	Generation & Forecast Availability (Month)	CDEC
Canela 1	2007	Wind	252,276 6,535,519 19	18,2	15	SIC
Canela 2	2009	Wind	252,456 6,532,721 19	60	15	SIC
Monte Redondo	2010	Wind	246,430 6,558,791 19	48	15	SIC
Eolica Totoral	2010	Wind	251,546 6,531,368 19	46	15	SIC
Talinay Oriente	21/03/2013	Wind	252,237 6,581,553 19	90	15	SIC
Ucuquer 2	22/10/2014	Wind	257,925 6,230,005 19	10,8	12	SIC
Cuel	05/02/2014	Wind	721,518 5,845,518 18	33	6	SIC
Eolica El Arrayan	06/06/2014	Wind	241,257 6,613,923 19	115	15	SIC
Punta Palmeras	10/11/2014	Wind	248,507 6,541,405 19	45	9	SIC
Solar Diego De Almagro	11/12/2014	Photovoltaic	398,306 7,081,876 19	28,1	15	SIC
Llano De Llampos	30/04/2014	Photovoltaic	383,921 7,000,014 19	101	11	SIC
Solar San Andres	30/04/2014	Photovoltaic	389,995 6,984,918 19	50,6	11	SIC
Talinay Poniente	26/05/2015	Wind	251,545 6,582,677 19	60,6	7	SIC
Eolica Taltal	09/02/2015	Wind	414,421 7,228,198 19	99	10	SIC
Chanares	28/05/2015	Photovoltaic	393,688 7,082,373 19	36	6	SIC
Lalackama	02/06/2015	Photovoltaic	367,831 7,221,038 19	71,5	6	SIC
Javiera	19/05/2015	Photovoltaic	378,889 7,090,428 19	65	6	SIC
PV Salvador	07/07/2015	Photovoltaic	413,357 7,089,238 19	68	5	SIC
Valle de los Vientos	21/03/2014	Wind	518151, 7514002, 19	90	13	SING
PAS3	07/06/2014	Photovoltaic	420752, 7760488, 19	16	13	SING
María Elena	21/01/2015	Photovoltaic	440406, 7543351, 19	68	13	SING

APPENDIX C– Performance metrics

Power Plant	RECMN	nRMSE [%]	nMAE[%]	Maximum error [%]	Minimum error [%]
CDEC-SIC[1]					
Canela 1	0.8	17	10.7	100	-75
Canela 2	0.8	21.7	14	96.2	-88
CUEL	0.4	14.9	10.2	80	-85
ELARRAYAN	0.6	19.6	12.4	58.3	-92
MONTEREDONDO	0.65	18.7	19.3	58.6	-90
PUNTAPALMERAS	0.61	18.6	12.5	60	-100
TALINAYORIENTE	0.67	16.5	11.6	69	-78
TALINAYPONIENTE	0.63	21.2	15.3	90.4	-90
TALTAL	0.7	25.1	16.2	94.3	-84
TOTORAL[2]	0.6	15.5	10.6	74.2	-95 (**-124**)
UCUQUER2	0.66	19.7	13.5	86.8	-88
CHANARES	0.5	26.6	19	37.5	-48
DIEGODEALMAGRO	0.45	20.2	14.9	18	-55
JAVIERA	0.42	26	19.6	40	-58
LALACKAMA	0.43	20.1	16.3	47.9	-49
LLANODELLAMPOS	0.4	27.1	19.1	50	-41
PVSALVADOR	0.4	26	21.4	70	-80
SANANDRES	0.54	29.6	20.2	50	-60
CDEC-SING[3]					
Valle de los Vientos	0.55	18.7	12.4	79.1	-64.8
PAS3	0.14	11.9	7.9	9.75	-9.55
María Elena	0.23	18.4	9.48	46.5	-33.86

(1) For Wind: Short-Term (12h) 50% Probability data is used for the calculation and for photovoltaic: day ahead (48h) 50% Probability
(2) Bad quality of Forecast: The forecast of 75% probability predicts a power, which is larger than the rated capacity of 46 MW (cf. Figure 35 of APPENDIX D– Data consistency)
(3) Calculations for CDEC-SING are based on short-Term (1dias)

APPENDIX D– Data consistency

The forecasts were provided by CDEC-SIC and CDEC-SING for various wind and photovoltaic plants to be used for the data assessment. As the organisation of the files and their format is not always consistent, the assessment of the data was a difficult process.

The date was scrutinized to assure a reliable data assessment and correspondingly reliable results. In general the files delivered follow the structure described in chapter 4.1.1. However, the file formats and structure are not always similar. To explain this issue, few examples are elaborated in the following paragraphs.

Most of the files have a comma separated values (.csv) files, which could be processed by different programs like excel from Microsoft. Nevertheless, in such files unexpectedly semicolons (;) where utilized as a delimiter instead of commas (,), which violates the definition. This occurs for the same plant, which means that the plant owner or the service provider changed the format of the files. Figure 31 depicts the change in the format for the power plant Canella II, which happened on the 12th of June in 2015. Not only did the format change but also the name of the file.

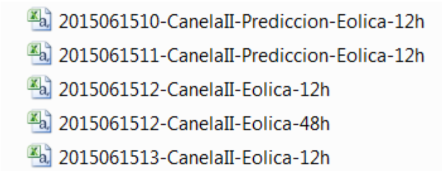

Figure 31 Example of non-consistency: Sudden change of the file name

Furthermore, some files are saved in an xls-format like the case of El Arrayan power plant. This case is shown in Figure 32, where different formats exist at the same day. Even some files are saved in the xls-format and not recognised by Microsoft excel.

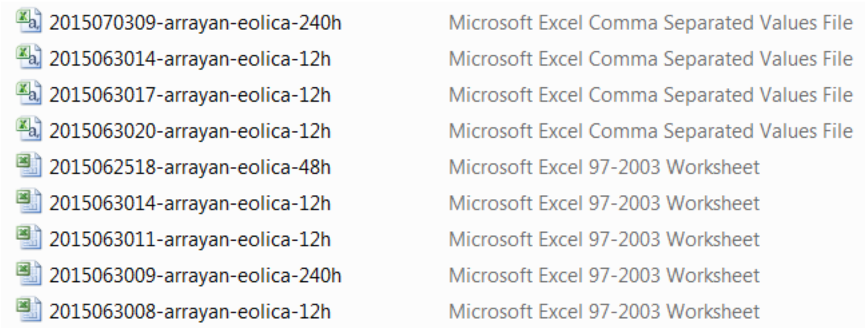

Figure 32 Example of non-consistency: Sudden change of the file format

Additionally, the limit is defined as text in some files and not in binary form as is the case in most of the files as shown in Figure 33.

Year	Month	Day	Hour	LIMITADO
2015	7	1	1	NO
2015	7	1	2	NO
2015	7	1	3	NO
2015	7	1	4	NO
2015	7	1	5	NO
2015	7	1	6	NO
2015	7	1	7	NO
2015	7	1	8	NO
2015	7	1	9	NO
2015	7	1	10	NO

Figure 33 Example of non-consistency: The limits are defined as text and not in binary form

Another non-consistency in the forecasts of CDEC-SING is that measurements for some hours are missing. E.g. (Maria-Elena) the 4 AM measurements (column in the left hand side) are missing, which is present in the forecast (Column in the right hand side). Furthermore, negative values of active power are available (cf. Figure 34). As the values are negligibly low this indicates a bias of the measurement device. But it could be also interpreted as own consumption of the plant.

2015-06-18 22:00:00.000	1	0	18.06.2015 22:00	0.0
2015-06-18 23:00:00.000	1	0	18.06.2015 23:00	0.0
2015-06-19 00:00:00.000	1	0	19.06.2015 00:00	0.0
2015-06-19 01:00:00.000	1	-0.09	19.06.2015 01:00	0.0
2015-06-19 02:00:00.000	1	-0.11	19.06.2015 02:00	0.0
2015-06-19 03:00:00.000	1	-0.12	19.06.2015 03:00	0.0
2015-06-19 05:00:00.000	1	-0.12	19.06.2015 04:00	0.0
2015-06-19 06:00:00.000	1	-0.11	19.06.2015 05:00	0.0
2015-06-19 07:00:00.000	1	-0.12	19.06.2015 06:00	0.0
2015-06-19 09:00:00.000	1	13.78	19.06.2015 07:00	0.0
2015-06-19 10:00:00.000	1	46.07	19.06.2015 08:00	3.3

Figure 34 Example of non-consistency: Measurements for some hours are missing

The Forecast files contain energy units in MWh and not Power units in MW, while the files for current generation has Power in MW (cf. Figure 35). In the same figure the minimum error is more than 100 (-ve), this is due to false forecast of bigger than the rated capacity of 46 MW

Central: Totoral.	
Predicción generada el 2015-08-08 a las 00:06:58. El huso horario corresponde a Chile Continental (UTC/GMT -3).	
Observaciones:	
Desde(dd-mm-aaaa HH:MM),Hasta(dd-mm-aaaa HH:MM),P25(MWh),P50(MWh),P75(MWh)	
08-08-2015 00:00,08-08-2015 01:00,31.81,43.61	56.08
08-08-2015 01:00,08-08-2015 02:00,31.52,43.61	56.37
08-08-2015 02:00,08-08-2015 03:00,31.50,43.61	56.39
08-08-2015 03:00,08-08-2015 04:00,31.48,43.61	56.41
08-08-2015 04:00,08-08-2015 05:00,31.50,43.61	56.39
08-08-2015 05:00,08-08-2015 06:00,31.80,43.61	56.09
08-08-2015 06:00,08-08-2015 07:00,32.31,43.61	55.58
08-08-2015 07:00,08-08-2015 08:00,32.71,43.61	55.17
08-08-2015 08:00,08-08-2015 09:00,32.88,43.61	55.01
08-08-2015 09:00,08-08-2015 10:00,32.70,43.61	55.18
08-08-2015 10:00,08-08-2015 11:00,32.03,43.61	55.86
08-08-2015 11:00,08-08-2015 12:00,31.50,43.61	56.38

Figure 35 Example of non-plausible forecasts: Values higher than installed capacity of 46 MW

Central: CanelaI.								
Predicción generada el 2015-06-03 a las 18:03:10. EL huso horario corresponde a America/Santiago (UTC/GMT -0300).								
Observaciones:								
º: Dirección de procedencia del viento en grados (0º viento del Norte, 90º viento del Este)								
Desde(aaaa-mm-dd HH:MM)	Hasta(aaaa-mm-dd HH:MM)	P25(MWh)	P50(MWh)	P75(MWh)	VelViento(m/s	DirViento(º)	Temperatura(	Presión(mbar)
03.06.2015 18:00	03.06.2015 19:00	0.2	0.53	5.34	7	157	18.1	1000
03.06.2015 19:00	03.06.2015 20:00	0.29	0.78	4.74	6.6	156	16.6	1000
03.06.2015 20:00	03.06.2015 21:00	0.23	0.62	3.74	6	156	15.4	1000

Figure 36 Example of unexpected forecast values: 25 and 75% probability for a day ahead (48 h) forecast, which supposed to have only 50% as required by the CDECs

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Acronyms

CDEC-SIC	CDEC-SIC *Centro de Despacho Económico de Carga del Sistema Interconec-tado Central*
	Economic Load Dispatch Center for the Central Interconnected System (SIC ISO)
CDEC-SING	CDEC-SING *Centro de Despacho Económico de Carga del Sistema Interconec-tado del Norte Grande*
	Economic Load Dispatch Center for the Northern Interconnected System (SING ISO)
CNE	CNE *Comisión Nacional de Energía*
	National Energy Comission (Regulator)
NTSyCS	NTSyCS Norma Técnica de Seguridad y Calidad de Servicio
ISO	Independent System Operator
PV	Photovoltaic generation