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VARIABLE RENEWABLE ENERGY FORECASTING SYSTEM DESIGN AND IMPLEMENTATION PLAN

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ACRONYMS

AEE	Spanish Wind Energy Association
AEMO	Australian Energy Market Operator
AESO	Alberta Electric System Operator
AGC	Automatic Generation Control
AI	Artificial Intelligence
ANN	Artificial Neural Networks
ASEFS	Australian Solar Energy Forecasting System
AWEFS	Australian Wind Energy Forecasting System
CAISO	California Independent System Operator
CET	Central European Time
CFD	Computational Fluid Dynamics
CM	Congestion Management
CSV	Comma-Separated Values
DA	Day-Ahead
DNVGL	Global Quality Assurance and Risk Management Company
DQC	Data Quality Control
DUID	Dispatchable Unit ID
EC	Energy Community
ECMWF	European Centre for Medium Range Weather Forecasting
EMMS	Electricity Market Management System
ENFOR	Forecasting and Optimization Solutions for the Energy Sector
ERCOT	Energy Reliability Council of Texas
EU	European Union
EWEA	European Wind Energy Association
FCAS	Frequency Control Ancillary Services
FTP	File Transfer Protocol
GEDF	Georgian Energy Development Fund
GEFS	Global Ensemble Forecast System
GENCO	Generation Company
GFS	Global Forecast System
GoG	Government of Georgia
GSE	Georgian State Electrosystem
HA	Hour Ahead
hPa	Hectopascal
HPP	Hydro Power Plant
ID	Intraday
IESO	Independent Electricity System Operator (Canada)
IP	Internet Protocol
IRATA	Industrial Rope Trade Association
ISO	Independent System Operator
JNT	Joint Numerical Testbed
KISR	Kuwait Institute for Scientific Research
kW	Kilowatt
LiDAR	Light Detection and Ranging
LoE	Level of Effort
MAD	Mean Absolute Deviation
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MET	Model Evaluation Tools
MoU	Memorandum of Understanding
MT PASA	Medium Term Projected Assessment of System Adequacy
MW	Megawatt
MWh	Megawatt Hour

NCAR	National Centre for Atmospheric Research
NCEP	National Centre for Environmental Prediction
NDA	Non-Disclosure Agreement
NEA	National Environmental Agency
NEM	National Energy Market
NEMDE	National Electricity Market Dispatch Engine
NOAA	National Oceanographic and Atmospheric Administration
NWP	Numerical Weather Prediction
NYISO	New York Independent System Operator
PDF	Probability Density Function
PJM	PJM Interconnection is a Regional Transmission Organization
PME	Presidency of Meteorology and Environment
PV	Photovoltaic
QC	Quality Control
QWF	Qartli Wind Farm
RAL	Research Applications Laboratory
RFP	Request for Proposals
RMSE	Root Mean Squared Error
RSD	Remote Sensing Devices
RTO	Regional Transmission Operator
SCADA	Supervisory Control and Data Acquisition System
SCE	Southern California Edison
sdv	Semicolon Divided Values
SFTP	Secured File Transfer Protocol
SLA	Service Level Agreement
SO	System Operator
SoDAR	Sonic Detection and Ranging
ST PASA	Short Term Projected Assessment of System Adequacy
TCP	Transmission Control Protocol
ToR	Terms of Reference
TSO	Transmission System Operator
TWh	Terawatt Hour
TYNDP	Ten-Year Network Development Plan
UCAR	University Corporation for Atmospheric Research
UIGF	Unconstrained Intermittent Generation Forecast
US	United States of America
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
VESTAS	Danish Manufacturer, Seller Installer and Servicer of Wind Turbines
VRE	Variable Renewable Energy
WA	Week Ahead
WG	Working Group
WGS	World Geodetic System
WPF	Wind Power Forecasting
WPPT	Wind Power Prediction Tool
WRF	Weather Research and Forecasting

CONTENTS

INTRODUCTION

The objective of USAID Energy Program is to support Georgia's efforts to facilitate investment in power generation capacity to increase national energy security, facilitate economic growth, and enhance national security. The investment objective will be achieved through the provision of technical assistance to a variety of stakeholders in the energy sector.

More specifically, with the aim to support more renewable energy integration to the transmission network USAID Energy Program supports the development and implementation of the Wind Power Forecasting system. This, in turn fully complies to preliminary determined condition set-in Ten-Year Network Development Plan (TYNDP) 2018-2028 for Variable Renewable Energy (VRE) integration to the network in regard to Wind Power Forecasting.

Wind and solar energy are among the most difficult weather variables to forecast. Topography, surface roughness, ground cover, temperature inversions, foliage, gravity waves, low–level jets, clouds, and aerosols, all affect wind and solar energy prediction skill.

With the Wind Power Forecast in place and validated meteorological input, Georgian State Electrosystem (GSE) would have access to detailed information, in advance, on where, when, and approximately how much electricity will be produced by each wind power plant. This, in turn helps to more efficient allocation of resources for meeting demand.

Also, it might allow GSE to have a greater confidence in the amount of electricity each wind farm would be capable of generating at a given time, which will decrease the need to commit more generation from other types of power plants. This, in turn should also help limit the number of times when there is not enough generation available and ready to produce electricity when wind speed and therefore, wind power plant output, is lower than the plant offered to provide.

The forecasting tool also might enhance GSE ability to prepare for wind-ramp events that might occur when storms or other high-wind events are predicted. These events can push wind turbines into "overspeed" and cause them trip offline suddenly, which can negatively impact the system reliability. The system operators are also using the long-term (seven day) wind forecast to help schedule generator and transmission outages.

USAID Energy Program has already supported the development and implementation of the forecasting system such as:

- Study of Available Models and Methodologies for Forecasting;
- Initial Survey of Forecasting Service Providers;
- Create Working Group (WG) and Launch the Forecasting of wind speed in test mode to Study National Environmental Agency (NEA) Capability on forecasting the wind speed;
- Assessment of the infrastructure capability to provide required data input for forecasting system;
- Assessment of legislation authorizing GSE access and / or retrieval of information required for forecasting system.

Work performed by USAID Energy Program, triggered interest of six suppliers of forecasting services. The performed work comprised the determination and list of data required for the wind and solar power forecasting, identification of willingness and capability of wind farm developers and operators to participate in a forecasting.

Nevertheless, the development and implementation of forecasting system is a complex issue and it is hard to perceive it as an "plug and play" activity. USAID Energy Program, with the studies listed above, created vital basis to continue support and shift to the Concept Design and Implementation Plan development stage.

Concept design is the development phase of VRE forecasting system, in which USAID Energy Program attempt to fully understand a problem and come up with the solution of this problem. It usually involves trying to design a practical feasibility of developing concept which considers both technical feasibility and estimated costs of developing. The implementation plan supplements the Concept Design and offers options and solution on the most efficient way of the concept design implementation.

BACKGROUND

Georgia is in the process of implementing reforms in the power generation sector that targets the generation of electricity from the renewable energy sources. In this process, the driving force is European Union (EU) Directive on Renewable Energy - 28/2009/Energy Community (EC) which determines certain obligations for Georgia to increase renewable energy share in final energy consumption. Georgia, as a country with a considerable potential of all types of renewable energy resources, has promising perspectives for complying with the mentioned directive to ensure the further development in this sector.

With the main purpose to support the increase of renewable energy's share in final energy consumption and meet the growing demand on electricity, the Government of Georgia (GoG) has been periodically signing Memorandum of Understanding (MoUs) with potential investors. Hydro Power Plant (HPP) projects firmly occupy the first place in terms of quantity, priority and importance. However, VRE - Wind and Solar is also considered to be an intrinsic part of Georgia's energy future. The contribution to the total power generation from the VRE projects theoretically can be estimated up to 6 TWh which might be 25% more than the projected demand for 2027[1].

Wind or solar and the resulting power produced by VRE plants are neither constant nor schedulable. A 10-15%[2] penetration of VRE power (measured as a percentage of annual generation) may be easily integrated in one power system while causing significant challenges in another, depending upon a range of factors including resource distribution, market rules, system size, grid reliability, level of interconnection, and system operation protocols.

One of the fundamental difficulties faced by power system operators is the unpredictability and variability of power generation on Wind and Solar Plants. This has both technical and commercial implications for the efficient planning and operation of power systems. Below are listed certain characteristics shaping the impact of variability and uncertainty of power generated on wind and solar power plants.

1. **Low short-run costs**. Once built, VRE generators produce energy with a very little additional cost. When the resources (wind or sun) are available, they will be among the first plants called upon (dispatched) to meet demand, frequently reducing the market share for generators with the higher short-run costs and reducing marginal generation costs;
2. **Variability**. Available power output from VRE fluctuates according to the instantaneous availability of the resource. The power system is designed to manage the variability in load, but VRE increases the magnitude of variation thereby increasing the stress on systems to maintain power quality. Conversely, VRE production may be low at times of high demand, which calls for rapid increase in output of dispatchable generators or alternative options to meet demand at these times;
3. **Uncertainty**. The availability and intensity of wind and solar resources can be predicted with a high accuracy only in the short term and if adequate forecast tools are in place;
4. **Location-constrained**. Linking resource-rich areas to demand may require new grid infrastructure at an additional cost. This change also calls for updated transmission planning and operating practices;
5. **Modularity**. Wind and solar plants consist of individual wind turbines and solar panels that can be deployed in different sizes, from offshore parks to individual turbines or solar home systems. Small plants connect to lower voltage levels in distribution grids, mandating changes in the way these are planned and operated;
6. **Non-synchronous technology**. Synchronous generators enjoy a direct, electro-mechanical link to the power system and have a considerable amount of spinning mass (inertia). VRE plants are linked to the power system via power electronics and have less or no spinning mass, i.e. non-synchronous generators. This may require changes in the way system stability is managed, especially during periods of high shares of VRE in power generation.

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[1] TYNDP 2018-2028 Table 1.1. Forecasted annual energy balances based on L3G3 (bln kWh)

[2] Source: Overview of Variable Renewable Energy Regulatory Issues Mackay Miller and Sadie Cox National Renewable Energy Laboratory

In view of several factors and above listed issues, TYNDP 2018-2028[3] adopted by the GSE proposes limits of the transmission system of new VRE capacity in terms of integration in a time and spatial scale.

To allow the integration of amount of wind and solar installation to the transmission network, TYNDP sets specific requirements regarding transmission system and generation facilities:

- Transmission system upgrade;
- New hydropower generation capacities with the regulated reservoirs;
- Generation facilities upgrade with the Automatic Generation Control (AGC) equipment;
- Integration into the European energy market.

Beyond the requirements listed above, one of the important requirements determined as a condition of VRE integration to the grid is the existence of Wind Power forecasting tools. The expected / required VRE production uncertainty level is in the range of 8-10%. Furthermore, if a developer of wind project decides to exceed the capacity limits for integration, set by the TYNDP, company shall build a storage plant or battery, which will, for at least 8 hrs., provide accumulation (consumption) of such power, by which its' wind station capacity will exceed the difference between the acceptable value and designed capacity of wind farm.

The VRE forecasting in Georgia is underdeveloped due to several factors. There is only one operable wind farm in Georgia - Qartli Wind Farm (QWF) with 20 MW Installed Capacity. The development and utilization of accurate models for prediction of VRE output power is a challenging task. However, the cost-benefit ratio on the use of predictive technologies in electrical systems with high penetration reaches 1:100 (European Wind Energy Association (EWEA), 2010). VRE forecasting plays an instrumental role in planning and is useful for power system operations, unit commitment, and economic dispatch.

[3] Source: TYNDP of Georgia 2017-2027 GSE Web Page Accessed 4/10/2018
http://www.gse.com.ge/sw/static/file/TYNDP_GE-2017-2027_ENG.pdf

EXECUTIVE SUMMARY

The production of power from the variable renewable resources, appearing on the Georgian grid would very closely be linked to weather. The difficulty of weather forecasting, which is well understood, leads to difficulty in forecasting the production of variable energy resources.

Due to variability of wind speeds and solar insolation, the actual output of power from VRE projects might vary significantly over a short period of time. Gusts of winds result is variation of power output of wind turbines. The shadows of clouds moving over the solar Photovoltaic (PV) arrays result in the variation of power production of the array. This process compounds the problem of balancing supply and demand in real time.

Technological advances have greatly improved the degree to which VRE output can be forecasted and controlled in real time. This means that system operators are able to evaluate the amount of wind and sun, they can count on reliably several hours in advance, which also allows the use of VRE to provide system services such as operating reserves.

The aim of this report is to introduce Design Concept of VRE forecasting system and Implementation Plan that enable the environment supporting the electric power grid to overcome the issues challenging the integration of VRE projects to the grid and support a penetration of clean energy from variable renewable resources. Furthermore, the Concept Design and Implementation Plan were drafted with the main aim to have basis for discussions with GSE what would be the most efficient way for arrangement of Wind Power forecasting system, its development and implementation in Georgia.

More specifically, Conceptual Design and Implementation Plan report provide description of options, main findings from the options and at some extent analysis of options and recommendations. The schematics and proposed distribution of roles and responsibilities of different agencies supplement the paragraphs of Conceptual Design and Implementation Plan with regard the Analysis and Recommendations. Furthermore, the Schematics of Conceptual Design of Wind VRE forecasting System is supplemented by the explanation of each element on schematics.

The main objective of the report is to provide insights on what is proposed and how it might be implemented in an efficient way. Respectively in regard to Conceptual Design of the Forecasting the followings are recommended:

Table 1: Recommendation on Conceptual Design

Item	Recommended Option
Type of Technology	Start with Wind Power Forecasting
Structure of Forecast	Apply to Wind Power Centralized Forecasting System approach Before the VRE penetration level doesn't exceeds 3-5% VRE centralized forecasting cost would be absorbed by System Operator (SO) or before the uncertainty of predictions becomes acceptable for both VRE Plant Operators and SO cost would be absorbed by SO
Wind Power Forecasting Approach	Centralized system implemented through the provision of VRE forecasting services by the third-party vendors
Hosting Agency	Hosting agency GSE – Dispatch licensee NEA provides alternative input and local observational data to the Wind Power Forecasting system
Type of Forecasts	Deterministic Forecast
Spatial Scale of Forecasting	At list wind farm level
Time Horizon and Time stamp of Forecasting	The time horizon and time scale at initial stage of VRE forecasting implementation would be set at: - At least 36 hours - for day ahead forecast with the granularity of 15 minutes; - 2 hours ahead with the granularity of 5 minute; - With the consideration of forecast, granularity forecast would be delivered in MW of active power[4]; - Day ahead and hour ahead forecast would be produced for both power and meteorological parameters and updated each hour; - If it would be requested by the hosting agency for VRE forecasting, the availability on per minute granularity should be checked with the suppliers of VRE forecasting and then it might be set to 1 min.
Control Measurements	Perform Control Measurement by LiDAR or SoDAR Further research requires to set preference on the equipment proposed to be utilized for control

[4] Active Power for the purposes of this report has the same meaning as Electric Power. Electrical power is a measure of the instantaneous rate at which electrical energy is consumed, generated or transmitted. In large electric power systems, it is measured in megawatts (MW) or 1,000,000 watts.

Item	Recommended Option
	measurement Autonomous source of power supply and trailer are required for the mobility of equipment After the procurement of equipment to make remote sensing data comparable to the conventional anemometry remote sensing data should be processed in the software capable to handle CFD

SO – System Operator; LiDAR – Light Detection and Ranging; SoDAR – Sonic Detection and Ranging

With regard the implementation plan its recommended:

Table 2: Implementation Plan

	Recommended Option
Forecast Parameters	QWF – Forecast of Active Power Wind Speed and Direction Infinite Energy & Caucasian Wind Energy – Forecast of wind speed and direction
Vendor Selection Approach	Least Cost Approach
Vendor Selection Approach	Mean Absolute Error & Mean Absolute Percentage Error
Contract and NDA	Contract -USAID Energy Program and GSE NDA - GSE
Data Exchange	GSE-Data Exchange design and implementation GSE- Data Exchange Testing
Setting up FTP Server	GSE if vendor of forecasting services doesn't provide data exchange platform

NDA – Non-Disclosure Agreement; FTP – File Transfer Protocol;

With the utilization of the Concept Design and Implementation Plan, provided in this report, USAID Energy Program proposal is to perform the forecast of Power and Meteorological parameters at the QWF site and because the meteorological parameters are important input for the prediction of Wind Power perform launch prediction of meteorological parameter related to the wind power only at two or three locations. Those are location where the developers of Wind Project have erected the meteorological towers with the main purpose to access the wind resource at specific location.

Currently, wind project developers are performing the measurement of Wind Speed, Direction, Ambient Temperature, Barometric Pressure and other meteorological parameters at this location. Those parameters might be available in a real time format.

Implementation Plan mainly considers 3 stages. Preparatory, Procurement and Implementation.

Figure 1: Preparatory Stage (Part 1)

1. Agreement on System Concept Design with GSE
2. Identification of Locations
3. Survey of Suppliers
4. Comply Deloitte / USAID Procurement Rules
5. Identify 2 least cost Supplier of VRE forecasting Services

Figure 2: Preparatory Stage (Part 2)

- Agreement on uncertainty metrics for performance assessment*
- Contractual Agreement with Vendors including NDA
- Setup FTP Server or Interconnection between GSE, Developer and Vendor for data exchange
- Test interconnection for data exchange

Figure 3: Procurement Stage (Advance Payment 10 to 30%)

- launch forecasting with the selected vendor
- Advance Payment
- Performance Assessment

Figure 4: Implementation Stage (Payment)

- Performance Assessment
- Monthly Payment
- Procurement of LiDAR

Wind power forecasting system if implemented successfully might be perceived as a significant factor on the way to enabling environment for the integration of wind power to network and rising the level of VRE penetration to the network.

METHODOLOGY

In general, the methodology that was applied for the development of the report considers:

- Collection and Review of materials, literature, regulations, publication pertaining to the experience of System Operators like Australia Energy Market Operator (AEMO), California Independent System Operators (CAISO), Alberta Electricity System Operator (AESO) with regard to the development and structure of VRE forecasting system;
- Documentation review/desk study to identify the Elements of Forecasting System Conceptual Design;
- Documentation review/desk study to justify the options for Elements of Forecasting System Conceptual Design;
- Consideration of VRE forecasting service suppliers survey results for developing the Concept Design;
- Consideration of Findings from Romania Study tour for the development of Concept Design and identification of equipment required for control measurements.

Consideration of experience on procurement for development of Implementation Plan.

OPTIONS FOR CONCEPTUAL DESIGN OF FORECASTING SYSTEM

LIST OF OPTIONS

Worldwide, the significant number[5] of power system operators are dealing with the VRE penetration in a way which considers the existence of centralized system for VRE Forecasting backed up with the models developed via utilization of in-house capacity or with forecasting software and services provided by the third-party vendors. Nevertheless, in some markets, VRE plant operators are required to offer a wind power forecast to the power purchaser or to the SO. These decentralized wind power forecasts might be produced either internally, with the assistance of a wind power forecasting company or with the prediction of power generation performed by the supplier of wind power plant equipment under the operation and maintenance contract.

Depending on the penetration level of VRE technology (Wind or Solar), SOs are starting either with the development of Wind Power Forecasting and later shifting to the Solar Power Forecasting for the system operations or vice versa. This was the case in Australia. AEMO started with the development and implementation of Australia Wind Energy Forecasting System (AWEFS).

In case of centralized forecasting system, the identification of “Hosting Agency” is dependent on the structure of the electricity sector and market arrangement. In Australia AEMO is hosting agency of forecasting system, whilst in Germany Transmission System operator is hosting the system. In the United States of America (US), State of California case is that CAISO is the hosting agency for the system.

Also, the time horizon, time stamp and type of forecasting are the constituent part of forecasting concept design for which the different options might be applied as it is depicted on the diagram provided below.

Figure 5: Options for Conceptual Design

Technology	Structure of System	Forecasting Approach
• Wind • Solar	• Centralized • Decentralized	• In House • Software and NWPs • Service Provision
Hosting Agency	**Type of Forecast**	**Scale**
• GSE • NEA	• Deterministic • Probabilistic	• SO, Area • Regional • Portfolio • Farm Level-Connection Point
Time Horizon and Stamp	**Control Measurement**	
• Hour Day and Week Ahead • 5 min 30 min 24 hour	• Agency – GSE - NEA • LiDAR or SoDAR	

NWP – Numerical Weather Prediction

TYPE OF TECHNOLOGY

According to the initial survey of VRE forecasting service providers, the forecasting services might be available for both technology Wind and Solar power generation. The challenging to the employment of the solar power forecasting services would be the nonexistence of utility scale solar power plant

[5] New York Independent System Operator (NYISO), California Independant System Operator (CAISO), Electric Reliability Council of Texas (ERCOT), Southern California Edison (SCE), PJM Interconnection is a regional transmission organization (RTO), Alberta Electric System Operator (AESO), Independent Electricity System Operator (IESO) Canada, ENERGYNET, Australia Energy Market Operator (AEMO)

connected to the transmission grid. Furthermore, TYNDP sets requirement on the existence of Wind Power Forecasting System.

STRUCTURE OF FORECASTING SYSTEM

Centralized Forecasting System

Centralized VRE forecasting is widely considered as a best-practice approach for the economic dispatch. Administered by the system operator, centralized forecasts provide system-wide forecasts for all VRE generators within a balancing area. The implementation of centralized forecasting system through the utilization of third-party vendors for forecasting has been practiced[6] by the entities listed in Table 3.

Table 3: Utilization of Forecasting Services

Country	System Operator
Germany	Ampirion GmbH
Canada	Alberta Energy System Operator
US	California Independent System Operator
US	Midwest Independent System Operator
US	New York Independent System Operator
US	PJM
US	Southern California Edison

Central wind power forecasts might offer several advantages over their decentralized counterparts. First, a central VRE power forecast will use a consistent/unified wind power forecasting approach and methodology for all VRE projects which will likely lead to more consistent (though not necessarily more accurate) results.

Under the centralized forecasting system, the grid operator will have access to VRE power generation parameter together with the meteorological data, that can be used to improve the performance of centralized wind power forecasting systems. VRE project operator may not have access to real-time data on meteorological and power data of other VRE projects because of confidentiality and proprietary reasons.

Moreover, Individual VRE power plant, as an alternative to access region or country wide historical or real time meteorological data, should apply to NEA which for the access to information and provision of services on real time meteorological data is charging an applicant with a certain amount of money.

Furthermore, centralized wind power forecasting system might benefit from the utilization of economies of scale, reducing the cost of forecasting per individual VRE project as compared to decentralized forecasting systems. This was observed even in the survey of VRE forecasting vendors performed by USAID Energy Program. In case of some vendors, the cost of provision of VRE forecasting services were calculated per MW of installed capacity, with the possibility of declining the cost of services with the increase in installed capacity of VRE units.

Compared to decentralized forecasts, centralized forecasts provide:

- Greater consistency in results due to the application of a single methodology;
- Lower uncertainty due to the system operator's ability to aggregate uncertainty across all generators;
- Reduced financial burden for VRE plants to produce and submit individual forecasts.

Regarding the cost recovery for centralized VRE forecasting. There are examples where the VRE power plants charged certain cost per MWh, whilst there are cases where the cost for forecasting fully absorbed by the SO[7].

Central wind power forecasts also has some disadvantages. If VRE forecasting is based on a single forecasting methodology and provider, the 'more consistent' result may be consistently wrong. When

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[6] Source: https://www.nrel.gov/docs/fy10osti/47853.pdf

[7] Two RTOs, the California ISO and NYISO, at least partly recover the wind power forecasting costs directly from wind generators, and AESO and IESO have also proposed charging wind generators for their central wind forecasting programs. Other RTOs and utilities have absorbed the full costs of central wind power forecasting, including PJM, ERCOT, the Midwest ISO, and SCE. Those with central wind power forecasting initiatives under development, other than AESO and IESO, have not announced whether they will assess a fee to wind generators or absorb the costs of central wind power forecasting. Source - Status of Centralized Wind Power Forecasting in North America May 2009 – May 2010

a single central VRE forecast is in place, competition and the ability to compare alternative results may be reduced or lost. A common way to improve centralized forecasts is through ensemble forecasting, whereby system operators combine and aggregate the results from different forecasts produced by multiple forecast providers or methods.

As an example, in case of Finland combining wind forecasts from different Numerical Weather Prediction providers was studied with different combination methods for 6 sites. Averaging different providers' forecasts were lowering the forecast errors by 6% for day-ahead purposes. When combining forecasts for short horizons like the following hour, more advanced combining techniques then simple average, such as Kalmar filtering or recursive least squares provided better results[8].

The benefits of a diversity of forecasts and opinions may be significant; some system operators, such as those in Germany, and Denmark have already implemented ensemble methods (i.e., systems that make use of a variety of methodologies or forecast providers) that use five or more forecasting services[9].

System operators, such as Amprion GmbH, find value in obtaining multiple forecasts from multiple (five or more) third-party forecasting services, paying each service a market rate for their forecasts, then doing an internal ensemble of the multiple forecasts to provide a better operating forecast than would be obtained from any single forecasting provider.

Figure 6: AMPRION GmbH Wind Power Forecast August-September[10]

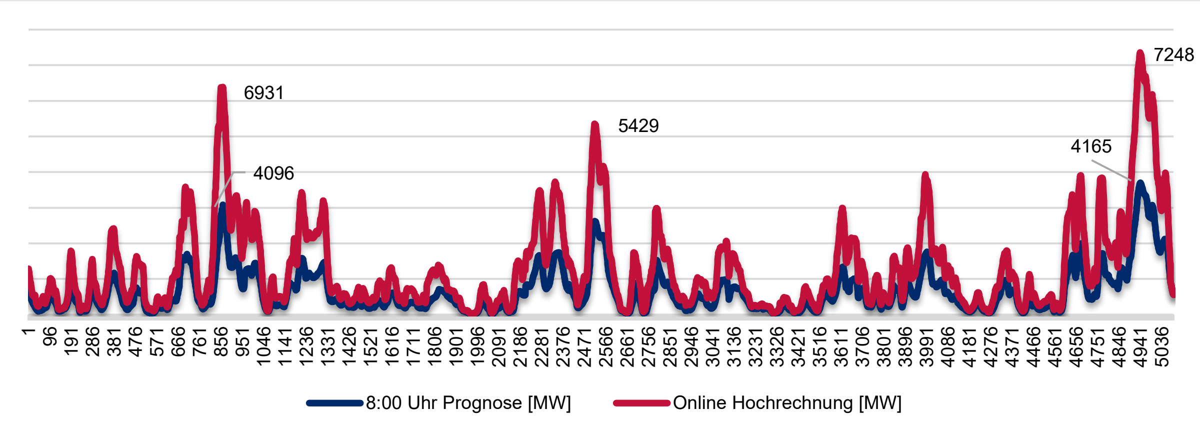
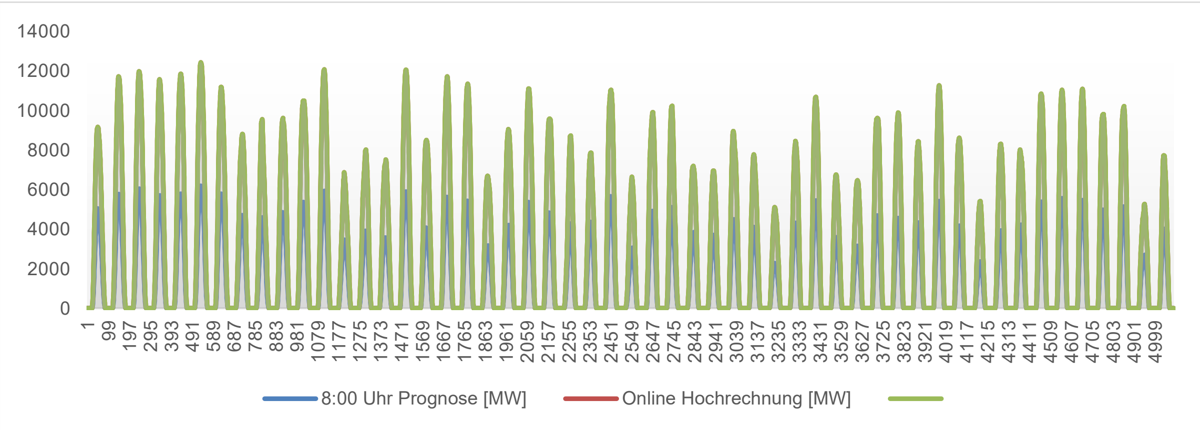


Figure 7: AMPRION GmbH Solar Power Forecast August-September[11]



As depicted in Figure 6 and Figure 7, Amprion GmbH publishes data on forecast with the time horizon of 8 hours and 15-minute granularity and actual generation of wind energy feed-in to the grid. The

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[8] https://www.vtt.fi/inf/pdf/technology/2013/T95.pdf
[9] Status of Centralized Wind Power Forecasting in North America May 2009 – May 2010 https://www.nrel.gov/docs/fy10osti/47853.pdf
[10] Source: https://www.amprion.net/Grid-Data/Wind-Feed-In/
[11] Source: https://www.amprion.net/Grid-Data/Photovoltaic-Infeed/

values of the anticipated grid feed-in are based on the forecasts, exchanged for the management of immediate horizontal exchange among transmission system operators.

While adding some cost, this ensemble approach does provide a system forecast with lower error and support a more vibrant, competitive and innovative marketplace for wind power forecasting services. But even this approach of ensemble forecast couldn't ensure 100% certainty in prediction as it can be observed from Figures 6 and 7.

On the other hand, since the performance of the multiple forecasting providers is directly available to the system operator for their system, the system operator can provide incentives and other type of motivations for all forecasting vendors to improve their methods and results.

In a restructured market environment, forecast errors may have an associated cost or penalty, as the VRE power producer usually ends up supplying an amount of energy that differs from the market bid. In the same market environment SO acquires all the reserve needed for the control area, in order to maintain a minimum reliability level.

For SO the function of VRE power forecasting is as follows:

- Determine the reserved capacity in reserve market according to the forecasting results. The assessment of the requirement and the bidding are influenced by the forecasting accuracy;
- In regulating market (real time market), the buying (selling) of the extra VRE generated power based on the updating forecasting results every 5 minutes. It is very important for SO to keep the stability of the power system;
- Ensure grid stability and reliability.

Furthermore, the forecasting results influence the financial benefits of the participants due to the payment of the electricity buying (selling) afforded by the power plants.

Decentralized Forecasting System

Decentralized VRE forecasting, administered by VRE project operators provides plant-level forecasts to help inform system operators of potential transmission congestion due to a single plant's output[12].

However, each wind farm follows its own forecast mechanism or forecast supplied by the vendor and there is no consistent approach. With many wind farms, the huge number of schedules received by the system operator may create difficulties in managing the schedules. As each wind farm must maintain the forecasts, there is no optimization of costs as well as forecasting system.

The approach, practiced by GSE, can serve as an example of decentralized VRE power forecasting. Each day QWF should submit Readiness Application on available capacity for next day to the GSE. To ensure the existence and timely delivery of Readiness Application QWF receives day ahead forecast of power generation from the VESTAS the supplier of wind farm equipment. Under the VESTAS online application, depending on the contract and location, it is possible to utilize at least three application which are related to the power forecasting:

- Power Forecast gives site-specific power forecasts every 10 minutes. It covers entire portfolio, both Vestas and non-Vestas turbines, and includes data down to turbine-level. The forecast is based on numerical weather prediction models and artificial intelligence neural network models;
- Weather Forecast allows to analyze and explore weather conditions without being on-site;
- Seasonal Forecast allows to investigate seasonal deviations and anticipate next season's production.

In House Capacity Development

In house development of the models, proposed for a centralized forecasting system of forecasting, might be performed in a different way. This might be either support of the third party in the development and implementation or utilization of local and/or mobilization of available resources.

An example of Australian Solar Power Forecasting System Development with the project cost of $7.6 Million[13] and $5.1 is provided as an example for the project costs for the development of VRE

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[12] Source: Forecasting Wind and Solar Generation: Improving System Operations Source: https://www.nrel.gov/docs/fy16osti/65728.pdf
[13] Australian Solar-Energy Forecasting System Final report: Project results and lessons learnt Source : https://arena.gov.au/assets/2016/07/Aus-Solar-Energy-Forecasting-System-Final-Report.pdf

forecasting with the support of the third party. The $5.1 million project developing a system to provide detailed forecasts of wind and solar irradiance at Kuwait's planned 2-Gigawatt Shagaya renewable energy plant.

Australian Solar Power Forecasting System - The 30-months, 7.6 million, project Australian Solar Energy Forecasting System (ASEFS) addressed the issue of solar power integration into the grid by means of a two-pronged approach:

- The development of an operational infrastructure component, also referred to as ASEFS, to be installed at, and operated by, the AEMO;
- The development of an advanced forecasting research program aimed at improving the forecasts produced by the operational system and at creating national capability in the area of solar irradiance and power forecasting.

The $5.1 million project will focus on developing a system to provide detailed forecasts of wind and solar irradiance at Kuwait's planned 2-Gigawatt Shagaya renewable energy plant. After US National Center for Atmospheric Research (NCAR) develops the system, the technology will be transferred to the Kuwait Institute for Scientific Research (KISR) for day-to-day operations[14].

The goal of this project is to improve and modernize the numerical weather prediction capability for Saudi Arabia Meteorological Service. The project will also conduct feasibility study for predicting dust storms in the region and provide training on numerical weather prediction. The model system research and development are components of the overall project, sponsored by the Presidency of Meteorology and Environment (PME), Saudi Arabia, through National Oceanographic and Atmospheric Administration (NOAA) corporative agreement with University Corporation for Atmospheric Research (UCAR). The other components include the implementation of the NCAR/ Research Applications Laboratory (RAL) Joint Numerical Testbed (JNT) Model Evaluation Tools (MET) for real-time model evaluation, development of forecast display system, and providing hands-on forecaster training programs[15].

Another way of hosting the agency that could deal with the in-house development of the models, required for the prediction of wind and solar power, is the utilization of local resources. Under the local resources for the purposes of this report we consider[16]:

- Expert in Statistics / Mathematics;
- Expert in Meteorology;
- Expert in Programming (Python);
- Expert In IT;
- Expert in SCADA (Supervisory Control and Data Acquisition System).

Furthermore, the Statistician and Programmer might be familiar with the architecture and operating principles of Artificial Intelligence (AI) and Artificial Neural Networks (ANN). Unfortunately, there is no experience of developing such kind of project in Georgia. Thus, to estimate the indicative budget of project, the same time frame can be assumed as it was required for the ASEFS - 30 months.

Table 4: Indicative Budget Estimation for VRE Forecasting Development

Expert	LOE days	Daily Rate	Salaries
Expert in Statistics/Mathematics	260	$100	$26000
Expert in Meteorology	260	$100	$26000
Expert in Programming (Python)	260	$100	$26000
Expert In IT	120	$100	$12000
Expert in SCADA	120	$100	$12000
Expert in Meteorological Equipment	120	$100	$12000
Contingencies 30%			
Project Raw Cost			$114000

LoE – Level of Effort

The above raw estimation doesn't consider the cost of hardware and some software required for the development of the VRE forecasting model. The Contingency 30% taken with the main purpose to

[14] Source: https://news.ucar.edu/126802/ncar-develop-advanced-wind-and-solar-energy-forecasting-system-kuwait
[15] Source: https://ral.ucar.edu/projects/wrf-based-rtfdda-system-for-pme
[16] Assumption

deal with the uncertainties with regard the Level of Effort (LoE) and daily rates. Project cost doesn't consider the setup of Numerical Weather Prediction (NWP) model specific to our region as it is indicated in case of agreement between the NCAR and Meteorological Agency of Kuwait.

Furthermore, the implementation of this project with inexperienced experts specific to the solar and wind power forecasting, does not imply the increase in the chance to complete project successfully. However, the use of experts experienced in the development of such model might be either more costly or challenging issue due to their availability for such task.

In case of foreign exerts' engagement, it is assumed that only the Expert in Statistics Meteorology and Programming would be substituted for the development of the forecasting model and setting up Numerical Weather Prediction Model. The daily rate for the purposes of estimation would be increased to $600 and LoE reduced 4 times.

Table 5: Indicative Budget Estimation for VRE Forecasting Development

Expert	LoE days	Daily Rate	Salaries
Expert in Statistics/Mathematics	60	$600	$36000
Expert in Meteorology	60	$600	$36000
Expert in Programming (Python)	60	$600	$36000
Expert In IT	120	$100	$12000
Expert in SCADA	120	$100	$12000
Expert in Meteorological Equipment	120	$100	$12000
Contingencies 30%			
Project Raw Cost			$144000

Even if the required LoE is reduced four times, the estimated cost might be no less than the cost estimated in case of the local experts' engagement in the development process.

The main disadvantage of this approach is that it might be costly and time consuming.

Utilization of VRE forecasting Software

Another way of dealing with the development of VRE forecasting system, is to employ the specific forecasting models set up as a software package. In this case, software would be installed on the server which is under the disposal of the hosting agency and the cost for the initial setup of software/model might be in the range of €10000 to €20000.

The input of real time power data might be ensured by GSE, but only real time power and meteorological data without the input derived from the NWPs would bind the time horizon of forecasting by 4-6 hours only. Thus, the supplier of software should be asked to setup the NWP input either from publicly available NWPs such as Global Ensemble Forecast System (GEFS) and Weather Research and Forecasting (WRF) or from the models like European Centre for Medium Range Weather Forecasting (ECMWF) which would be costly (€25000).

It might be the case that the supplier of software/model can supply the meteorological parameters derived from ECMWF as well since it has full membership, the cost of which is recovered from several clients. In this case, the cost for meteorological input derived from NWP would be significantly less.

The cost of meteorological input, derived from the NWP, might be less in case the local agency, such as NEA, would deliver forecasts from several NWPs. In this case, sharing cost amongst the clients would be the principle which cause the cost reduction for meteorological prognosis comparative to full membership cost.

Furthermore, in case of software installation on the server of hosting agency, at the initial stage the software could be maintained by the supplier. The only difference compared to the provision of VRE forecasting services which might be observed in this case is that forecasting software/model is installed on the server of the hosting agency and there is no need to share the real time power information to the supplier of the VRE forecasting services. The said is the advantage of this approach with the consideration of the sensitivity of SCADA information and hosting agency will avoid the procedures required for signing the Non-Disclosure Agreement (NDA).

Disadvantage of this approach would be observed if vendor of the software doesn't deal with data input which is meteorological data derived from hosting agency or plants and NWP, then the quality control of both prediction and data input, procurement and setting up the server or other hardware might be the duty of the client.

Procurement of Forecasting services

The procurement of forecasting services considers the engagement of third-party vendors for the delivery of forecasting services to the hosting agency. Hosting agency ensures the supply of real time power generation and meteorological data together with the historical dataset to ensure the data input for forecast with the range 0-6 hours. Also requires the supply of outage information and grid curtailments to forecast provider so that this information can be considered in the forecasting process.

The advantage of this approach is that, it might be the least costly approach. Moreover, vendors might be capable of utilizing several NWP as a meteorological data input of forecasting model which means that power forecasts are based on multiple weather model input, i.e. weighted combination is generated to ensure high accuracy.

Furthermore, most of the forecasting services vendors are capable of fitting their services to the needs of customers since they have flexibility to match additional requirements such as aggregating forecasts on certain levels (e.g. regions or balancing areas) or provide extra information on expected ramps or forecast uncertainty.

The disadvantage which might be observed in this case is that real time power and meteorological data together with the static data should be shared with the vendor of forecasting services. This requires signing the NDA between the hosting agency and vendor. Also, despite the existence of quality control of data and forecasts under the vendor disposal, the existence of data quality and forecast quality control instruments are required at the hosting agency as well.

HOSTING AGENCY

Due to availability of significant number of VRE forecasting vendors, nowadays it is not a very challenging issue to find a reliable supplier of the VRE forecasting neither for SO nor for the VRE plant operator. What matter is the cost for forecasting service or models and funds availability.

For the process of VRE forecasting system development or implementation, the data input availability and / or authority/possibility to access or request required data from the respective sources as well as authority / possibility to utilize forecasts in a most effective way would be of high importance.

Those two criteria could be applied to the process when determining the VRE Forecasting Centralized System Hosting Agency. The rationale behind the mentioned approach is that, without the proper data input the VRE forecasting system predictions are useless due to high uncertainty of forecasts. Moreover, according to worldwide practice, the VRE forecasting should be utilized in a manner which supports the grid reliability and the increase in VRE penetration level to the system.

It should be mentioned that data required for the proper functioning of the Wind Power Forecasting system is under the disposal of two organizations. GSE is authorized to obtain and access dynamic and static data generated at the wind farms, whilst the meteorological parameter predictions such as forecast of wind speed and direction derived from NWP is under the disposal of NEA. If only dynamic and static data are available for the forecasting model then the forecasting time horizon would be limited to 6 hours. After the NWP meteorological forecast becomes available for the system, time horizon might be extended at list to 168 hours.

As depicted in Table 6, wind and solar power forecasting systems, whether they are based on a physical or statistical approach, beyond the static information which derives from design data and technical specifications of the plant, require real-time information from the VRE units to calculate precise forecasts.

Table 6: Data Required for AWEFS

Static Data	Data for Wind Farm Identification
Static Data	Data for Wind Farm Status
Static Data	Wind Farm Nominal data
Static Data	Wind Farm Location & Terrain data
Dynamic Data	Wind Farm SCADA Data

The experience of countries in VRE installations in their electricity generation portfolio is that these requirements are integrated into the Network Rules (Grid Code) or relevant Business Practice Manuals and guidelines set mandatory by the SOs or energy sector regulators.

The significant portion of data, required as an input of AWEFS, might be obtained under the existing data requirement of Network Rules[17]. According to the same rule, Dispatch Licensee is authorized to request and access specific (VRE project or plant related) data which is deemed necessary for network short term, long term and operational planning. Moreover, Dispatch licensee is authorized to have access to the III level SCADA of VRE Power Plant. Even though III Level SCADA considers the combination of software and technical facilities of producer that collects, monitors and manages regime of plant parameters, if SCADA has the module for acquisition of meteorological parameters then, with minor changes in Network Rules, Dispatch Licensee might be authorized to have access to the meteorological data as well.

Furthermore, according to Market Rules Dispatch licensee obligation is:

Article 16[1] – Basic obligations, functions and powers of the dispatch licensee

1. The dispatch licensee shall be obliged to:

a) ensure the sustainability, safety and reliable operation of the electricity system, also to meet the requirements of all respective licensees, small-power stations, importers, exporters and direct consumers in such a way that ensures the performance of the direct contracts registered by them;

b) develop regimes to ensure the performance of direct contracts, facilitate efficient operation of electricity sector and to these ends, apply the respective administrative leverage granted to it by the legislation, including the preparation of appropriate operative and dispatch instructions and reports;

To fulfill its obligation According to the Market Rules the main functions (part of functions) of the dispatch licensee is listed below:

Article 16[1] – Basic obligations, functions and powers of the dispatch licensee

2. Basic functions of the dispatch licensee shall be as follows:

a) to ensure the balancing of electricity supply and consumption at any given time;

b) to plan and conduct dispatching of the unified energy system in such a way as to ensure the compliance of electricity parameters (frequency, voltage, etc.) with the established standards;

Additionally, according to the Network Rules:

Article 43 – The System Service

1. Basic system service that is important for proper functioning of the transmission network and that defines electricity (capacity) quality of supply is:

a) Frequency control;
b) Voltage control;
c) Operational reserves;
d) Black Start of the system.

2. The Dispatch Licensee shall completely control all system services. It should determine which system service should be provided, when and by whom it should be provided.

Article 46. Transmission Network Congestion Management

3. In case if limitations set under paragraph 2 of this Article arise the Dispatch Licensee shall undertake relevant measures for improving situation in order to suppress or minimize limitations into the transmission network for defending and restoring electricity system functioning in accordance with reliability criteria N-1. Depending on the overload the Dispatch Licensee determines measures to be taken for improving situation due to their effectiveness and enforces them immediately. Those measures are:

a) Activation of operating reserves;
b) Changing dispatch schedule (re - dispatching);
c) Undertaking relevant procedures of operational procedures by the Dispatch Licensee, including voltage reduction;
d) Reduction or termination of scheduled supply to the User;
e) Reduction or termination of scheduled export or import;
f) Load shedding of the customer.

As depicted in Table 7, the forecasting time horizon of VRE forecasting might range from several hours to week ahead and more. The areas of application depending on time horizon of the forecast are ranging from transmission outage and maintenance planning, peak load analysis to reliability and unit commitment, day ahead or hour-ahead market bidding, and real-time commitment and dispatch. For VRE plant operator, the utilization of forecast might consider plant level whilst for SO the utilization factor is extended to the transmission systemwide.

[17] USAID Energy Program Assessment for Variable Renewable Energy Forecasting

Furthermore, the different types of wind forecast users have very different motivations. A system operator is primarily concerned with the reliable and economic operation of its power system, and while a better forecast is always desirable it might not significantly alter the production cost, reserves, or operating practices of the system operator. Wind plant owners look to maximize the revenue from their investment in the wind plants.

Table 7: Forecast time horizon and potential users

Time Horizons [a]	GENCOs	ISO/RTO/TSO
S models	Intraday market (1h)	Ancillary services management (5-10 min.)
(H up to 6 h)	Real-time market (1h)	Unit commitment (up to 3 h)
(S – 10 min.)		
(R 10 to 60 min.)	Ancillary services management (10 min.)	Economic dispatch (up to 3 h)
		Congestion management (up to 3 h)
Time Horizons [a]	**GENCOs**	**ISO/RTO/TSO**
R NWP/S models	Intraday market (3 hr. to 24 hr.)	Unit commitment 3h to 12 h)
(H up to 72 h)	Wind farm and storage devices coordination (3 h to 72h)	Economic dispatch (1 h to 12 h)
(S – 30 min.)		
(R 30 to 60 min.)	Maintenance planning of wind farms (3 h to 12 h)	Congestion management (1 h to 12 h)
Time Horizons [a]	**GENCOs**	**ISO/RTO/TSO**
R NWP models	Day-ahead market (>12 h)	Maintenance planning of network lines (12 h to 72 h)
(H up to 72 h)		Congestion management (12 h to 72 h)
(S – 60 min.)	Maintenance planning of wind farms (12 to 72 h)	
(R 12 h)		Day-ahead reserve setting (12 h to 72 h)
		Unit commitment and economic dispatch (12 h to 72 h)
Time Horizons [a]	**GENCOs**	**ISO/RTO/TSO**
G NWP models	Maintenance planning of wind farms (72 h to 168 h)	Maintenance planning of network lines (72 h to 168 h)
(up to 7 days)		
(H up to 7 days)	Maintenance planning of conventional generation (72 h to 168 h)	
(S – 60 min.)		
(R 24 h)		

[a] H – Horizon (h); S – Time Step (min.); R – Refreshment (h). G NWP – Global NWP, R NWP Regional NWP.

GENCO- Generation Company ISO – Independent System Operator RTO – Regional Transmission Operator TSO Transmission System Operator

Nevertheless, theoretically NEA might be amongst the developers of forecasting model considering the example of NCAR which has developed the wind and solar power forecasting models for Xcel energy. Moreover, theoretically it might be the provider of forecasting services as well. However, since it is almost impossible to find the cases where the environmental or meteorological agency is hosting the centralized system of wind power forecasting, the delivery of meteorological prognosis, derived from NWP models under the disposal of NEA, will be more realistic as an alternative option for forecast system data input.

For wind speed forecasting, NEA employs the WRF Model developed by the NCAR. It is a mesoscale NWP system designed for both atmospheric research and operational forecasting applications. It features two dynamical cores, a data assimilation system, and a software architecture supporting parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers.

The WRF model input comprise data from Global Forecast System (GFS) and ECMWF model together with the data from the local meteorological stations.

The GFS from US National Center for Environmental Prediction (NCEP) is the most widely used data source as it is free of cost and represents a good model. The models are run at 27 km resolution globally, which is not enough resolution to predict local geographically and thermal effects such as sea breezes.

TYPE OF FORECASTS

Weather Forecasts are either deterministic or probabilistic[18]. **Deterministic:** forecasts of an event of a specific magnitude at a specific time and place. **Probabilistic:** forecasts of the probability of an event of a certain (range of) magnitudes may occur in a specific region in a particular time period.

[18] Source: http://www.unc.edu/courses/2008ss2/geog/111/001/ForecastTypes/ForecastTypes.htm

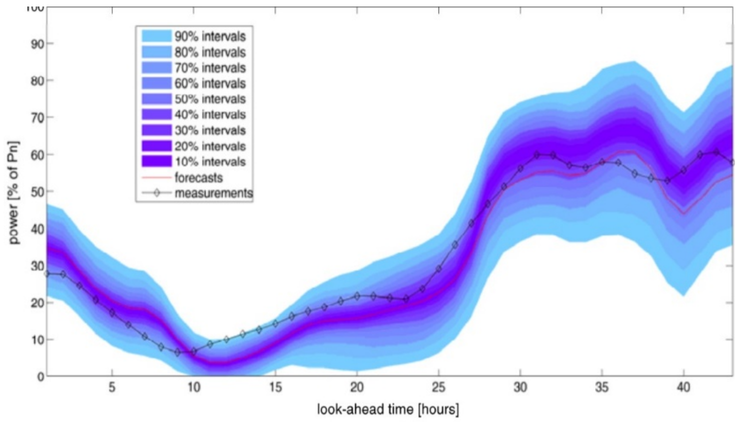
Historically, the classical view of wind power forecasting has been a deterministic view: forecasts have mainly taken the form of point forecasts, that is, giving one value of expected power production for each look-ahead time in the future. However, it has appeared that the accuracy of such forecasts may be too low on average, and highly variable depending upon meteorological conditions.

Nowadays, the power production point prediction and prediction with uncertainty forecasting are more practiced in VRE. Three main representations of the uncertainty in power forecasting might be usually considered, i.e. Probabilistic Forecasting, Risk index, and Scenario Forecasting.

A point forecast represents a single value for each look-ahead time horizon, which contains the conditional expectation at each time step. It is essential to generate, together with (or as an alternative to) point forecasts, a representation of the wind power uncertainty by a description of the Probability Density Function (PDF)[19].

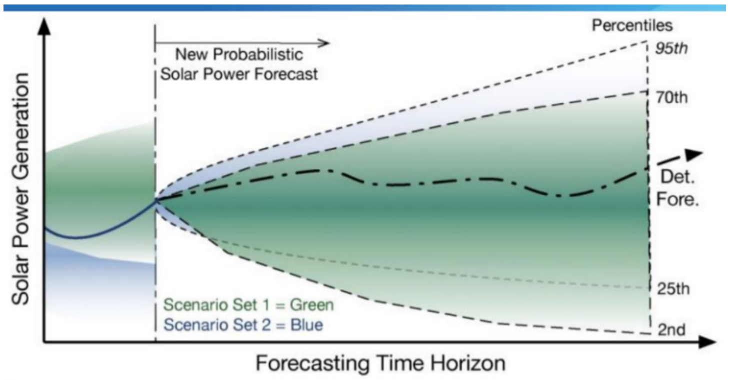
VRE Power Uncertainty Forecasting estimates the marginal distributions for each time step, for example, in the form of intervals, quantiles, or scenarios, which represents information on the uncertainty. Such forecasts can help forecast users in their decision-making processes (e.g., enabling derivation of advanced strategies for market participation).

Figure 8: Example of 2 day-ahead forecasts of wind power for a region in the Northern part of Denmark.



These forecasts depicted in Figure 8 give both the expected power production and the probability distribution of power production for each look-ahead time[20].

Figure 9: Example of day-ahead forecasts of solar power for a region under the coverage area of Energy Reliability Council of Texas

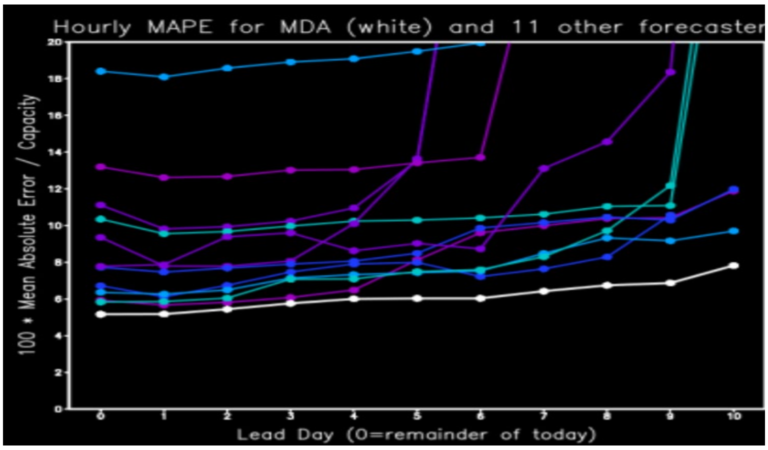


These forecasts depicted in Figure 9 gives the expected power production deterministic forecast, the probability distribution of power production for look-ahead time and the scenarios for the look ahead time.

[19] Argone Use of Wind Power Forecasting in System Operation
[20] Forecasting of Wind Generation, Source: http://pierrepinson.com/docs/pinsonetal_forecasting.pdf

The system of Power forecasting employed by the ERCOT already produce well-calibrated probabilistic solar power forecasts (see below, and currently deliver the 80% exceedance value to ERCOT operationally.

Figure 10: ERCOT Solar Forecast System performance[21]



Today, the most common applications for uncertainty forecasts are[22]:

- Reserve allocation;
- Unit commitment considering VRE power generation uncertainty;
- Trading and dispatch processes using a best guess from uncertainty forecasts;
- Situational awareness and risk assessment.

In general, the main focus of system operators is grid security and supply reliability which they basically intend to guarantee with improved deterministic forecasts or a meta-forecast, typically a weighted average of a number of deterministic forecasts, respectively. The traditional deterministic view of many power system operators translates to preferring single-valued forecasts[23]. These so-called point predictions are easier to appraise and handle at the time of making decisions.

SPATIAL SCALE OF FORECASTING

In the beginning of 2018, USAID Energy Program surveyed providers of VRE forecasting services regarding the applicability of VRE forecasting services to Georgia. At the same time, our project studied the methods and models which are under the disposal of potential vendors of forecasting services.[24]

The study revealed that the vendors, depending on the model employed and available input, might be capable of providing VRE forecast at the Turbine level, Cluster level[25], Farm, portfolio as well as regional and country level. Furthermore, the specification of service provision on their webpage's states that forecasts and its characteristics might be suited to the need of customer.

As an example, below are provided the capabilities on provision of VRE forecasting services of surveyed vendors.

[21] Source: https://www.energy.gov/sites/prod/files/2018/10/f56/Solar-Forecasting-2-Kickoff-NREL-Hodge.pdf
[22] M. A. Matos and R. Bessa, "Setting the operating reserve using probabilistic wind power forecasts," IEEE Transactions on Power Systems, vol. 26, no. 2, pp. 594–603, May 2011
[23] Wind Energy: Forecasting Challenges for Its Operational Management https://arxiv.org/pdf/1312.6471.pdf
[24] VRE forecasting Methods and Models USAID Energy Program
[25] A "cluster" corresponds to a group of wind turbines of similar type in the wind farm and within a reasonable geographic area - AEMO Wind Energy Conversion Model

Table 8: Scale of VRE Forecast Services by Surveyed Vendors

	Turbine	Cluster	Farm	Portfolio	Region/Country or Nodal level
ENFOR[26]		X	X		X
AWS True Power [27]	X	X	X	X	X
DNVGL[28]			X		X
NCAR[29]	X	X	X		X
VAISALA[30]	X	X	X	X	X
Meteologica[31]	X	X	X	X	X

ENFOR – Forecasting and Optimization Solutions for the Energy Sector; DNVGL - Global Quality Assurance and Risk Management Company

Please note: Information was extracted from specifications provided on vendors webpages. The preciseness of information in regard to provision of VRE forecasting services in Georgia would be tested at the second stage of survey. The mentioned survey is proposed as a part of VRE forecasting services procurement preparatory stage.

As indicated in Table 8, vendors are capable to forecast power generation at turbine or Solar PV array level. Also, they are capable to make predictions for each separate asset and a sophisticated post–processing algorithm converts the hub–height wind predictions and site-specific solar irradiation prediction into energy predictions. Then the energy generation values for each turbine, wind or solar facility and connection node are provided to client.

As indicated in Table 8, most of the vendors are capable to provide prediction of power generation on VRE plant even at the turbine or Solar PV array level (see below Figure 11 and 12.)

Figure 11: Photovoltaic Panels Array[32]

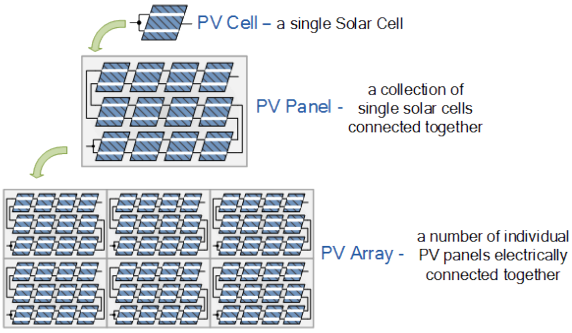
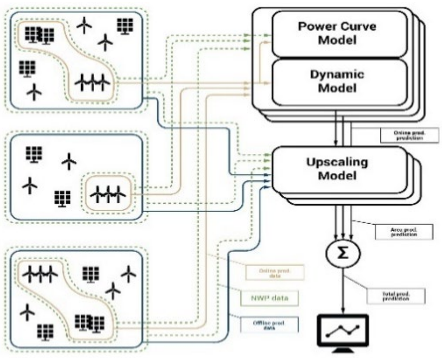


Figure 12: Mixture of plants with geographical information to create portfolio[33]



For instance, in case of NCAR, the wind predictions are made for each wind turbine and a sophisticated post–processing algorithm converts the hub–height wind predictions into energy

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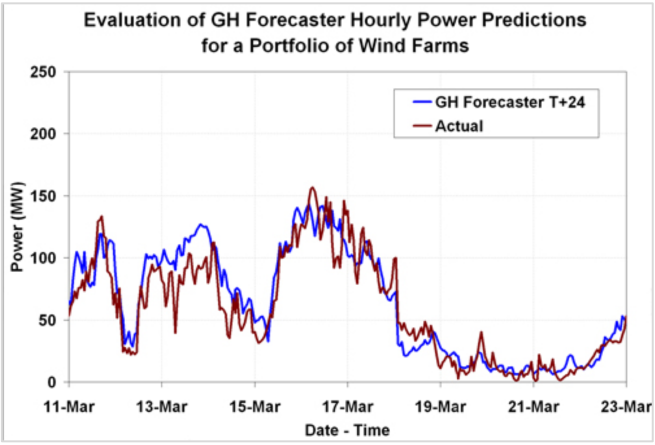
[26] https://enfor.dk/services/windfor/example-configuration-2/
[27] https://aws-dewi.ul.com/solutions/forecasting-grid-integration/curtailment-and-revenue/
[28] https://www.all-energy.co.uk/__novadocuments/393648?v=636420367963070000
[29] https://ral.ucar.edu/solutions/products/empirical-wind-energy-conversion-algorithm
[30] https://www.vaisala.com/sites/default/files/documents/WEA-ERG-AMER-Regional-Forecasting-Mini-Insert-B211711EN.pdf and https://www.vaisala.com/en/products/data-subscriptions-and-reports/energy-forecasting/windforecasting
[31] http://www.meteologica.com/services.html
[32] Source: http://www.alternative-energy-tutorials.com/solar-power/pv-array.html
[33] Source: https://enfor.dk/services/solarfor/

predictions. The energy generation values for each turbine, wind facility and connection node are provided to Xcel Energy[34].

Neither the [35] licensing rules for electricity generation, nor the law of Georgia on Electricity and Natural gas restrict the existence of several licenses for electricity production or several VRE plants under the ownership of the one company. In case of several wind farms comprising the energy production portfolio of company, the so called “Smoothing’’ effect could be achieved which at some extent softens the variability of VRE generation decreasing the imbalances caused by the low uncertainty in prediction. Due to the wide regional distribution of wind plants, short-term and local wind fluctuations are not correlated and therefore largely balance each other out. As a result, the maximum amplitudes of wind power fluctuations experienced in the power system are reduced.

Figure 13: Time Series of Power Forecast for a Portfolio of Seven wind farms at T+24h[36]



Moreover, if portfolio considers several wind farms scattered through the region or country the uncertainty of the wind power forecast might be reduced as well, as depicted in Figure 13.

However, one of the responsibilities of SO is Congestion Management (CM). The aim of the transmission network congestion management is to ensure the electricity system reliability and security and at the same time satisfaction of customers’ demand as far as possible A method classically used by SOs is to manage congestion in day-ahead planning by curtailment or disconnection of generation.

In case the system operator receives the wind power forecast for entire state or area as one entity, the system operator can see one overall wind power forecast value. Under this mechanism, system operator does not perform the wind power forecast for individual wind farms. It would be difficult to anticipate transmission system congestion if only the aggregate forecast is available for entire region country and even for portfolio. For CM, at list the forecast at the plant level is required.

TIME HORIZON AND TIME STAMP OF FORECASTING

Wind power cannot be dispatched so the production levels need to be forecasted for electricity market trading which in most of the cases considers the day ahead and intraday markets. Lower prediction errors mean lower regulation balancing costs, since relatively less energy needs to go through balance settlement.

To determine the appropriate time horizon in case of Georgia, it is assumed that Short Term VRE forecasts are used mainly in electricity markets and Nord Pool electricity platform is in operation as its proposed by GSE[37].

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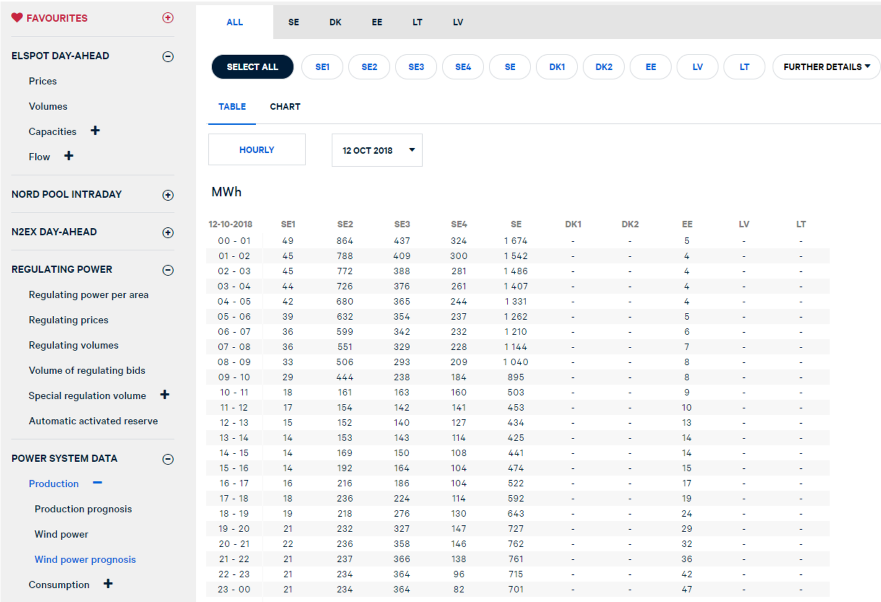
[34] Source: https://ral.ucar.edu/solutions/products/empirical-wind-energy-conversion-algorithm
[35] GNERC resolution №3 1999 on licensing rules
[36] Wind Energy the Facts Portfolio Effect https://www.wind-energy-the-facts.org/portfolio-effects.html
[37] Regular Working Session for Preparation of Power Markets Was Held in Munich http://www.gse.com.ge/communication/news/2018/Regular-Working-Session-for-Preparation-of-Power-Markets-Was-Held-in-Munich

Bids to the Day Ahead (DA) electricity market on Nord Pool trading platform are based on the best view of participant's power production in the near future. In Nord Pool trading platform 12:00 Central European Time (CET) is the deadline for submitting bids for power which will be delivered the following day. Hourly prices are typically announced to the market at 12:42 CET or later. Once the market prices are calculated, trades are settled. From 00:00 CET the next day, power contracts are physically delivered (meaning that the power is provided to the buyer) hour for hour according to the contracts agreed. Therefore, there is a 12-hour gap from the closure of Elspot to the first delivery hour.

Furthermore, on Intraday (ID) market at 14:00 CET, capacities available for Nord Pool's[38] intraday trading are published. This is a continuous market, and trading takes place every day around the clock until one hour before delivery. Prices are set based on a first-come, first-served principle, where best prices come first – highest buy price and lowest sell price. Bids for the day ahead market must include volume and price information, and the bids are set for each delivery hour separately.

Figure 14: Prediction of Wind Power Generation in MWh for Nord Pool Areas[39]



12-10-2018	SE1	SE2	SE3	SE4	SE	DK1	DK2	EE	LV	LT
00 - 01	49	864	437	324	1 674	-	-	5	-	-
01 - 02	45	788	409	300	1 542	-	-	4	-	-
02 - 03	45	772	388	281	1 486	-	-	4	-	-
03 - 04	44	726	376	261	1 407	-	-	4	-	-
04 - 05	42	680	365	244	1 331	-	-	4	-	-
05 - 06	39	632	354	237	1 262	-	-	5	-	-
06 - 07	36	599	342	232	1 210	-	-	6	-	-
07 - 08	36	551	329	228	1 144	-	-	7	-	-
08 - 09	33	506	293	209	1 040	-	-	8	-	-
09 - 10	29	444	238	184	895	-	-	8	-	-
10 - 11	18	161	163	160	503	-	-	9	-	-
11 - 12	17	154	142	141	453	-	-	10	-	-
12 - 13	15	152	140	127	434	-	-	13	-	-
13 - 14	14	153	143	114	425	-	-	14	-	-
14 - 15	14	169	150	108	441	-	-	14	-	-
15 - 16	14	192	164	104	474	-	-	15	-	-
16 - 17	16	216	186	104	522	-	-	17	-	-
17 - 18	18	236	224	114	592	-	-	19	-	-
18 - 19	19	218	276	130	643	-	-	24	-	-
19 - 20	21	232	327	147	727	-	-	29	-	-
20 - 21	22	236	358	146	762	-	-	32	-	-
21 - 22	21	237	366	138	761	-	-	36	-	-
22 - 23	21	234	364	96	715	-	-	42	-	-
23 - 00	21	234	364	82	701	-	-	47	-	-

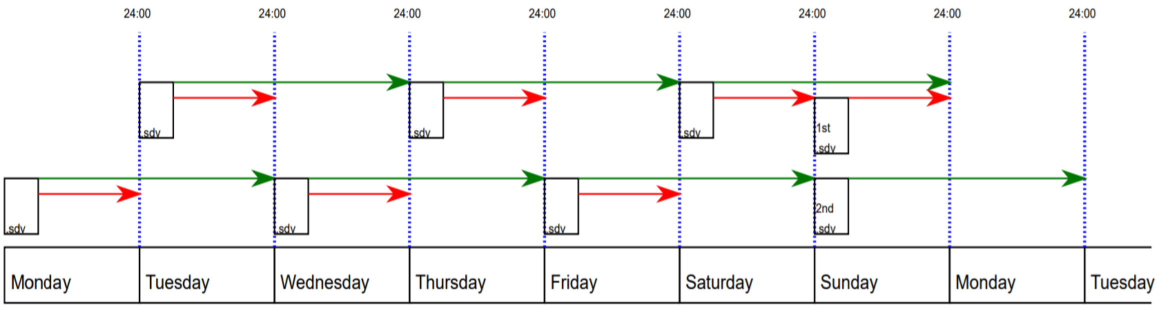
As depicted-in Figure 14 Wind power forecast data for the North European power system (Norway, Sweden, Denmark, Finland, Estonia, Latvia and Lithuania) are free and available on the Nord Pool spot web-page. Thus, a forecast tool is needed with a forecast capability at least 36 hours ahead, with at least an hourly time resolution and hourly update.

For instance, aggregated forecasts from the wind power plants in Sweden are send to Nord pool spot by the Swedish TSO Svenska kraftnät in Semicolon Divided Values (sdv) file.

Updates on the forecasted production for 24 delivery hours are done every five minutes if any changes are anticipated. Range of update includes forecasts for the day that the file is generated and for the next day, e.g. in the updates made on Mondays two types of forecasts are stored (see figure Fig 15). First intra-day forecast for Monday (red arrow) and day-ahead for Tuesday (green arrow). Similarly, on Tuesday intra-day forecasts for Tuesday are available and day-ahead for Wednesday etc. It is worth noticing, that on Sundays, update consists of two files. First with the intra-day forecasts for Sunday and second the day-ahead forecasts for Monday. Every time the update is sent, the forecasted values are overwritten without preservation of old files. For this reason, forecasts on the Nord Pool spot web-page contain values from the most recent update.

[38] https://www.nordpoolspot.com/Market-data1/Power-system-data/Production1/Wind-Power-Prognosis/ALL/Hourly/?dd=EE&view=table
[39] Wind Prognosis for Nord Pool Zones https://www.nordpoolspot.com/Market-data1/Power-system-data/Production1/Wind-Power-Prognosis/ALL/Hourly/?view=table

Figure 15: Conceptual Scheme of Sweden Wind farm forecasting delivery to Nord Pool[40]



**Red arrows represent forecast for the day that file was downloaded and green -forecast for the next day*

It might be assumed that one reason the forecast of the Wind power is indicated as the separate line item on Nord Poll web page, is that it is a priority dispatch[41] utilized in regard to Wind power in countries participating in Nord Pool. Priority Dispatch has been very important for the development of the wind industry. Respectively from the power system operator point of view, VRE power forecast errors will impact the system net imbalances when the share of VRE increases, and more accurate forecasts mean less regulating capacity will be activated from the real time Regulating Power Market.

In case of Georgia, if the bids at DA market is submitted at 12:00 PM, then at least 36-hour forecast must be available for the bidder, and for the purpose of participating in ID market it should be updated hourly.

Above, the time horizon and granularity of short term VRE forecasting is described mainly from a VRE power producer point of view. From the power system operator viewpoint, to ensure the system reliability and stability, also to perform congestion management, considering the existing practice of other SOs, the granularity of VRE forecasting should be no less than dispatch interval the transmission network is operated for.

For instance, under the disposal of AEMO[42] there is ASEFS and AWEFS.

ASEFS is designed to produce solar generation forecasts for large solar power stations and small-scale distributed PV systems, covering forecasting timeframes from 5 minutes to 2 years. ASEFS produces solar generation forecasts for all National Energy Market (NEM) forecasting timeframes as follows:

- Dispatch (five minutes ahead);
- 5 Minute Pre-dispatch (five minute resolution, one hour ahead);
- Pre-dispatch (30 minute resolution, up to 40 hours ahead);
- ST PASA[43] (30 minute resolution, seven days ahead);
- MT PASA[44] (daily resolution, two years ahead);

AWEFS was established in response to the growth in intermittent generation in the NEM, and the increasing impact this growth was having on NEM forecasting processes. The system aims to provide better forecasts that will drive improved efficiency of overall NEM dispatch and pricing and permit better network stability and security management.

The system will produce wind generation forecasts for all NEM wind farms (>= 30 MW) for all NEM forecasting timeframes as follows:

- Dispatch (five minutes ahead);
- 5 Minute Pre dispatch (five minute resolution, one hour ahead);
- Pre-dispatch (30 minute resolution, up to 40 hours ahead);

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[40] Analysis of Swedish Wind Power Forecast Quality over Forecast Horizon and Power System Operation Implications Degree Project in Electrical Engineering, Second Cycle, 30 Credits Stockholm, Sweden 2017

[41] Under the ''Priority Dispatch'' Transmission System Operators must accommodate all wind energy produced, which thus has the priority over energy produced by conventional plants; in the "no priority dispatch" policy, TSOs can decide not to inject all potential wind power in the grid in order to limit congestion problems Source: https://inis.iaea.org/search/search.aspx?orig_q=RN:46025521

[42] Australian Energy Market Operator Wind and Solar Power Forecasting https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Solar-and-wind-energy-forecasting

[43] Short Term Projected Assessment of System Adequacy (ST PASA)

[44] Medium Term Projected Assessment of System Adequacy (MT PASA)

- ST PASA (30 minute resolution, seven days ahead);
- MT PASA (daily resolution, two years ahead.

The dispatch of semi-scheduled wind and solar farms depend on the output of AWEFS and ASEFS. The generation forecasts produced by AWEFS and ASEFS use a combination of statistical methods and Numerical Weather Prediction-based models, covering forecasting timeframes from 5 minutes (Dispatch) to 2 years (MT PASA). These models uses the following inputs:

- Real time SCADA measurements from the power station;
- Numerical Weather Prediction data from multiple weather data providers;
- Standing data from the solar power station as defined in the Energy Conversion Model;
- Additional information provided by the power station, including inverters/ turbines under maintenance and upper MW limit on the facility.

In the dispatch timeframe (5 minute ahead), AWEFS and ASEFS produce Unconstrained Intermittent Generation Forecasts (UIGF), which are used to produce the dispatch targets for semi-scheduled generators. Dispatch targets for all scheduled generating units, semi-scheduled generating units, scheduled network services and scheduled loads are derived by National Electricity Market Dispatch Engine (NEMDE) after co-optimizing the energy market with the Frequency Control Ancillary Services (FCAS) market[45]. Where possible, dispatch instructions will be issued electronically via the Automatic Generation Control (AGC) system or the AEMO Electricity Market Management System (EMMS) interfaces.

NEMDE uses price bids, available capacity information and constraint equations (represent limitations on network) to determine dispatch levels for generators. Conventional generators submit both price bids and available capacity information to NEMDE. However, wind generators only submit price bid information after available capacity is determined by AWEFS.

For all semi-scheduled generators, the UIGF forecasts are used in place of the generating unit availability. The NEMDE will then dispatch the semi scheduled generator in a similar manner to a normal scheduled generating unit, based on the bid information provided and the UIGF provided from AWEFS / ASEFS, with the only difference being that a semi-scheduled cap flag will also be provided.

This flag may be set based on constraint limitations or bidding reasons. If this cap is set to false then the intermittent generator is not required to follow dispatch targets. If the flag is set to true, then the intermittent generator is required to follow the dispatch target however, output must not exceed the dispatch target value and shall be monitored by the noncompliance monitor.

There are certain instances when AEMO turns off the UIGF forecasts that are generated by AWEFS. These include:

- Early stages of commissioning for a new wind generator: For newly commissioning wind generators, the forecasting modules in the AWEFS system require tuning and development, for which enough active power generation (MW) and wind speed data needs to be accumulated. To allow enough time to build enough history, AEMO has the functionality to turn off the UIGF forecasts generated by the AWEFS system during this period. Once the forecasts are turned off, they are replaced by the active power generation (MW) SCADA from the wind generator, in NEMDE, to generate the dispatch level for the next Dispatch Interval;
- The UIGF forecasts from AWEFS are turned on, prior to the wind generator's date of completion for commissioning, and at a stage when AEMO has enough confidence in the quality of the forecasts generated by the AWEFS system;
- Periods when forecasts are seen to be unreliable: If the forecasts generated by the AWEFS system is seen to be unreliable or interfering with market outcomes, AEMO will turn off the UIGF forecasts generated by AWEFS. Unreliable forecasts can be generated due to incorrect SCADA inputs from the wind generator or inaccurate weather forecasts.

From above provided example the granularity of forecast for both wind and solar considers:

- 5-minute for hour ahead;
- 30 minutes for day ahead;

[45] Report Australian Market Operator Dispatch

- 30 minutes for week ahead;
- 24 hours for two years ahead.

The granularity of forecast (time resolution) might be less at list in case when VRE forecasting model, as an input, utilizes the predicted meteorological parameters derived from Numerical Weather Prediction models. The input from NWP requires for the forecast time horizon more than 5-6 hours.

Nevertheless, in case of forecasting wind speed in Test Mode organized by the USAID Energy Program, the wind speed forecast time series delivered by the NEA considers 1 (one) minute granularity for wind speed as depicted in Figure 16. If the wind speed is available, then with the utilization of the wind turbine power curve it might be converted to the power. Thus, the day ahead forecast of power produced at wind turbine might be delivered in 1 (one) minute granularity as well.

Figure 16: NEA Wind Speed Forecast in Test Mode 9-10 October

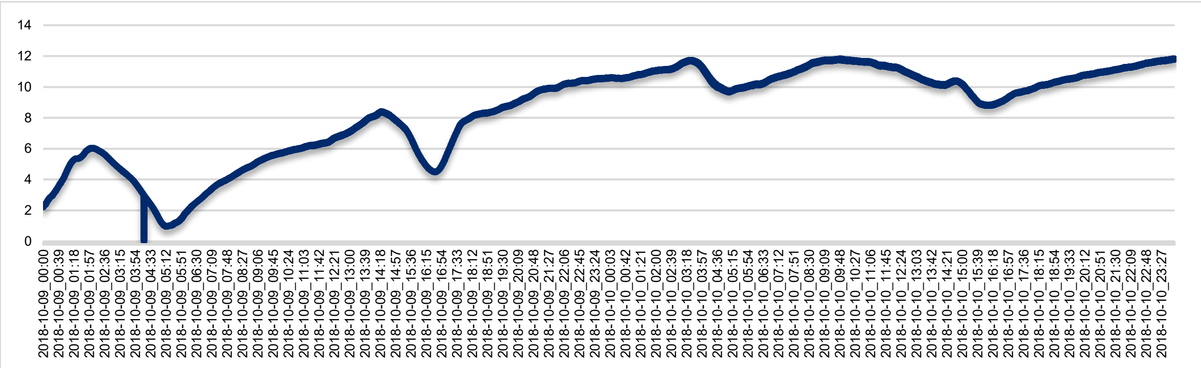
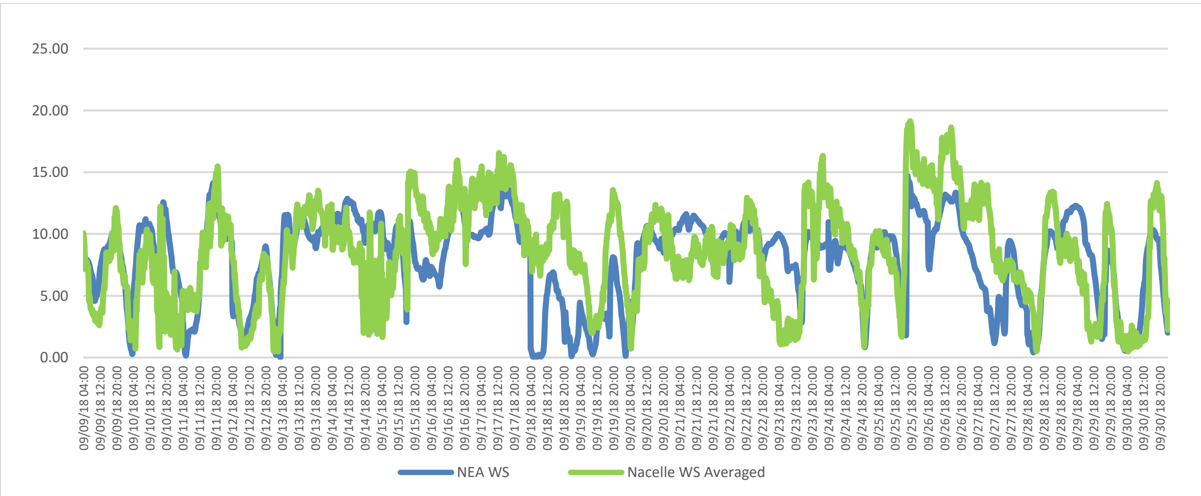


Figure 17: Comparison of NEA Wind Speed Forecast and Wind Speed Measured at Nacelles of QWF 9-30 September



CONTROL MEASUREMENTS

The real time meteorological data, measured either at nacelles of wind turbine or on meteorological tower in a very proximity to wind turbines, represents the dataset which has significant impact on an accuracy of forecast delivered by the supplier of forecasting services.

Thus, verifying the availability and reliability of measurements within a specified measurement range is central to the control application because range determines the prediction time for the turbine and uncertainty of prediction caused by the non-proper measurement of meteorological parameters.

For validation of measurements performed on nacelles of wind turbine or on met mast it's not cost effective to erect met mast at each required location with the equipment which is calibrated, modern and provides reliable input.

In such cases there is a need of mobile equipment which should perform validation of measurement, could be located at any convenient place and can be operated remotely with the autonomous energy source like solar panels and batteries.

In case of Met Mast for wind speed and direction measurement wind profiling mobile equipment might be utilized to:[46]

- Verify neglected or old met masts with industry reference profiler;
- Identify flow distortion at the anemometer caused by the mast itself;
- Confirm any deterioration in anemometry calibration that can occur over time;
- Discover misalignment of anemometry with respect to the mast;
- Detect anemometry failings during freezing temperatures or other extreme wind events;
- Validate wind shear model used for wind speeds above met mast while on site.

Under the wind profiling mobile equipment considered Light Detection and Ranging (LiDAR), or 'laser radar' and Sound Detection and Ranging (SoDAR), or 'acoustic radar'. Those are mobile devices and with both technologies possible to measure wind speed direction, profiling the wind and resource assessment.

This would be beneficial for Hosting Agency GSE, VRE Forecasting supplier and wind project developer. Overall, the existence of such kind equipment would increase the reliability of meteorological data input to the forecasting model and contribute to the forecast accuracy. The latest, in turn could be perceived as a significant factor on the way to enabling environment for the integration of wind power to network and rising the level of VRE penetration to the network.

[46] Turning the Tides on Wind Measurements: The Use of Lidar to Verify the Performance of a Meteorological Mast

MAIN FINDINGS – CONCEPTUAL DESIGN OF FORECASTING SYSTEM

TYPE OF TECHNOLOGY

Different forecasting models should be utilized for the forecast of wind and solar power. TYNDP set emphasis on the existence of wind power forecasting system.

Irradiation measurement is performed at two locations and there is no utility scale operational solar power plant in Georgia.

Wind farm Static and dynamic data might be supplied to the supplier of forecasting service. There is QWF which is operational and static and dynamic data is available from the plant.

Infinite Energy and Caucasus Wind Company are still performing the remote measurements of meteorological parameters such as wind speed, direction, temperature and barometric pressure.

STRUCTURE OF SYSTEM

Centralized VRE forecasting is widely considered as a best-practice approach for economic dispatch. Administered by the system operator, centralized forecasts provide system-wide forecasts for all VRE generators within a balancing area. The implementation of centralized forecasting system through the utilization of third-party vendors for forecasting has been practiced in the US, Canada, Europe with the penetration level of wind 40%.

Centralized systems[47]

- Owned or contracted by the grid operator;
- Lower total cost for multiple plants;
- Easier to set and enforce standards, maintain consistent quality;
- Potential to aggregate data from different plants and improve forecast quality;
- Can make shared investments, e.g., targeted observational network;
- May not allow enough competition.

Decentralized systems

- Forecasts supplied individually by wind projects;
- No external funding needed;
- therefore, often the easiest choice;
- Standards can be set, but enforcement may be difficult;
- May lead to greater competition among forecast providers.

Centralized system has some advantages over the decentralized system

- To recover cost of Centralized VRE forecasting, cost (fully or partially) might be charged to VRE project Operators or absorbed by the SO;
- The VRE forecasting (models) might be employed by both SO and VRE plant operators as well.

Centralized VRE forecasting system would benefit from ensemble forecasting if under the centralized forecasting approach VRE project operators would be obliged to perform and submit forecasts of their plant production with the acceptable level of uncertainty and in a time horizon and granularity similar as it would be requested by the SO.

VRE FORECASTING APPROACH

The development of VRE forecasting system with the support of the third party and / or mobilization of resources is time consuming and requires significant financial resources.

In case of forecasting software procurement, meteorological input which derives from the NWP remains challenging. The maintenance of software would remain with the supplier and in case of

[47] Source: http://web.mit.edu/windenergy/windweek/Presentations/Brower_MIT_Wind_Workshop.pdf

setting up the NWP input together with the quality control, the only difference which remains between the procurement of the software and services is non-disclosure of real time power generation data.

Forecasting Services require less time to launch and less financial resources compared to the above listed options. The payment for the services would be dependent to the performance of the supplier and requires signing of NDA and delivery of the real time dynamic data to the vendor of services.

HOSTING AGENCY

Data required for the proper functioning of the Wind Power Forecasting system is under the disposal of two organizations. GSE is authorized to obtain access to dynamic and static data generated at the wind farms, whilst the meteorological parameter predictions such as forecast of wind speed and direction derived from NWP is under the disposal of NEA.

For the process of VRE forecasting system development, the data input availability and/or authority/possibility to access or request required data from the respective sources as well as authority/possibility to utilize forecasts in a most effective way would be very important.

Those two criteria could be applied when determining the VRE Forecasting Centralized System Hosting Agency.

TYPE OF FORECASTS

In VRE power production forecasts nowadays practiced power production point prediction and prediction with uncertainty forecasting e.i. Deterministic and Probabilistic Forecasts.

Today, the most common applications for uncertainty forecasts are[48]:

- Reserve allocation;
- Unit commitment considering VRE power generation uncertainty;
- Trading and dispatch processes using a best guess from uncertainty forecasts;
- Situational awareness and risk assessment.

Many power system operators grant preference to deterministic - single-valued forecasts[49]. These so-called point predictions are easier to appraise and handle at the time of making decisions.

SPATIAL SCALE OF FORECASTING

Vendors of forecasting services surveyed by USAID Energy Program are capable to forecast power generation at turbine or Solar PV array level. Also, they are capable to make predictions for each separate asset. The approach of vendors is to suit to the need of client which means that if needed the upscaled to portfolio, regional, state level forecasts could be provided.

In case the system operator receives the wind power forecast for the entire state or area as one entity, the system operator can see one overall wind power forecast value which is challenging for the congestion management.

TIME HORIZON AND TIME STAMP OF FORECASTING

For the **Producer** of Electricity to trade on a platform like the Nord Pool it's a must to have a day ahead and hour ahead prediction of power generation.

In case of Georgia, if the bids at DA market are submitted at 12:00 PM then at least 36-hour forecast must be available for the bidder, and for the purpose to participate in ID market it should either be supplemented by 2 hours ahead forecast or DA forecast should be updated hourly.

AWEFS producing wind generation forecasts for all NEM wind farms (>= 30 MW) for all NEM forecasting timeframes as follows:

- Dispatch (five minutes ahead);
- 5 Minute Pre-dispatch (five minutes resolution, one hour ahead);

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[48] M. A. Matos and R. Bessa, "Setting the operating reserve using probabilistic wind power forecasts," IEEE Transactions on Power Systems, vol. 26, no. 2, pp. 594–603, May 2011

[49] Wind Energy: Forecasting Challenges for Its Operational Management https://arxiv.org/pdf/1312.6471.pdf

- Pre-dispatch (30 minutes resolution, up to 40 hours ahead);
- ST PASA (30 minutes resolution, seven days ahead);
- MT PASA (daily resolution, two years ahead.

For a very short term forecast the granularity coincides with the dispatch intervals. With the consideration of on minute time stamp available in the wind speed forecast delivered by the NEA in test mode the forecast granularity might be reduced to one minute.

Also, it might be the case that GSE in the nearest future utilize 15 minute intervals for ancillary services.

CONTROL MEASUREMENTS

Verifying the availability and reliability of measurements within a specified measurement range is central to the control application because range determines the prediction time for the turbine and uncertainty of prediction caused by the non-proper measurement of meteorological parameters.

For the validation of measurements performed on nacelles of wind turbine or on met mast, it the effective way is to employ wind profiling mobile equipment such as LiDAR or SoDAR.

ANALYSIS AND RECOMMENDATIONS ON OPTIONS FOR CONCEPTUAL DESIGN

	Analysis	Recommended Option
Type of Technology	TYNDP requirement in Wind power forecast and availability of data input for wind forecasting are the factors supporting the recommendation to start with wind power forecasting.	**Start with Wind Power Forecasting**
Structure of Forecast	Centralized system of forecasting has some advantages over the decentralized system: - Owned or contracted by the grid operator; - Lower total cost for multiple plants (To recover cost of Centralized VRE forecasting, cost (fully or partially) might be charged to VRE project Operators or absorbed by the SO); - Easier to set and enforce standards, maintain consistent quality; - Potential to aggregate data from different plants and improve forecast quality; - Can make shared investments, e.g., targeted observational network. Under the centralized forecasting approach VRE project operators would be obliged to perform and submit forecasts of their plant production with the acceptable level of uncertainty and in a time horizon and granularity similar to what would be requested by the SO.	**Apply to Wind Power Centralized Forecasting System approach** **Before the VRE penetration level doesn't exceeds 3-5% VRE centralized forecasting cost would be absorbed by SO or before the uncertainty of predictions becomes acceptable for both VRE Plant Operators and SO cost would be absorbed by SO.**
Wind Power Forecasting Approach	Forecasting Services require less time for launch and less financial and human resources compared to the in-house capacity development or utilization of software and setting up the NWP by the hosting agency. The payment for the services would be dependent on the performance of the supplier which is good approach to mitigate risk in case of supplier of forecasting services underperforms. Requires signing NDA and delivery of the real time dynamic data to the vendor of services.	**Centralized system implemented through the provision of VRE forecasting services by the third-party vendors**
Hosting Agency	According to data input availability and forecasting utilization criteria GSE Dispatch licensee is the agency proposed as a hosting agency. It is almost impossible to find the cases where the environmental or meteorological agency are hosting the centralized system of wind power forecasting. NEA would ensure the supply of meteorological predictions to the forecasting system which derives from NWP models under the disposal of NEA.	**Hosting agency GSE – Dispatch licensee** **NEA provides alternative input and local observational data to the Wind Power Forecasting system**
Type of Forecasts	In general, the focus of system operators is grid security and supply reliability which they basically intend to guarantee with improved deterministic forecasts or a meta-forecast, typically a weighted average of a number of deterministic forecasts, respectively. Many power system operators grant preference to deterministic- single-valued forecasts[50]. These so-called point predictions are easier to appraise and handle at the time of making decisions.	**Deterministic Forecast**

[50] Wind Energy: Forecasting Challenges for Its Operational Management https://arxiv.org/pdf/1312.6471.pdf

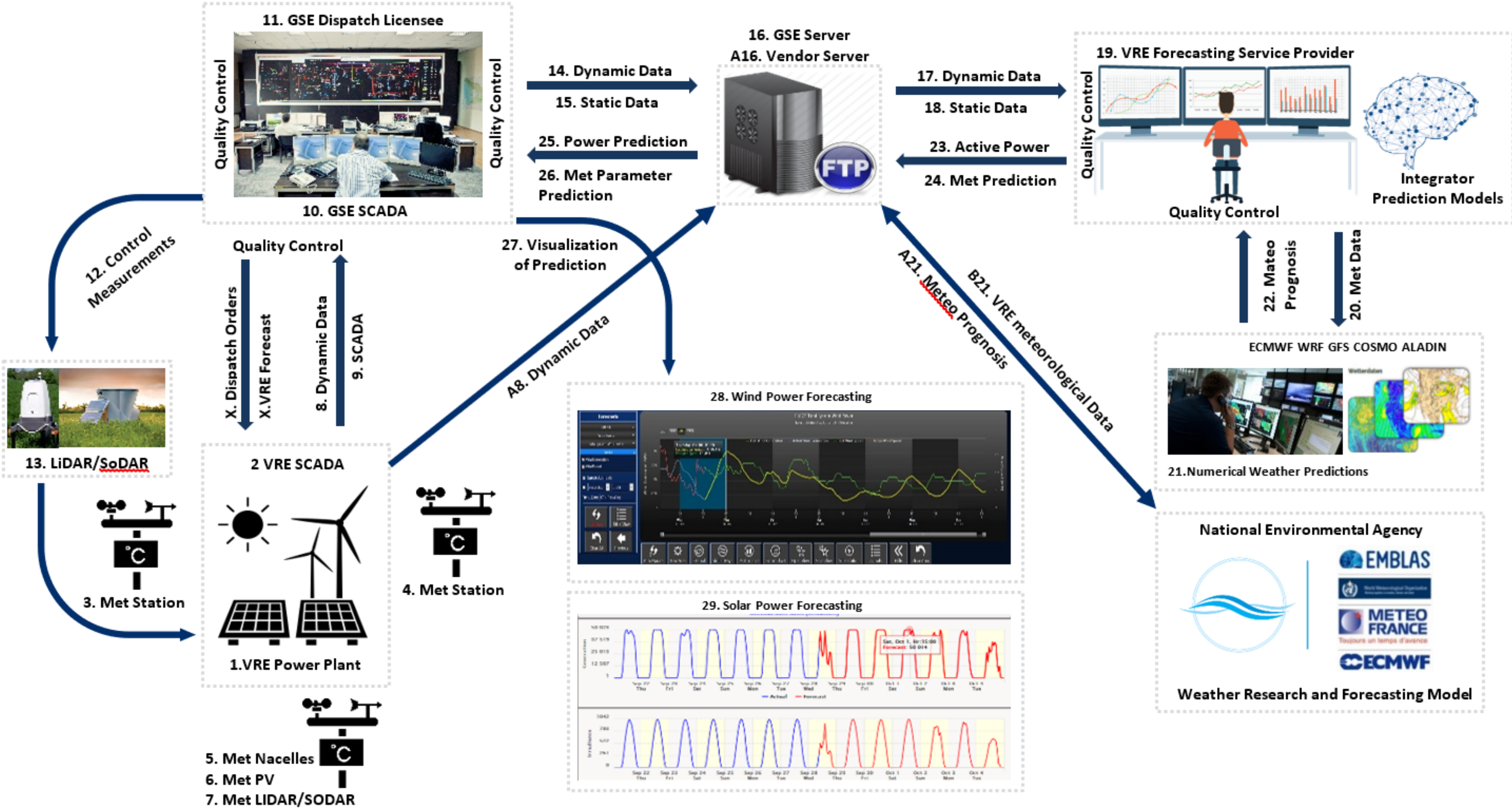
	Analysis	Recommended Option
Spatial Scale of Forecasting	Surveyed suppliers are capable to deliver wind power forecast at wind turbine, wind farm or connection node, regional and state wide. In case the system operator receives the wind power forecast for the entire state or area as one entity and the system operator can see one overall wind power forecast value which is challenging for the congestion management.	**At list wind farm level**
Time Horizon and Time stamp of Forecasting	In case of Georgia, if the bids at DA market are submitted at 12:00 AM on ID market at 14:00 AM then at least 36-hour forecast must be available for the bidder, and for the purpose to participate on an ID market it should be either updated hourly or supplemented with the 2 hours ahead forecast. AWEFS producing wind generation forecasts for all NEM wind farms (>= 30 MW) for all NEM forecasting timeframes as follows: - Dispatch (five minutes ahead); - 5 Minute Pre-dispatch (five minute resolution, one hour ahead); - Pre-dispatch (30 minutes resolution, up to 40 hours ahead); - ST PASA (30 minutes resolution, seven days ahead); - MT PASA (daily resolution, two years ahead. For a very short term forecast the granularity coincides with the dispatch intervals. With the consideration of on minute time stamp available in the wind speed forecast, delivered by the NEA in test mode, the forecast granularity might be reduced to one minute.	**The time horizon and time scale at initial stage of VRE forecasting implementation would be set at:** - **least 36 hours - for day ahead forecast with the granularity of 15 minutes** - **2 hours ahead with the granularity of 5 minute** - **With the consideration forecast granularity forecast would be delivered in MW of active power**[51] - **Day ahead and hour ahead forecast would be produced for both power and meteorological parameters and updated hourly** - **If VRE forecasting is requested by the hosting agency, the availability on per minute granularity should be checked with the suppliers of VRE forecasting and then it might be set to 1 min**
Control Measurements	For the validation of measurements, performed on nacelles of wind turbine or on met mast, the effective way is to employ wind profiling mobile equipment such as LiDAR or SoDAR. Local observational meteorological data from nacelle. Meteorological towers and meteorological stations are proposed as necessary input for increasing the accuracy of forecast. Control Measurement is proposed for the assessment of meteorological data input reliability which in turn will improve the forecast accuracy. Initial findings set preference on utilization of LiDAR. Using a flow model, such as Computational Fluid Dynamics (CFD), it is possible to compute set of factors that enable the conversion of remote sensing data measurements to ones comparable with those from the point measurement sampled by conventional anemometry.	**Perform Control Measurement by LiDAR or SoDAR** **Further research requires to set preference on the equipment proposed to be utilized for control measurement** **Autonomous source of power supply and trailer are required for the mobility of equipment** **After the procurement of equipment to make remote sensing data comparable to the conventional anemometry remote sensing data should be processed in the software capable to handle CFD**

[51] Active Power for the purposes of this report has the same meaning as Electric Power. Electrical power is a measure of the instantaneous rate at which electrical energy is consumed, generated or transmitted. In large electric power systems, it is measured in megawatts (MW) or 1,000,000 watts.

SCHEMATICS OF VRE FORECASTING CONCEPT DESIGN

With the consideration of above provided analysis and recommendation the schematics provided below aims to summarize and introduce for the discussion with GSE -proposed as hosting agency another stakeholder concept design of Wind Power Forecasting.

Figure 18: VRE Forecasting Concept Design



ROLES AND RESPONSIBILITIES UNDER THE CONCEPTUAL DESIGN

Data Requirement	VRE Operators		VRE Developers
Data Required for Forecasting	2 VRE SCADA (Processed and Converted) 3 Meteorological Tower – VRE Plant 4 Meteorological Station – VRE Plant 5 Met Nacelles – VRE Plant 6 Met PV -VRE Plant 7 LiDAR / SoDAR – VRE plant		3 Meteorological Tower 4 Meteorological Station 7 LiDAR /SoDAR – VRE plant
Data Delivery	8 Dynamic Data – VRE Plant 9 SCADA Forecasting - VRE Plant (Processed and Converted)		8 Dynamic Data – VRE Plant 8 Dynamic Data – VRE Limited by the meteorological data only
Data Exchange	**VRE**	**GSE**	**VENDOR**
Data delivery to Vendor	A8 Dynamic Data VRE Plant A8 Dynamic Data VRE project Limited by the meteorological data only	14 Dynamic Data 15 Static Data	17 Dynamic Data 18 Static Data
Data Exchange Platform		16 GSE Server	A16 Vendor Server
NWP Meteorological Forecast	**VENDOR**		**NEA**
NWP Prediction	21 Numerical Weather Prediction 22 Meteo Prognosis- Vendor A21 Meteorological Prognosis		A21 Meteorological Prognosis
NWP - Local observation data assimilation	20 Met Data-Vendor		B22 VRE Meteorological Data
Forecast of Wind parameters and Wind Power	**VENDOR**		**NEA**
Upload of forecast to File Transfer Protocol (FTP) server	23 Power Prediction-Vendor 24 Meteorological Parameters Prediction – Vendor		A21 Meteorological Prognosis
Control Measurements	**GSE**		**NEA**
Control measurement procedures	11 GSE Dispatch Licensee 12 Control Measurement -GSE		
Control Measurement Equipment (Wind)	13 LiDAR / SoDAR GSE		
Utilization and Dissemination of Forecast	**GSE**		**NEA**
Download forecast from FTP	25 Power Prediction -GSE 26 Prediction of Meteorological Parameters - GSE		
Visualization	27 Visualization of Predictions		

EXPLANATORY OF THE SCHEMATICS OF CONCEPTUAL DESIGN

#	Component	Description	Note
1	VRE Power Plant	Wind Power Plant with one connection point to the Transmission Network	
2	VRE SCADA	For now, day's most of the utility scale VRE plant are equipped with the	Standard 61400 -25 for Wind Turbines sets requirement for the

#	Component	Description	Note
		SCADA systems	management and communication equipment. SCADA dynamic data is the main input of forecasting system. Georgia Network Code also requires the existence of III Level SCADA at Generation Facility
3	Meteorological Tower – VRE Plant	A measurement tower or met mast usually with the height of 80m and more is a free-standing tower, equipped with meteorological instruments for the meteorological parameter measurement such as Anemometer, thermometers, barometer etc.	In some cases, the existence of met mast is a must or it might be substituted with the LiDAR or SoDAR. The data derived from measurement utilized as an input of forecasting system
4	Meteorological Station – VRE Plant	Met mast usually with 10 m height with instruments and equipment for measuring atmospheric conditions. The measurements taken include temperature, atmospheric pressure, humidity, wind speed, wind direction, and precipitation amounts	In some case of AEMO CAISO the existence of met station is a must for Utility Scale Solar Power Plants. The data derived from measurement utilized as an input of forecasting system
5	Met Nacelles – VRE Plant	Most of the wind turbines, installed recently, are equipped with the ultrasonic anemometer measuring the wind speed and direction. That meteorological equipment is installed on nacelles of the wind turbines.	Main input for the short-term forecasting and forecasting model performance estimation. AEMO and NCAR preference is Nacelle wind speed and direction for forecasting.
6	Met PV -VRE Plant	Flat surface temperature sensors can be mounted on each solar panel or on selected representative solar panels to provide temperature measurement profiles of the solar panel array. Also, it measures the temperature backwards of the solar panel A flat surface temperature sensor will provide temperature measurement data to an overall monitoring system	Solar panel power output is directly affected by the temperature of the solar panel. The data on temperature allows forecasting model to consider potential power output issues caused by changes in a solar panel's temperature
7	LiDAR / SoDAR – VRE plant or GSE	LiDAR - Light Detection and Ranging, or ‘laser radar’ and SoDAR Sound Detection and Ranging, or ‘acoustic radar’. Those are mobile devices and with both technologies possible to measure wind speed direction, profiling the wind and resource assessment. Both systems require autonomous source of energy supply. In most cases, it is the diesel generator or solar panels and batteries.	AEMO and CAISO allows substitution of meteorological towers with the SoDAR and LiDAR. Depending on the model, both might be in compliance with the International Electric Technical Commission and utilized for resource bankability assessment. The data derived from SoDAR and LiDAR requires processing/modeling in software capable to handle Computational Fluid Dynamics. Using a flow model, such as CFD, it is possible to compute set of factors that enable the conversion of remote sensing data measurements to ones comparable with those from the point measurement sampled by conventional anemometry This process is key for ensuring reduction of uncertainty between the Remote Sensing Devices (RSD) and measurement performed by the conventional anemometry in complex terrains. Those models should be under the disposal of GSE, if it is utilized for the Control Measurement required for the GSE. It might be utilized for the control measurement ordered to GSE But if the LiDAR and SoDAR are proposed as a substitute of met mast, in this case postprocessing of the measurement data in complex terrains should be performed by the VRE plant owner either with in house capacity or with the support of third party vendors.

#	Component	Description		Note
8	Dynamic Data – VRE Plant	- Wind farm active power - Number of wind turbines available for generation data - Number of wind turbines actively generating - Local Limit - Wind speed data - Wind direction data - Temperature data - Wind Farm Control System Set-Point - Pressure or humidity data - Historical data available from this wind farm with regard the items listed above	Global horizontal irradiance Global inclined irradiance Ambient temperature Wind speed Wind direction Relative humidity Barometric pressure Module surface temperature Solar farm control system set-point Local limit Estimated Power Active power generation Reactive power generation Number of inverters available Reduction through soiling Actual tracking slope angle Actual tracking azimuth angle Tracking share of modules not on track Trackers online	In AEMO AWEFS and ASEFS those are main inputs for the forecasting which should be delivered in a real-time format. It is common that Variable Renewable Energy Forecasting accuracy is dependent on an optimal combination of Static Data – mostly the design and actual parameters of Wind or Solar Power Plant and Dynamic Data consistent of measurement of meteorological parameters and power generation which derives from VRE power plant SCADA and SO SCADA after it was processed. The latest does not mean that forecasting model would have the access to the SCADA system of plant or SO. The purpose of VRE Power Plant Dynamic Data delivery in a real time format to the GSE in the context of VRE forecasting implementation considers: - Processing of data in a format convenient for the VRE forecasting service provider; - Dynamic Data quality Control (please see line item of this table on Quality control).
A8	Dynamic Data VRE Plant	Description of Dynamic Data is the same provided inline Item 8 of this table		Alternatively, to the line Item 8, Under this option the Dynamic Data Might be Uploaded Directly to the FTP Server Which might be provided by the GSE or Vendor. Under the Vendor might be considered the Vendor of Forecasting Services as well as Vendor and Hosting Services
9	SCADA Forecasting - VRE Plant	For the purposes of VRE Forecasting Design SCADA forecasting means forecasting of active power on VRE power Plant delivered through the communication channels connecting VRE SCADA to the GSE SCADA. Communication Element of I Level SCADA – a combination of tools/equipment located at units/facilities of Transmission Licensees and users (electricity producer and Distribution Licensee) that ensures in real time: the collection of III Level SCADA and II Level SCADA data and its transmission to I Level SCADA. The delivery of forecasts from the VRE plants makes possible for the system operator to benchmark its own forecast results with the supplied forecasts. For the other benefits of such approach please see paragraph related to the Centralized System of Forecasting.		Wind power forecasting can be applied to save costs when wind farm owners/operators need to schedule wind project maintenance and construction. Wind projects often require that turbines be taken down during the commissioning of new turbines. This can take hours to weeks depending in part on weather. Precipitation, high winds and extreme temperatures need to be avoided for obvious reasons. Without accurate forecasting information, the chances of idling a mobilized work crew and necessary equipment (such as large cranes) increases. The associated costs can exceed $100,000 per day (Lerner and Garvert, 2009). By not taking advantage of the right weather conditions for construction, operations, and maintenance, overall project costs increase as deadlines are not met, plant generation is diminished, and resultant production revenues from Green Tags or Production Tax Credits are

#	Component	Description	Note
			lost. No matter whether the Centralized Forecasting System is in place or not, in any case the operator of VRE plant needs forecast of power generation and meteorological parameters to optimize its generation, react on market signals and properly plant its maintenance works.
10	GSE SCADA – Dispatch and Transmission Licensee	I Level SCADA – a combination of software and technical facilities under the ownership of the Dispatch Licensee that collects, monitors and manages regime parameters of the electricity system. II Level SCADA – a combination of software and technical facilities under the ownership of the Transmission Licensee that collects, monitors and manages regime parameters of a concrete substation and/or transmission network III Level SCADA – a combination of software and technical facilities under the ownership of Distribution Licensee and/or producer that collects, monitors and manages regime parameters of a distribution network and/or concrete units of a producer; Communication Element of I Level SCADA – a combination of tools/equipment located at units/facilities of Transmission Licensees and users (electricity producer and Distribution Licensee) that ensures in real time: a) the collection of III Level SCADA and II Level SCADA data and its transmission to I Level SCADA; b) the management of electricity transmission network, as well as units, where this element is located, as is envisaged in Article 45(8) and Article 45(10), in case of existence of a respective agreement, of the above-mentioned Rules, via III Level SCADA and II Level SCADA (7.10.2016)	I Level SCADA communicates with the II Level (Transmission Licensee) and III LEVEL (Distribution and Generation Licensee) through the communication equipment under the disposal of Dispatch Licensee. Dispatch licensee would receive the data from III level SCADA and if it requires it would be supplemented by the data from II Level SCADA. No direct access to the SCADA would be ensured by the Dispatch licensee and plant operator. Data would be processed and converted to the agreed with the service provider format. It should be ensured that the data requirement prescribed in the Network Rules under the Dynamic Data considers the real time data on meteorological parameters as well.
11	GSE Dispatch Licensee	GSE represented by its Dispatch licensee recommended as a Hosting Agency of VRE forecasting System.	Please See Paragraph Hosting Agency of VRE forecasting System
12	Control Measurement - GSE	Validation of time and measurement certainty range for the meteorological equipment measuring the wind speed and direction For the solar plant such validation might consider the validation of measurement performed on equipment measuring the Irradiance.	For the Short-Term forecasting the meteorological data input in a real time format is a priority for the improving the model performance. Thus, verifying the availability and reliability of measurements within a specified measurement range is central to the control application because range determines the prediction time for the turbine and uncertainty of prediction caused by the non-proper measurement of meteorological parameters For the validation of measurements performed on nacelles of wind turbine or on met mast it is not cost effective to erect at each required location met mast with the equipment which is calibrated, modern and

#	Component	Description		Note
				provides reliable input. In such cases there is a need of mobile equipment which should perform validation of measurement, could be located at any convenient place and capable to be operated remotely with the autonomous energy source like solar panels and batteries. In case of Met Mast for wind speed and direction measurement Lidar might be utilized to:[52] - Verify neglected or old met masts with industry reference lidar; - Identify flow distortion at the anemometer caused by the mast itself; - Confirm any deterioration in anemometry calibration that can occur over time; - Discover misalignment of anemometry with respect to the mast; - Detect anemometry failings during freezing temperatures or other extreme wind events; - Validate wind shear model used for wind speeds above met mast while on site.
13	LiDAR / SoDAR - GSE	Please for the description refer to the line item 7 of this table		GSE mainly would utilize LiDAR / SoDAR for the 12. Control Measurements
14	Dynamic Data	Dynamic Data which passes through the Data Quality Control (DQC)		For the VRE forecasting Purposes the Dynamic Data (meteorological and power generation related data) from VREs should go either through the GSE DQC or DQC of VRE forecasting vendor. The existence of QC requires quality control of data communicated through the SCADA. After processing and conversion, data should be uploaded to FTP server which might be under the disposal of GSE or Vendor. Quality Control (QC) should be in place to detect and fix data uploaded by user or extracted from market web sites. Experienced technical team should continually monitor data quality and the performance of forecast models. If a degradation of accuracy is detected, the models should be recalibrated and retrained immediately to achieve optimal performance.
15	Static Data – VRE Plant or GSE	**Wind farm identification** - Name - Dispatchable Unit ID (DUID) - Region **Wind farm Status** - Status of the wind farm	**Solar farm identification** - DUID - Facility Name - Region **Solar farm nominal data** - Nameplate rating	Existing Network Code authorize Dispatch Licensee to request Static Data during the connection to the grid process. Furthermore, the data which is not set as requirement in Network Code might be obtained as a supplementary data. Either GSE would obtain data listed herein from VRE plant or some

[52] Turning the Tides on Wind Measurements: The Use of Lidar to Verify the Performance of A Meteorological Mast

#	Component	Description	Note
		- From which date is or will the wind farm be fully operational? - From which date will the wind farm be first connected to the grid or energized? **Wind farm nominal data** - Nameplate Rating - Maximum Capacity **Wind farm location & terrain data** - Geographical coordinates (UTM WGS-84) - Geographical coordinates - Wind farm altitude - Wind farm geometry - Orography information - Mesoscale roughness coefficient - Roughness of surrounding area - Met mast measuring height - Met mast Geographical coordinates - Air density - Maximum capacity **Solar farm status** - Status of the solar farm - From which date is or will the solar farm be fully operational? - From which date will the solar farm be first connected to the grid or energized? **Solar farm location and terrain data** - Facility latitude - Facility longitude - Facility altitude - Facility map - Facility time zone **Solar farm miscellaneous** - Number of clusters - List of measurement devices (Device ID)	amendments to the Network Code would oblige and allow the provision of such kind of data to VRE forecast vendors without the direct access to the SCADA system.
16	GSE Server	The FTP server proposed as a platform for the data exchange between GSE and Forecasting Service Provider or GSE, VRE plant and Forecasting Service Provide. FTP server and respective architecture helps in exchanging of files over internet. An FTP server needs a Transmission Control Protocol (TCP) / Internet Protocol (IP) network for functioning and is dependent on usage of dedicated servers with one or more FTP clients. To ensure that connections can always be established from the clients, an FTP server is usually switched on. FTP, or "File Transfer Protocol" is a popular method of transferring files between two remote systems. Secured File Transfer Protocol (SFTP), which stands for SSH File Transfer Protocol, or Secure File Transfer Protocol, is a separate protocol packaged with SSH that works in a similar way over a secure connection.	The existence of FTP server for the forecasting data retrieval and required for the forecasting data upload
A16	Vendor Server	Description of the item is the same as Item 16 of this table.	Vendors delivering forecasts in a Comma-Separated Values (CSV) file format through the email or making specific to the VRE plant forecast are available at their FTP server. The retrieval of the forecasts might be established automatically.
17	Dynamic Data	VRE forecasting Supplier Retrial of Dynamic Data from FTP Server	
18	Static Data	VRE forecasting Supplier Retrial of Static Data from FTP Server	

#	Component	Description	Note
19	VRE Forecasting Service Provider	Either Private Companies or Research Institutions (Like NCAR) providing the forecasting of Wind and Solar Power on a commercial and Contractual basis worldwide.	Under the Current Concept Design, VRE Forecasting System Supplier is recommended as a least costly approach. Later, if the SO decides, the centralized forecasting system might be shifted to the models supported by the software installed on the server of GSE.
20	Met Data-Vendor	Metrologic da ta collected from the nacelles of wind turbines and mete masts, and meteorological stations near the solar PV might be requested by the operator of the Numerical Weather Prediction model.	The operator of Numerical Weather Prediction Model might request meteorological data for the Analysis which aims to get the initial condition of the atmosphere in the model. It can be used to draw weather map and input for the NWP forecast. Data assimilation is the process of combining different sources of information in order to better estimate the state of a system and minimize the forecast error. It can improve the accuracy of forecasting data through putting monitored weather data from wind and solar farm in data assimilation process. The following is a brief description of the major components of the analysis systems.[53] 1. Observational data are received from the GTS, Internet and dedicated network. They are decoded according to their code forms. 2. Various pre-analysis procedures, such as quality control, data selection and bias correction, are applied to the decoded observational data. In the pre-analysis process, first guess fields retrieved from forecast models are used as a reference of the present atmospheric conditions. 3. The four-dimensional variational method is adopted in the global analysis and the meso-scale analysis. And the three-dimensional variational method is adopted in the local analysis.
21	Numerical Weather Prediction-Vendor	Numerical Weather Prediction: NWP uses the power of computers to make a forecast. Complex computer programs, also known as forecast models, run on supercomputers and provide predictions on many atmospheric variables such as temperature, pressure, wind, and rainfall.[54]	
A22	Meteorological Prognosis – NEA	NEA employs The Weather Research and Forecasting (WRF) Model developed by the US National Center for Atmospheric Research and capable to provide same meteorological input vendor is utilizing as an input of its forecasting model.	With the several meteorological inputs available to GSE the last could benchmark each performance and even if utilized simple average from the values delivered its possible to reduce the uncertainty for forecasting of met parameters.
B22	VRE meteorological Data	Download of Metrologic data collected from the nacelles of wind turbines and mete masts, and meteorological stations near the solar PV might be requested by the operator of the Numerical Weather Prediction model NEA with the main purpose to assimilate the local	

[53]Source: https://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2013-nwp/pdf/outline2013_02.pdf
[54] Source http://ww2010.atmos.uiuc.edu/(Gh)/wwhlpr/numerical_weather_prediction.rxml

#	Component	Description	Note
		observations in utilized NWP to determine the model initial conditions	
22	Meteo Prognosis-Vendor	In particular case of the Wind Power Forecasting the Main input of Power Prediction Model for the time horizon more than six hours are output of the NWP	
23	Power Prediction-VRE Forecast Suppler	The parameter which would be predicted in a time horizon and granularity for each time horizon should be the Active Power Expressed in (kW). Prediction in a CSV file format would be uploaded to the FTP server	In most of the cases the prediction of active power delivered in a CSV file format
24	Meteorological Parameters Prediction - VRE Forecast Suppler	The parameters which would be predicted in a time horizon and granularity for each time horizon should be: - Wind Speed Wind Dir Temperature Pressure [hPa] - Irradiance, wind speed, Temperature, Precipitation Prediction in a CSV file format would be uploaded to the FTP server	In most of the cases the prediction of active power delivered in a CSV file format
25	Power Prediction -GSE	Same as line item 23 of this table but it relates to the retrieval of data from FTP server	
26	Prediction of Meteorological Parameters - GSE	Same as line item 24 of this table but it relates to the retrieval of data from FTP server	
27	Visualization of Predictions	The data handling system for the visualization might be built by web-based applications, it allows the users to check in the separate PC in real-time and to set the initial setting in the user's PC. The information provided in the visualization system is about the weather status and forecasts of the power generation. The meteorological data is the prediction data received from the monitoring system on the weather status data, temperature, wind direction, wind speed, etc. It also provides the weather information produced from the physical model within the prediction area, temperature, solar radiation, wind speed distribution and horizontal wind fields	

OPTIONS FOR IMPLEMENTATION PLAN

A draft Implementation Plan is developed with the main purpose to define the most effective way to ensure the existence of wind power forecasting which in turn would be the step forwards enabling the environment to integrate more capacity generated on VRE power plants. The focus is on the followings:

- Options for implementation of wind power forecasting system;
- Discuss and agree on the roles and responsibilities under the draft concept design;
- Form an implementation team from the start;
- Identify and assemble resources for implementation;
- Agree on accuracy metrics with stakeholders and vendors;
- Agree on concept design and implementation plan with stakeholders;
- Introduce and agree on procurement options and performance monitoring.

Accomplish preparatory work and shift to procurement and implementation stage.

Figure 18: Components of Procurement and Implementation Stage

Forecast Parameters	• WInd Speed and Active Power • Active Power
Vendor Selection Approach	• Trial Benchmarking • Least Cost Approach
Vendor Performance Assesment	• GSE • USAID Energy Program
Metrics For Vendor performance Assessment	• Root Mean Squared Error (RMSE) • Mean Absolute Error (MAE) & Mean Absolute Percentage Error (MAPE)
Contract and NDI	• GSE • USAID Energy Program
Data Exchange	• WInd Project Developers and Operator • GSE • USAID Energy Program
Setting up FTP Server	• GSE • USAID Energy Program

The following subparagraphs would provide necessary description of options to justify the applicability of the option to the implementation plan.

FORECAST PARAMETERS

USAID Energy Program proposal is to launch VRE forecasting services on two locations only for the wind speed and direction forecasting and launch forecasting of active power and wind speed and direction on one location.

Those Locations indicated on the map are provided below.

Figure 19: Location of Equipment Measuring the Meteorological Parameters

Georgia Energy Development Fund (GEDF), Infinite Energy and Caucasus Wind Company responded to the survey of USAID Energy Program and expressed willingness to participate in the process of VRE forecasting Vendor Selection and real time meteorological data availability at the mentioned locations.

The basis for the above provided proposal is that, in case of Infinite Energy and Caucasus Wind Company, all parameters provided in the survey questionnaire are measured and are available in high granularity, whereas in case of QWF it is already proved, the historical and at some extent the real-time data is available since data was provided for Test Mode on permanent basis.

From the listed companies only one - QWF operates the existing wind farm. Other companies are developers and are proposing the development of a project. Under their disposal is a wind mast, erected with the main purpose to measure the meteorological parameters at the proposed location. The mentioned activity requires the wind resource assessment. Those measurements could be retrieved either directly from datalogger or uploaded to the FTP server.

In the proposal to launch the forecast of power and meteorological parameters at different locations USAID Energy Program is following the experience of AESO and CAISO.

AESO in conjunction with the Alberta Energy Research Institute and the Alberta Department of Energy, initiated a wind power forecasting pilot project in the summer of 2006 (Industry WG, 2008). In the project, three very different forecasting methodologies were trialed. The forecasters selected were AWS Truewind from US, WEPROG from Denmark, and Energy & Meteo Systems from Germany.

The forecasters provided forecasts for 12 different wind power facilities (7 existing facilities and 5 future facilities) spread out across southern Alberta in four regions. From May 1, 2007 to May 1, 2008, forecasts were delivered each hour, predicting the next 48 hours. The forecasts included the hourly average, minimum and maximum of wind speed, wind power, and wind power ramp rates at each facility.

In case of AESO the pilot project performed in 2007-2008 was predecessor of announcing the Request for Proposals (RFP) on provision of Wind Power Forecasting (WPF) in 2009. Using the knowledge and experience gained from the pilot project, the AESO worked with stakeholders to develop a recommendation for a wind power forecasting service which provides the AESO with wind power forecasts updated at least once per hour and for the next 48 hours for the province of Alberta.

The AESO's intention to have the wind power forecast service were successfully implemented and now it is utilizing “Centralized Forecast Service”. Near real-time and day-ahead forecasting for wind aggregated generating facilities in Alberta, performed using a centralized approach of collecting the real time data and predicting output for all plants. The AESO has contracted with a forecast vendor to produce all the forecasts.

Currently, Wind Power Generation makes up nine per cent of Alberta's generation capacity and AESO is working with the government, wind generation developers, and stakeholders to bring even more wind-generated power to the grid. To see the performance of forecasting under the disposal of AESO please refer to the Annex 2 Day Ahead Wind Power Forecast vs. Actual Wind Production for the Month of Oct 2018.

Additionally, below are provided several examples of wind forecasts pilot projects which were performed with the main aim to determine the main challenging issues for performance of the different WPF models at different locations. Moreover, the main objectives as it's indicated in the cases listed below were the comparison of different global NWP (ECMWF, GFS), identification of most effective WPF approaches together with evaluation of forecasting models with the consideration of local distinctive weather patterns and terrain specification.

Case 1: ANEMOS Project (launched in 2002). During the exercise, there was an evaluation of 11 forecasting models (e.g., AWPPS, LocalPred, Prediktor, Previento, Sipreólico, WPPT) from nine different institutes in six test-case wind farms with different types of climatology and terrain.

Case 2: Asociación Empresarial Eólica (AEE) - Spanish Wind Energy Association). Seven wind farms located in Spain were chosen for this exercise as they represent different types of terrain. Eight companies (Meteológica, Meteotemp, CENER, Casandra, Garrad Hassan, Meteosim / AWS Truewind, Aleasoft, Aeolis) provided forecasts for these wind farms for a period of 13 months. Throughout this forecasting exercise, it was possible to compare different global NWP (ECMWF, GFS) models.

The availability of real time power generation and meteorological data and willingness to participate in a VRE Forecasting System development project would be double checked by the USAID Energy Program before the VRE Forecasting System Implementation starts.

VENDOR SELECTION APPROACH

Two options for the forecast vendor selection Trial Benchmarking and least cost approach would be described under this paragraph.

The trial / benchmark is the process which usually precedes the final selection of the forecasting service provider. This process occurs in situations where there is a portfolio of VRE generation in place and its clearly declared that after the Trial / Benchmarking there will be contract for example for the next 3 years (The term of the contract also meters as well) for the vendors showing the best results or planned portfolio of VRE generation coming soon enough to rise interest of forecasting supplier.

To apply the trial benchmarking approach there is one necessary condition: The existence of a plan, before performing benchmarking trial or pilot is a must. Below is a good example[55] of the required capacity and effort to perform planning for Trial / Benchmark project.

Figure 20: Procurement Stage Components

Trial planning & Setup	Evaluation Data	Representativeness of Sample
• Accurate locations of forecast sites • Content and format of data • Mechanism and frequency of providing data • Precise definition of forecast target variables • Mechanism and frequency of forecast delivery • Expected outcomes (selection criteria etc.)	• Exactly how the raw evaluation data will be quality-controlled so that the providers can perform the identical Quality Control (QC) • Provide the exact QC'd dataset that will be used to evaluate the forecasts	• SIZE: should be large enough to produce statistically meaningful results • Adjacent forecast cases are often highly correlated • Differences in forecast performance may be variable and noisy • 3 months may be adequate under ideal circumstances • important modes of variability for the forecast parameter • Trial timing (winter, summer etc.) & duration should be chosen carefully

[55] Wind and solar forecasting trials experience: do's and don'ts Part 2: introduction to the IEA wind task 36 guideline for evaluation of forecasting approaches and selection John W Zack, Ph.D. Vice President – Grid Solutions jzack@awstruepower.com

The assessment of 4 vendors forecast performance participating in Trial / Benchmarking which lasted 7 months with the participation of 4 vendors Launched by the CEZ Group Fontanelle Cogelac wind farm were performed by the company proficient and experienced in statistics. The quality of forecasts was accessed from 4 providers. Assessment was performed monthly for each day forecast (For the main finding from study tour to fontanel Cogelac Wind Farm Romania please see Annex 3).

In case USAID Energy Program applies the trial/benchmarking approach, this process will last at least for 7 months. Also, there will be a need for the selection of a company proficient in statistics to perform the evaluation of a vendor's performance.

Furthermore, it is unlikely that without the payment and without the prospects for future contract either short term or long-term potential vendors would agree to participate in the trial/benchmarking. This, in turn would require the payment for each participant in amount similar to what would be required by one supplier of forecasting services annually.

Company hired for the assessment will have to deal with the setup of data exchange and other issues, but it will require payment as well.

With the consideration of the above mentioned, the selection of supplier based on the least cost approach might be an alternative to the trial. The vendors of VRE forecasting services would be asked to provide their offers in regard to specification of forecasts indicated in concept design.

In this case the obligation of the client (USAID Energy Program and /or GSE) would be the selection of metric for accuracy and daily performance assessment. Furthermore, it would be necessary to deal with data exchange, its security issues, and data quality control together with the FTP server setup.

In case of the least cost selection approach, USAID Energy Program will develop Terms of Reference (ToR) and Questionnaire for the procurement procedures of VRE Forecasting Services and wind profiling mobile equipment. During the development of a document, survey and procurement process, USAID Energy Program shall strictly follow regulation of USAID and Deloitte applied in case of services and goods procurement.

Questionnaire are intended to survey the suppliers of VRE forecasting services who expressed the interest at the initial stage. Those Suppliers are:

- NCAR;
- UL- AWS Trupwoer;
- VAISALA – (Acquired 3 TIER);
- ENFOR;
- DNVGL;
- Meteologica.

Overall, based on survey of the VRE forecasting suppliers the ceiling of indicative budget (annual cost for services) for VRE forecasting services might be $30 000- $35000.

If the budget allows 2 candidates, with the lowest cost for annual services, would be selected for the provision of forecasting services. This would allow USAID Energy Program and beneficiary of services-GSE perform benchmark and start implementation of the VRE forecasting system with the conditions and approach quite similar utilized by the other SOs.

Furthermore, questionnaire would be utilized for the procurement of wind profiling mobile equipment[56]. At first stage it would be utilized to determine the tentative budget of the procurement and later through the interest expression process to reveal the best supplier.

It would be appropriate if the wind profiling equipment procurement process start after the procurement of VRE forecasting services.

VENDOR PERFORMANCE ASSESSMENT

Trial benchmarking plan should consider the selection of uncertainty metrics which would apply to the Trail process. These metrics might be Mean Absolute error or Route Mean Square Error. However, if a company proficient in statistics is engaged in Trial / Benchmarking then it will be up to a company to

[56] There are two types of non-stationary remote sensing systems on the market: SoDAR (Sonic Detection and Ranging) and LiDAR (Light Detection and Ranging). SoDAR instruments measure the wind conditions by means of sound; LiDAR instruments use light to measure the wind characteristics.

select the metrics for the forecast assessment. Justification would be provided to USAID Energy Program and GSE as well. The selection of uncertainty metric would be finalized by the agreement of metrics with USAID Energy Program and GSE.

In case USAID Energy Program applies the least cost approach for the selection of VRE forecasting service provider, the preference will be given to uncertainty metrics which is easier to understand and indicates the deviation of forecast from the actual values.

Mean Absolute Error (MAE) Or Mean Absolute Deviation (MAD): MAE measures the average magnitude of the errors in a set of predictions, without considering their direction. It's the average over the test sample of the absolute differences between prediction and actual observation where all individual differences have equal weight.

Figure 21: Mean Absolute Deviation Formula

$$\mathrm{MAD} = \frac{\sum_{t=1}^{n} |A_t - F_t|}{n}$$

Root Mean Squared Error (RMSE): RMSE is a quadratic scoring rule that also measures the average magnitude of the error. It's the square root of the average of squared differences between prediction and actual observation.

Figure 22: Route Mean Square Error Formula

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{t=1}^{n} (A_t - F_t)^2}{n}}$$

Both MAE and RMSE express average forecast error in units of the variable of interest. Both metrics can range between 0 to and are indifferent to the direction of errors. They are negatively-oriented scores, which means lower values are better.

Distinct advantage of RMSE over MAE is that RMSE avoids the use of taking the absolute value, which is undesirable in many mathematical calculations.

Furthermore, RMSE gives a relatively high weight to large errors. This means the RMSE should be more useful when large errors are particularly undesirable. RMSE does not necessarily increase with the variance of the errors. RMSE increases with the variance of the frequency distribution of error magnitudes.

From an interpretation standpoint, MAE is clearly the winner. RMSE does not describe average error alone and has other implications that are more difficult to tease out and understand.

MAE enables to deal with the average magnitude of errors in a set of predictions and interpretation is more acceptable. Respectively, in case of forecast assessment the preference would be given to the uncertainty metric - MAE. More specifically the preference would be given to the MAE expressed in percentage which is a Mean Absolute Percentage Error (MAPE).

Figure 23: MAPE Formula

$$\mathrm{MAPE} = \frac{\sum_{t=1}^{n} \left|\frac{A_t - F_t}{A_t}\right|}{n} \times 100$$

CONTRACT AND NDA

NDA are an important legal framework used to protect sensitive and confidential information from being made available by the recipient of that information. NDAs may be unilateral whereby only the recipient of the information is required to keep silent, or mutual where both parties agree not to share each other's sensitive information[57]. A unilateral NDA is a contract in which one party agrees not to disclose certain information of another. Most NDA contracts fall under this umbrella. A mutual NDA, on the other hand, is when both parties agree not to share the other's information. Commonly, mutual NDAs are signed when two businesses share protected communication.

In case of procuring the VRE forecasting services form vendor, unilateral agreements should be signed with a vendor of forecasting services. NDA requires not to make public the real time power generation data of QWF and meteorological data obtained from QWF and developers of wind farms.

Beneficiary of forecasting services would be GSE whilst the "Client" for the forecasting services vendor would be USAID Energy Program. In such kind of contractual arrangement USAID Energy Program and VRE forecasting services vendor would be the counterparts. To ease the administrative procedures, it will be better if NDA is signed between GSE and a vendor. GSE in case of QWF is authorized to have access to real time data.

Furthermore, it might be the case, that VRE project developer and even QWF ask USAID Energy Program to sign NDA. VRE project developer's data might be commercially sensitive since it relates to the assessment of wind resource which is affecting the project bankability. In this case signing the NDA with GSE would be more beneficial since data input for the VRE forecasting services are proposed to be provided by the GSE.

As an alternative, the concept design considers the provision of the real time power generation and meteorological data by VRE project operator and developer, however in this case, NDA should be signed between each participants of the project separately.

Since GSE is beneficiary of the forecasting services in the contractual agreement GSE might be authorized to monitor performance of a vendor and act as a counterpart with the contractual relations with a vendor.

The regulations of the contract may suggest, that vendor might be allowed to get 10- 30% advance payment for provision of VRE forecasting services calculated from the annual service fee and/or 30% of model/software initial setup cost if a vendor would install forecasting software at the servers of GSE.

The mentioned uncertainty metrics would apply to the specific time horizon forecast each week with the main purpose to perform the monthly payments.

Table 9: VRE Forecast Specification

Time Horizon	Specification of recast	Acceptable Uncertainty
Day Ahead	DA - At list 36 Hour / 10 min Granularity	First 3 months from launching at list 18 hours per MAPE should be no more than 25%, the following 3 months 20%, next 3 months 15% and last three months no more than 12%
Hour Ahead	HA – At list 2 Hour Ahead / 5 min Granularity	First 3 months from launching at list 18 hours MAPE should be no more than 15%, the following 3 months 12%, next 3 months 10% and last three month no less than 12%
Week Ahead	WA – At least 168 hours Ahead	First 3 months from launching at daily MAPE should be no more than 25%, the following 3 months 20%, next 3 months 15% and last three months less than 12%

DATA EXCHANGE

The real time power generation and meteorological data represent the main input for the forecasting horizon for up to six hours. Furthermore, mentioned data is utilized for the improvement of the accuracy of forecast for the time horizon beyond 6 hours.

VRE projects are delivering the real time power generation and meteorological data to AEMO and CAISO. Thus, the proposed are the delivery of real time power and meteorological data from QWF and real time meteorological data from Infinite Energy and Caucasian Wind Company to forecasting system provider.

The above mentioned would be the future data exchange arrangement proposed by USAID Energy Program for centralized forecasting system as well. VRE plants are delivering the real time power and

[57] Source: https://www.investopedia.com/articles/investing/041315/how-ndas-work-and-why-theyre-important.asp#ixzz5W4htezpX

meteorological data to SO and then SO delivers or uploads this data to the File Transfer Protocol (FTP) server to make it available for forecasting system provider.

Below it provided some example of designing data exchange[58]:

- data exchange key concepts and terminology;
- the different types of data exchange methods e.g. system-to-system, SFTP, bulk upload versus single instances, real time versus near real time, large transactions, bulk uploads, and one-off or scheduled etc.;
- how to overcome the barriers to data exchange;
- the use of process flow diagrams, data architecture, modelling and mapping to support data exchange;
- mapping interdependencies so that there is an understanding of associated complexities;
- data quality in the context of data exchange and links to the Data Quality Standard and associated toolset;
- common and recurring schemas, patterns and methods for exchanging data including industry standards;
- technology and data storage considerations;
- usage considerations including data linkages, integration and transformation;
- contracts and Service Level Agreement (SLA) considerations.

With the consideration of above described there might be several options for data exchange but hereunder would be discussed only options listed below.

a) Wind Project Developers and Operator would supply meteorological and power generation data either directly to forecasting service provider or upload data to the FTP server and data would be downloaded by a vendor.
b) GSE would receive the power generation and meteorological data and deliver it directly to the forecasting service provider or upload data to the FTP server and data would be downloaded by a vendor.
c) USAID Energy Program would receive the power generation and meteorological data and deliver it directly to the forecasting service provider or upload data to the FTP server and data would be downloaded by a vendor.

The development of VRE forecasting system is proposed for boosting GSE capacity in dealing with the uncertainty and variability of power generated at VRE power plants.

With the consideration of the above-mentioned, an organization responsible for data exchange need to have a past experience in designing and implementing data exchange. This is proposed to be the criteria when justifying to whom goes the responsibility of data exchange.

QFW power plant equipped with SCADA is operated and maintained by the VESTAS under the maintenance contract. From the SO point of view, it’s an III level SCADA. The arrangement of communication between the II Level SCADA and I level SCADA is an obligation of GSE - Dispatch licensee according the existing network rules.

In case of Infinite Energy and Caucasian Wind Company, data exchange should be established between the datalogger at the site managing and collecting data from the meteorological equipment and FTP server. It might be the case that, although FTP server belongs to the provider of meteorological equipment, data logger can be uploading measurement data to that server. In this case the participation of companies in the data exchange arrangement is minor and limited by the access to the FTP server with the login and password.

USAID Energy Program recently has an experience of establishing FTP server for simplest data exchange between the NEA QWF and USAID Energy Program. NEA forecasts of wind speed were uploaded automatically to FTP server whilst USAID Energy Program performed download and upload manually.

[58] Data Exchange Framework, Source: https://www.enterprisesolutions.vic.gov.au/wp-content/uploads/2018/07/Data-Exchange-Framework.pdf

SETTING UP FTP SERVER

Building FTP (File Transfer Protocol) server can be one of the easiest and most convenient solutions to transfer file through a private or public network without limitations and restrictions typically found with most cloud storage services.

There are also many benefits in running FTP server. For example, private and absolute control could be established. It's fast (depending on internet connection speeds), and there are virtually no limits on the amount and type of data it can store.

Even at the Nord Pool's data exchange was ensured through the FTP-server[59]. Access to the FTP-server is by subscription and/or by a special agreement. All participants trading at the Physical Nordic Power Exchange have FTP access.

Organization dealing with the data exchange issues would deal with the FTP server issue as well if it's not arranged by the VRE service provider.

[59] Nord Pool FTP Server – Directions and Contents Source : https://www.nordpoolgroup.com/globalassets/download-center/power-data-services/outline-nord-pool-ftp-server.pdf

MAIN FINDINGS – IMPLEMENTATION PLAN

FORECAST PARAMETERS

In the proposal to launch the forecast of power and meteorological parameters at different locations USAID Energy Program is following the experience of AESO and CAISO.

During the trial organized by the AESO three forecasters provided forecasts for 12 different wind power facilities (7 existing facilities and 5 future facilities) spread out across southern Alberta in four regions. From May 1, 2007 to May 1, 2008, forecasts were delivered each hour, predicting the next 48 hours. The forecasts included the hourly average, minimum and maximum of wind speed, wind power, and wind power ramp rates at each facility.

Wind's power is proportional to the cube of its speed. Forecasted wind speed, direction and temperature derived from NWPs are those meteorological parameters which, as a data input for the forecasting time horizon beyond 6 hours has a great importance. Wind is one of the parameters best predicted by NWPs, as it can be directly calculated from the physical equations of pressure that govern its movement[60]. However, local winds are considerably affected by topography, the global numerical weather models of which are not able to reproduce due to their limited resolution.

Respectively Wind power forecasting models developed for one location usually don't match the other site due to variety of reasons such as change in terrain, different wind speed patterns, different atmospheric factors - temperature, pressure, humidity, density[61].

With the forecasting wind speed at several location, the forecasting vendor's capability would be tested to provide precise forecast for the time horizon for more than 6 hours.

VENDOR SELECTION APPROACH

Trial Benchmarking would require the selection of a company proficient in statistics to compensate the nonexistence of experience in performing trials and benchmarking for forecasting vendors. The same company would deal with the development or trial benchmarking plan and selection of accuracy metrics for the evaluation of participants performance. Dealing with the data exchange and setting up the FTP server would be the responsibility of this company as well.

A company hired for this purpose will have to deal with almost all issues related to preparation of Trial / Benchmarking, implementation and monitoring. The timeframe of the process would be no less than one year considering the time required for the selection of the company proficient in statistics and performing the Trial / Benchmarking

The development of ToR, survey of suppliers, data exchange arrangement, setup of FTP server and 2 vendors performance assessment are proposed under the least cost approach. Those would be the responsibility of USAID Energy Program at some extent shared with GSE. Selection process wouldn't last for more than 3-4 months, whereas the budget for this approach might be several times less than in case of TRIAL benchmarking.

VENDOR PERFORMANCE ASSESSMENT

In case USAID Energy Program applies the least cost approach for the selection of VRE forecasting service provider, the preference will be given to uncertainty metrics which is easier to understand and indicates the deviation of forecast from the actual values.

If a company proficient in statistics is engaged in Trial / Benchmarking, then it will be up to them to select the metric for the forecast assessment. Justification would be provided to USAID Energy Program and GSE as well. The selection of uncertainty metric would be finalized by the agreement of metrics with USAID Energy Program and GSE.

[60] A Method for Wind Speed Forecasting in Airports Based on Nonparametric Regression Source: https://journals.ametsoc.org/doi/10.1175/WAF-D-14-00006.1
[61] A Review of Wind Power and Wind Speed Forecasting Methods with Different Time Horizons Saurabh S. Soman, Hamidreza Zareipour, Senior Member, IEEE, Om Malik, Life Fellow, IEEE, and Paras Mandal, Member, IEEE

CONTRACT AND NDA

Contract on provision of forecasting services would be signed between USAID Energy Program and VRE forecasting service provider. GSE might be counterpart in contract as well since GSE is the beneficiary of the services.

To avoid complex administrative procedure in regard to NDA, it will be beneficial if GSE signs NDA with the selected supplier of forecasting services.

DATA EXCHANGE

GSE seems the most experienced in designating and establishing data exchange. Before launching the delivery of forecasting services, the test should be undertaken for checking how properly data might be uploaded and downloaded from FTP server. In the contractual agreement with a vendor it might be the obligation of the vendor.

SETTING UP FTP SERVER

The easiest way to deal with the setup of FTP server is to oblige forecasting services vendor to maintain server and ensure the proper upload and retrieval of data.

If selected vendor sets permission system for access to forecast information with usernames and passwords for every forecast tool and establishes secure password protected web host server for all data transfers, then the need for FTP server might be neglected.

If GSE has to deal with data exchange design, then it is appropriate if GSE would deal with the FTP server as well.

ANALYSIS AND RECOMMENDATIONS ON OPTIONS FOR IMPLEMENTATION PLAN

ANALYSIS AND RECOMMENDATION

	Analysis	Recommended Option
Forecast Parameters	Wind power forecasting models developed for one location usually don't match the other site due to variety of reasons like change in terrain, different wind speed patterns, different atmospheric factors such as temperature, pressure, humidity, density. With the forecasting wind speed at several locations, a forecasting vendor's capability would be tested for providing precise forecast for time horizon for more than 6 hours at several locations.	**QWF – Forecast of Active Power Wind Speed and Direction** **Infinite Energy & Caucasian Wind Energy – Forecast of wind speed and direction**
Vendor Selection Approach	In case of Trial / Benchmarking, the timeframe of the process would be no less than one year considering the time required for the selection of the company proficient in statistics and performing the Trial / Benchmarking Under the least cost approach, it is proposed that the selection process wouldn't last more than 3-4 months and budget for this approach might be several time less compared to TRIAL benchmarking.	**Leas Cost Approach**
Vendor Performance Assessment	Under the Least Cost approach for the selection of the VRE forecasting service provider the accuracy metrics which is easier to understand and indicates the deviation of forecast from the actual values would be the most efficient to utilize. With the Mean Absolute Error metrics, it is possible to deal with the average magnitude of the errors for accuracy in a set of predictions and from the interpretation point of view MAE is more acceptable. More specifically the preference would be given to the MAE expressed in percentage which is a Mean Absolute Percentage Error-MAPE.	**MAE & MAPE**
Contract and NDA	Contract on provision of forecasting services would be signed between USAID Energy Program and VRE forecasting service Provider. GSE might be counterpart in contract as well since GSE is the beneficiary of the services. To avoid complex administrative procedure in regard to NDA, it would be beneficia if GSE signs NDA with the selected supplier of forecasting services.	**Contract - USAID Energy Program and GSE** **NDA- GSE**
Data Exchange	GSE seems most experienced in designating and establishing data exchange Before launching the delivery of forecasting services, it should be tested how properly data might be uploaded and downloaded from FTP server. In the contractual agreement with a vendor it might be obligation of a vendor. Specific condition should exist in the contract to ensure the proper operation of the FTP server and data exchange.	**GSE-Data Exchange design and implementation** **GSE- Data Exchange Testing**
Setting up FTP Server	If selected vendor sets permission system for access to forecast information with usernames and passwords for every forecast tool and establish secure password protected web host server for all data transfers, then the need to have and FTP server might be neglected. If GSE has to deal with data exchange issue, it would be beneficial if GSE sets up the FTP server.	**GSE if vendor of forecasting services doesn't provide data exchange platform**

IMPLEMENTATION PLAN

Below is provided an Implementation Plan, developed with the main purpose to define the most effective way to ensure the existence of wind power forecasting system. The focus is on the following:

- Agreement on concept design with the stakeholders;
- Agree with the stakeholders and vendors on accuracy metrics;
- Discuss and agree roles and responsibilities under the draft concept design;
- Accomplish preparatory and shift to the procurement and implementation stage.

In general, the implementation plan consists of the following steps: preparation, procurement and implementation, as provided in the schematics below:

Figure 24: Preparatory Stage (Part 1)

1. Agreement on System Concept Design with GSE
2. Identification of Locations
3. Survey of Suppliers
4. Comply Deloitte / USAID Procurement Rules
5. Identify 2 least cost Supplier of VRE forecasting Services

Figure 25: Preparatory Stage (Part 2)

- Agreement on uncertainty metrics for performance assessment*
- Contractual Agreement with Vendors including NDA
- Setup FTP Server or Interconnection between GSE, Developer and Vendor for data exchange
- Test interconnection for data exchange

Figure 26: Procurement Stage, Cost $30000-$35000 (Advance Payment 10 to 30%)

- Launch Forecasting with the selected vendor
- Advance Payment
- Performance Assessment

Figure 27: Implementation Stage (Cost-Advance Payment)

- Performance Assessment
- Monthly Payment
- Procurement of LiDAR

ROLES AND RESPONSIBILITIES UNDER THE DRAFT IMPLEMENTATION PLAN

#	Preparatory Stage 1	USAID Energy Program	GSE	NEA	VENDOR	VRE
1	**Agreement on System Concept Design and Plan with GSE and other stakeholders**	Presentation	Acceptance	Acceptance		Acceptance
2	**Identification of forecast locations**	Presentation	Acceptance	Acceptance		Acceptance
3	**Survey of Suppliers**					
3.1	**ToR on VRE forecasting Services**	Development and Presentation	Discussion	Discussion		Discussion
3.2	**ToR on Control Measurement Equipment**	Development and Presentation	Discussion	Discussion		Discussion
3.3	**Perform Survey**	Survey	Consultation	Consultation	Feedback	Consultation
4	**Comply Deloitte / USAID Procurement Rules**	Presentation to USAID & Deloitte Design Concept and Plan together with ToR Deloitte Procurement Procedures				
5	**Selection of Vendors**	Engagement is minor	Engagement is minor	Engagement is minor	Engagement is minor	Engagement is minor
5.1	**Forecasting Services**	Engagement is minor	Engagement is minor	Engagement is minor	Engagement is minor	Engagement is minor
5.2	**Equipment**	Engagement is minor	Engagement is minor	Engagement is minor	Engagement is minor	Engagement is minor

	Preparatory Stage 2	USAID Energy Program	GSE	NEA	VENDOR	VRE
1	**Agreement on Accuracy Metrics and Time intervals of Assessment**	Development/Support	Acceptance	Support	Acceptance	Support
	Contractual Agreement with Vendors including NDA					
	Contract	Deloitte, USAID Energy Program Support	Discussion	Discussion	Sign	Discussion
	NDA	Support	Sign	Sign	Sign	Sign
	Setup FTP Server or Interconnection between GSE, Developer and Vendor for data exchange					Sign
	Data Exchange	Minor Engagement	Design and Implementation of data exchange	support	Design and Implementation of data exchange	Support
	FTP Server	Minor Engagement	Set Up Server	Minor Engagement	Set Up Server	Minor Engagement
	Test interconnection for data exchange	Minor Engagement	Test	Minor Engagement	Test	Support

	Procurement Stage	USAID Energy Program	GSE	NEA	VENDOR	VRE
1	**launch forecasting with the selected vendor**	Support in Performance Assessment	Performance Assessment	Launch	Vendor Launch	Discussion
2	**Advance Payment**	Deloitte, USAID Energy Program				
3	**Performance Assessment**	Deloitte, USAID Energy Program Support in Performance Assessment	Weekly Performance Assessment and Acceptance	Support	Daily Performance Assessment	Discussion of Performance

	Implementation Stage	USAID Energy Program	GSE	NEA	VENDOR	VRE
1	**Monitoring and Performance Assessment**	Deloitte, USAID Energy Program	Weekly	Support	Daily Performance	Discussion of

	Implementation Stage	USAID Energy Program	GSE	NEA	VENDOR	VRE
		Support in Performance Assessment	Performance Assessment and Acceptance		Assessment	Performance
2	**Monthly Payment**	Deloitte, USAID Energy Program	Acceptance	Support	Acceptance	Discussion
3	**Procurement of LIDAR**					
	Procurement Procedures	Deloitte, USAID Energy Program Support	Support	Support		Discussion
	Transfer of Equipment	Deloitte, USAID Energy Program Support	Accept			
	Testing of Equipment		Test	Support		

THE WAY FORWARD

As a way forward, the following steps are recommended:

- Discuss Concept Design and Implementation Plan with stakeholders;
- After discussion make necessary changes in design and plan;
- Apply the actions prescribed in the preparatory - procurement and implementation stage;
- Start discussions in regard to required changes in Network Rules to incorporate the centralized forecasting processes by the system operator through the possibility to utilize the forecasting services;
- Initiate development of amendments to the network Rules together with the methodology for the recovery of forecast cost.

ANNEX 1: LIDAR AND SODAR PRICES AND GENERAL SPECIFICATIONS

SoDAR Tritonâ Wind Profiler – $72000

- High height data — to 200 meters;
- No permitting required;
- Extremely low power consumption (7 watts);
- Data access and monitoring via secure web portal;
- Maximum height 200 m (656 ft);
- Wind data capture heights 40, 50, 60, 80, 100, 120, 140, 160, 180, and 200 m;
- Wind speed 0 … 40 m/s;
- SD memory card socket 2 GB SD card records a minimum of 2 years of 10 min data;
- Data upload rate Every 10 minutes, via satellite/cell link 1);
- Automatic data buffering and backfilling protocol;
- Data recovery rate (unfiltered) > 98 % (at all heights);
- Filtered data correlation Within 2 % of anemometers;
- Nominal Filtered Data Recovery Rate (With > 90 % Quality Factor) 2);
- At 100 m (328 ft) Approx. 90 … 95 % or higher;
- At 120 m (393 ft) Approx. 88 … 92 % or higher;
- At 140 m (459 ft) Approx. 85 … 90 % or higher.

ZephIR DM -€110000

- Range 10 - 200 meters (Lidar measurement);
- Range 0 - 10 meters (onboard met weather station) Horizontal wind speed and yaw misalignment;
- Wind veer (change in wind direction with height);
- Vertical wind shear (change in wind speed with height);
- Turbulence intensity;
- Hub-height and rotor-equivalent wind speed;
- Lidar Control Unit (LCU) mounted in the nacelle;
- Lidar Optical Head (LOH) mounted on the Turbine Integration Kit (TIK) which is mounted on to the nacelle roof;
- 10 Horizontal measurement ranges and up to 13 Vertical Slices at each range – the most comprehensive measurement capability of any Lidar, delivering Rotor Equivalent Wind Speed and Slices for IEC Power Curves;
- Extensive 3-year service life as standard.

ZephIR 300 -€92000

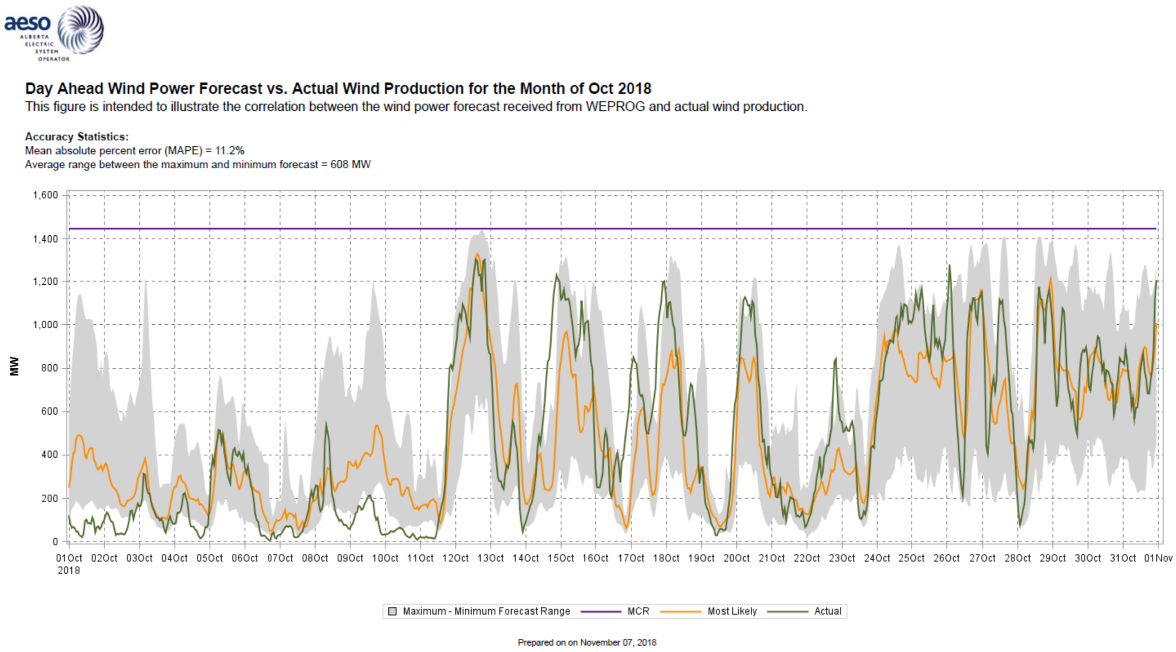
- MEASUREMENT PRINCIPLE: LIDAR (LIGHT DETECTION AND RANGING);
- MEASUREMENT RANGE: 10 ... 200 M (UP TO 10 HEIGHT MEASUREMENTS - CONFIGURABLE);
- WIND SPEED: 0 ... 70 M/S;
- ACCURACY (HORIZONTAL WIND SPEED): < 0.5%;
- ACCURACY (WIND DIRECTION): < 0.5%.

SoDAR AQSystems AQ510 -€ 39000

- Zenith Angle 15;
- Range (min/max) 40 – 200 m Height resolution 5 m;
- Accuracy -± 2 %;
- Data Availability 100m > ~98%;
- Data Availability 150m > ~85%;
- Data Availability 200m > ~70%;
- Environmental limitations;
- Temperature range -40°C to + 60°C;
- Humidity range 10 to 100 % HR;
- Antenna dimension;
- Antenna height 1,2 m;
- Antenna width 1,0 m;
- Weight 70 kg.

ANNEX 2: DA WIND POWER FORECAST VS ACTUAL WIND PRODUCTION FOR THE MONTH OF OCTOBER 2018

Figure 28: Correlation Between the Wind Power Forecast Received WEPROG and Actual Wind Production[62]



[62] Source: https://www.aeso.ca/grid/forecasting/wind-power-forecasting/

ANNEX 3: CASE STUDY: CEZ GROUP – FONTANEL COGEALAC WIND FARM

Below its provided example of Wind power forecasting implementation for the portfolio of wind farms power prediction and its utilization for dispatch purposes.

The Fântânele - Cogealac Wind Farm is the largest onshore wind farm in Romania and in Europe, with installed nameplate capacity of 600 MW from 240 General Electric 2.5xl wind turbines.

The turbines are distributed among 3 companies connected to the grid through the 400KV transmission line. Step Up Substation is under the ownership of CEZ group, whilst lines are owned and operated by the Transelectrica. The wind farm occupies 1,100 hectares (2,700 acres) of open field, 600 hectares (1,500 acres) in Fântânele and 500 hectares (1,200 acres) in Cogealac communes. [3] The wind farm is north of Constanţa, 17 kilometres (11 mi) west from the shore of the Black Sea

In October 2013, a record production, of 1.25 TWh, was recorded in CEZ's wind farms. CEZ's wind farm alone reported at the end of 2017 a realized amount of over 1,323 GWh, by 14% higher than in 2016, benefiting from an average wind force of 7.25 m/s (when wind force drops below 3-4 m/s or reaches 25 m/s the wind turbine stops to protect its integrity).

Wind farm includes 240 turbines of 2.5 MW each, it reported a capacity factor of 25.18%. It means that of the 240 turbines, approximately 61 generated green energy.

Wind Farm is operated and maintained by the team comprising 30-35 persons. Persons engaged in operation and day to day maintenance process especially the staff dealing with the maintenance of the blades pass Industrial Rope Trade Association (IRATA) certification process and are authorized to perform such maintenance works.

Crawler crane and excavators, truck and pickups for stuff transportation, endoscope and other tools to timely reveal defects and damages to equipment, and some other safety related equipment are under the disposal of maintenance team.

Wind Farm Supervisory Control and Data Acquisition System transfers signals to the server which is located at Cologne Operational Office. The latest 10 (ten) hours signals from meteorological sensors are available with the 10 second granularity and then 10-minute averages if it's not recorded for the special purposes.

Signals are transferred to the server from Wind Turbine's as well as from 6 meteorological towers distributed amongst the 3 entities which are the owners of Fontanelle Cologne Wind Farm. The transfer of Signals implemented through the Fibber Optic cables via ethernet.

For the operation and control of wind farm CEZ group is utilizing the software provided from General Electrics - GE Mark VI[63].

Access to SCADA data might be allowed only for Wind Farm Dispatch centre which is operated by the private company owned by CEZ. Interconnection to DC implemented by the Fibreoptic Cable. CEZ group owns and operates fibre-optic network for internet distribution purposes. As an alternative for Interconnection the Fibber Optic Network, owned and operated by the Transelectrica, might be utilized.

To bid on the day ahead and intraday markets as well as to operate wind farm and properly plan maintenance works, Fontanal Cologne Wind farm each day receives day ahead forecast of both power generation and wind speed. Now power hour ahead and day ahead forecast of power generation together with the wind speed forecast are provided by the EnerCast Germany based Company. Also, Meteologica -Spain based company delivers wind speed forecast with the same horizon and granularity. The uncertainty in some cases for the delivered predictions might reach up to MAPE - 30%.

[63] Source: https://www.ge.com/content/dam/gepower-renewables/global/en_US/downloads/brochures/battery-energy-storage-plant-controls.pdf

Both Enercast and Meteologica were selected through the Trial / Benchmarking process which started in June 2017 and continued until the March 2018. 5 entities including Enercast and Meteologica were engaged In the Trial / Benchmarking from vendors / suppliers of forecasting services side, each three months the assessment of vendors performance was performed by the third-party vendor proficient in statistics. The statistics company were employed with the main purpose to develop the trial benchmarking plan and unified uncertainty metrics to reveal the best one.

Fontanelle Cogelac wind farm power generation and meteorological data from nacelles of wind turbines and meteorological towers uploaded to the FTP server. Server has been created with the purpose to ensure the proper data supply to the forecast vendors. Wind speed, direction, ambient temperature is measured at the nacelles of wind turbines. Wind speed and direction is measured at meteorological towers at different height 60-80-97m. Additionally at the meteorological towers' ambient temperature together with the barometric pressure is measured. Each year the devices measuring the meteorological parameters are calibrated.

Furthermore, under the disposal of the Fantanel Cogelac wind farm there is a device called LiDAR, which is applied for the measurement of wind speed at the farm site, power curve determination and power generation and meteorological measurement calibration purposes.

Each day the day ahead probabilistic forecast of wind speed and power generation is delivered to the wind farm. Those predictions are updated each hour.

USAID Energy Program

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