NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind Plant Performance Prediction (WP3) Benchmarking Project

Version:	Draft V2
Date:	December 23, 2017
Prepared by:	Jason Fields
Reviewed by:	

1617 Cole Boulevard
Golden, CO 80401-3305
Phone: 303-275-3000

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Table of Contents

List of Figures

List of Tables

1 Overview

An industry consortium (IC) has requested that the National Renewable Energy Laboratory (NREL) undertake a validation to benchmark consultant provided wind farm pre-construction energy assessments. Consultants and other participants will be referred to as "third-party participants" (TPPs) herein. This document is intended to detail the proposed scope of work and schedule for the project. Additionally, it will detail the division of responsibility between entities and clearly outline the expectations for project success and participation. This project represents an unprecedented platform for data sharing and wind industry advancement including pre-construction and operational data from up to 100 or more modern operational wind projects.

1.1 Project Motivation

For years, the wind industry has struggled with poor accuracy in energy estimates for new facilities. This has impacted our credibility with investors, and increases risk for project owners. Over time, large consultants with access to operating wind farm data have been able to validate their methods by comparing predicted to actual production. However, each consultant has a different dataset for validation and different methods and definitions for what should be eliminated from the study, making it hard for the rest of the industry to know what to make of the results. In addition, newer entrants to the WRA market have emerged but have been largely unsuccessful at gathering operating wind farm data in volumes sufficient to perform a meaningful validation exercise. Industry progress in the WRA field has slowed as a result - The average one standard error uncertainty for US wind projects is 7%. When a 3% deviation in energy from P50 means $17MM in NPV (typical 200MW project in Texas), this is not an acceptable level of uncertainty.

Additionally it is important to continue to reduce the Levelized Cost of Energy (LCOE) from wind plants due to increasing price pressure in US markets. One such way to reduce the LCOE is to reduce the risk profile for capital investors and thereby reduce the risk premium as well. Early estimates indicate that there is an opportunity to reduce the LCOE by ~10% through risk reduction activities.

As individual organizations, we can have a limited impact on this problem due to sample size and organizational risk. As a group, we can put a statistically significant number of projects in the hands of scientists that want to solve this problem of poor accuracy and high uncertainty.

1.2 Project Goals

1. Generate accurate, independent benchmarks of pre-construction energy assessments
2. Improve accuracy and reduce uncertainty in pre-construction energy estimates
3. Create a platform for sharing data to advance the state-of-the-science for pre-construction energy assessments.

1.3 Project Outcomes

1. Report(s) outlining summary of benchmarking exercise for industry consumption
   a) Verify accuracy of Annual Energy Production (AEP) prediction process including:

   i) Loss estimation process
   ii) P50 central estimate values
   iii) Uncertainty estimation process (P75, P90, P95, P99 values)
   b) Define sources of deficiency in pre-construction energy estimates
2. U.S. Department of Energy (DOE) access to high-quality data sets for research projects (Pending proprietary information (PI) owner approval)
   a) Prioritization of future research and development (R&D) projects
   b) Recommendations for bias correction and physical model improvements

1.4 Stakeholder Interests

Owner/Developer

- Verify consultant energy estimate methodology bias or lack of bias
- Verify uncertainty estimate accuracy
- Determine main drivers of project performance variance from estimate
- Establish path to move toward greater accuracy.

Consultants

- Prove methods are unbiased
- Improve credibility with developers, owners, and investors
- Improve pre-construction methods via operational data sets.

NREL/DOE

- Serve as an independent data broker for industry advancement
- Materially reduce the Levelized Cost of Energy (LCOE) of wind energy
- Conduct R&D using real data
- Create benchmarking report
- Prioritize future R&D agenda using data driven approach
- Improve alignment between industry and DOE/NREL through supported Joint Industry Project.

2 Wind Plant Performance Prediction (WP3) Stakeholder Responsibilities

2.1 Technical Work Activities

The benchmarking exercise will rely on input from the Industry Consortium (IC) and Third Party Participants (TPP) to ensure that the project offers maximum value for all stakeholders. This input includes the design of experiment and execution of the technical work where appropriate.

Industry Consortium

The IC will provide wind plant pre-construction and operational data to NREL in a uniform organized and documented fashion. The IC will be available for specific questions, clarifications, and processing of the data as needed. The IC will provide feedback on the design of experiment approach and final parameters. Additionally, the IC will make itself available to discuss the project approach and results on an as-needed basis.

Third Party Participants

The benchmark participants will provide feedback on the design of experiment approach and final parameters. Additionally, the benchmark participants will make themselves available to discuss the project approach and results on an as-needed basis. The benchmark participants will be available for specific questions, clarifications, and processing of the data as needed. They are expected to complete the response information and templates as agreed upon in the design of experiment.

2.2 Data Confidentiality Considerations

The benchmarking exercise will be designed to ensure that PI is used to generate meaningful improvements in pre-construction energy estimation methodology for the benefit of all industry participants. PI will be protected by nondisclosure agreements between NREL and the benchmark participants. Some specific considerations for PI stakeholder groups are included as follows.

Industry Consortium

The IC will have control over the usage and application of shared data sets including but not limited to the option of DOE-related research activities. Data will be grouped and anonymized for reporting purposes. No project- or owner-specific data will be disclosed publicly.

Third Party Participants

Benchmark participants are only allowed to discuss the PI directly with NREL. They will be able to have their methods benchmarked against the broader field of anonymized respondents and are expected to erase PI at the conclusion of the benchmarking project.

3 Project Structure

The project structure will have NREL act as the independent broker of information between the Industry Consortium and the Third Party Participants. NREL will interface directly with the IC for data sharing and contracting. NREL will then interface directly with the TPP to transmit project data and receive benchmark submissions, all while under the protection of contracts, which will protect the IC data from further commercial use.

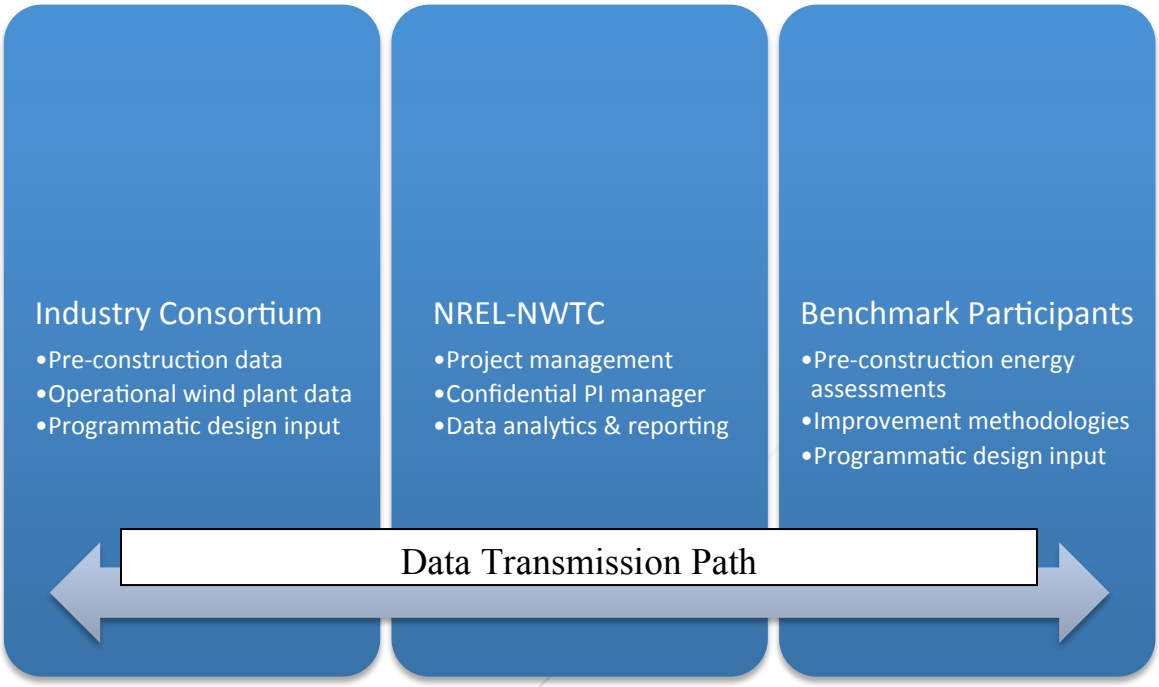

Figure 1. Project Structure Overview

Industry consortium partners: EDF RE, EDPR, Pattern Energy, RES Americas, E-ON C&R
Potential additional partners: ENEL, Brookfield Renewable Power, Avangrid, Apex, NextEra.

Potential benchmark participants: DNV-GL, AWS Truepower, Natural Power, Vaisala, Prevailing Analysis, V-Bar, WSP, Ensemble Wind, Sgurr.

Table 1. Contact Details

Role	Designate	Contact
NREL Point of Contact	Jason Fields	jason.fields@nrel.gov +1 303 384 7150
Industry Consortium Point of Contact	Erik Hale, EDF-RE	erik.hale@edf-re.com
Benchmark Participants	TBD	Contact through J. Fields
NREL Business Support	Tiffany Byrne	tiffany.byrne@nrel.gov

		+1 303-275-4907

4 Approach

The IC will transfer project data to NREL for cataloging and disbursement to the TPP. NREL will facilitate confidentiality agreements as well as manage the technical responses from the TPP. NREL will then analyze responses and report on the accuracy of pre-construction estimate methodologies compared to actual production. The full details and data metrics will be agreed upon in the design of experiment. Upon submission of project pre-construction energy yield assessments (EYA), the TPP will then be given access to operational data for the wind farms and asked to calibrate their EYA estimates. The results of the calibration process will be aggregated and reported on in Phase 3.

- Phase 1. Project setup and design of experiment
- Phase 2. Pre-construction energy estimate benchmarking
- Phase 3. Pre-construction methodology improvement with operational wind farm data.

After successful completion of a single pilot project, it is anticipated that the benchmark project will enter an ongoing cycle of prediction benchmarking followed by prediction improvement. This will be an integrated, ongoing process to facilitate TPP partners of various capacities. It is also logistically challenging and labor- and time-intensive to complete energy yield predictions. Therefore, an ongoing cycle is required to process as many projects as possible in the benchmarking study.

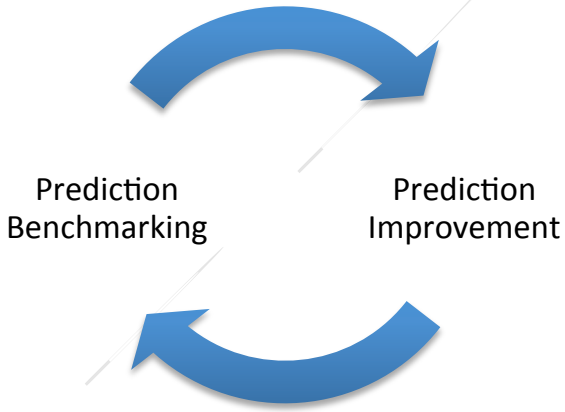

Figure 2. WP3 Process Cycle

4.1 Design of Experiment

Design of Experiment will consist of identifying the proper workflows, deliverables, calculations and metrics. This phase of the project will ensure that stakeholder needs, logistics challenges, and end-user requirements are all addressed. There will be multiple iterative discussions on the project workflow in addition to the level of public disclosure acceptable to project partners. This iteration will be conducted in the form of hosted discussions and document reviews.

Pilot Project

The pilot project will be a trial run to debug the process. A single project will be given to TPP to conduct an EYA. In parallel NREL will perform an operational assessment (OA) of that project. NREL will then aggregate the EYA results and compare them with the OA baseline. The results will be aggregated and displayed in the proposed format of the final public report. Stakeholder comments will be taken and integrated into the final rules and procedures for the Wind Plant Performance Prediction (WP3) project. Additionally, NREL will make available the details of the OA and EYA aggregation procedures so that partners can review and validate the process. This will be made available via an online code repository, which can be downloaded and tested independently. Additionally the use of an online repository will allow for all partners to contribute to the process thereby leveraging the collective knowledge of the industry.

4.2 Project Block One

Project Block One represents the formal launch of the WP3 project. TPP will be given pre-construction data for 10 wind projects. The TPP will return an EYA for those 10 projects, which will be aggregated by NREL and compared with the OA baseline. Upon completion of the 10 EYAs, the TPPs will receive operational data for those projects. The TPPs will then have an opportunity to revise their methods based on the operational data. Both the initial EYA and the revision will be included in the final results summary along with a high-level explanation of the revision.

Project Block One-Revision Cycle

The TPPs will be given an opportunity to revise their EYA for project block one after receiving the operational data. This revision is not intended to be a bias correction but representative of a methodological change, which would apply to all projects or subsets of projects with common characteristics. The EYA method change should be documented such that it is clear to external parties the rationale for the revision and how it would be applied in future EYAs.

4.3 Self-Paced Project Cycle

After completion of the first 10 projects, the TPPs will be able to move through the projects at their own pace based on their own budgets and time availability. Projects will be disbursed in blocks of five. The EYA for all five projects must be completed before receiving the operational data. EYA response aggregation and public reporting will then be performed on an ongoing basis every 3-6 months. TPP submissions will be included in the report as they are available. The report release will happen on a quarterly or biannual basis.

4.4 Project execution methodology

The complex and multi-faceted nature of the project requires an open, collaborative platform for success and to foster stakeholder buy in. The appropriate platform is a blend of technologies that are openly accessible to all stakeholders combined with a rigorous documentation and

transparency approach. NREL is following the reproducible research[1] protocol in order to attain this high level of transparency, repeatability and consistency throughout the project. All code and documentation will be published on the public NREL github.com site:

- Technical documentation: https://github.com/NREL/wp3-docs
- Post-construction codebase: https://github.com/NREL/wp3-postcon (not yet live)
- Pre-construction codebase: https://github.com/NREL/wp3-precon (not yet live)

The work flow diagram in Figure 3 shows the various aspects of the Operational Assessment and Pre-construction EYA aggregation activities. This includes data ingest, quality control, normalization, and analysis:

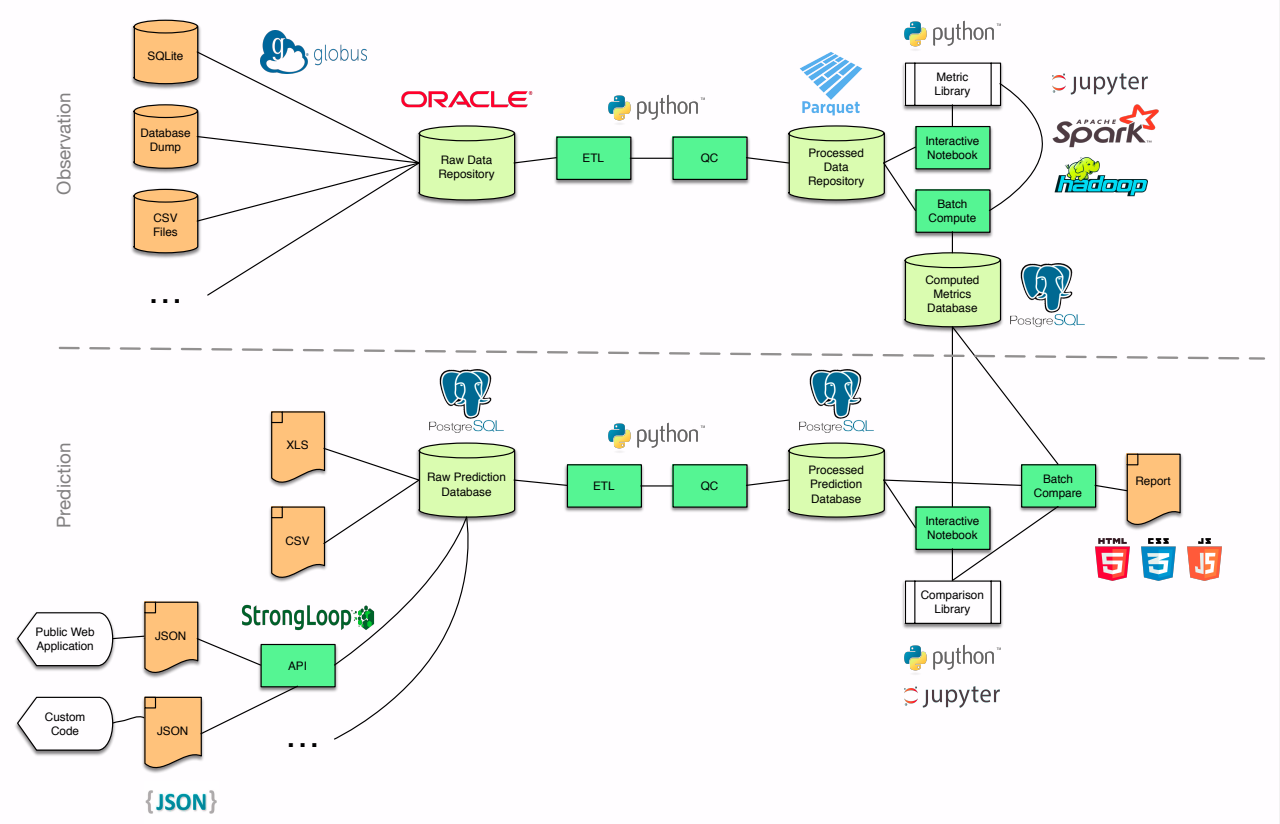

Figure 3. WP3 Benchmarking Process Diagram

Operational Assessment

NREL will develop an operational assessment methodology that can integrate multiple operational wind plant datasets into a single uniform database. This database can then be queried

[1] Reproducible Research is described in greater detail here: https://github.com/NREL/wp3-docs/blob/master/reproducible_research.md

for a variety of metrics that can be compared to pre-construction EYA values. The exact metrics and calculation methodologies will be discussed amongst the project stakeholders and will strive to fulfill the project objectives of identifying project losses, uncertainties and P50 performance levels. The use of a GitHub repository will also allow project stakeholders to contribute directly to the calculation methodologies thereby utilizing the best available practices and knowledge across the industry. The operational assessment will utilize existing standards and industry best practices such as IEC 61400-26, ORAPwind, and NERC GADS.

Pre-construction Energy Yield Assessment Aggregation

NREL will in conjunction with stakeholders develop a common energy yield assessment template that is based upon industry best practice. This common format is currently a pre-publication version of the IEC 61400-15 framework and will ensure that results from pre-construction energy estimates are similar and facilitate an "apples to apples" comparison. The exact content and transmission mechanism for the template will be finalized during the design of experiment and tested during the pilot project. The exact metrics and calculation methodologies for pre-construction EYA will be discussed amongst the project stakeholders and will strive to fulfill the project objectives of identifying project losses, uncertainties and P50 performance levels. The use of a github repository will also allow project stakeholders to contribute directly to the aggregation methodologies thereby utilizing the best available practices and knowledge across the industry.

5 Schedule

The experiment will commence no later than 1 month after the notice to Proceed has been received along with all funds and equipment. If a delay is expected, JIP participants will receive notification in writing. Below is a tentative schedule based on a notice to proceed and funds as of January 1, 2017.

Design of Experiment	Oct to Dec 2016
Pilot Project	Jan to Jun 2017
Project Block 1 (First 10 Projects)	Jul 2017 to Mar 2018
Improvement Cycle	Mar 2018 to Nov 2018
Self-Paced Cycle (Five project blocks)	Mar 2018 to Sep 2019

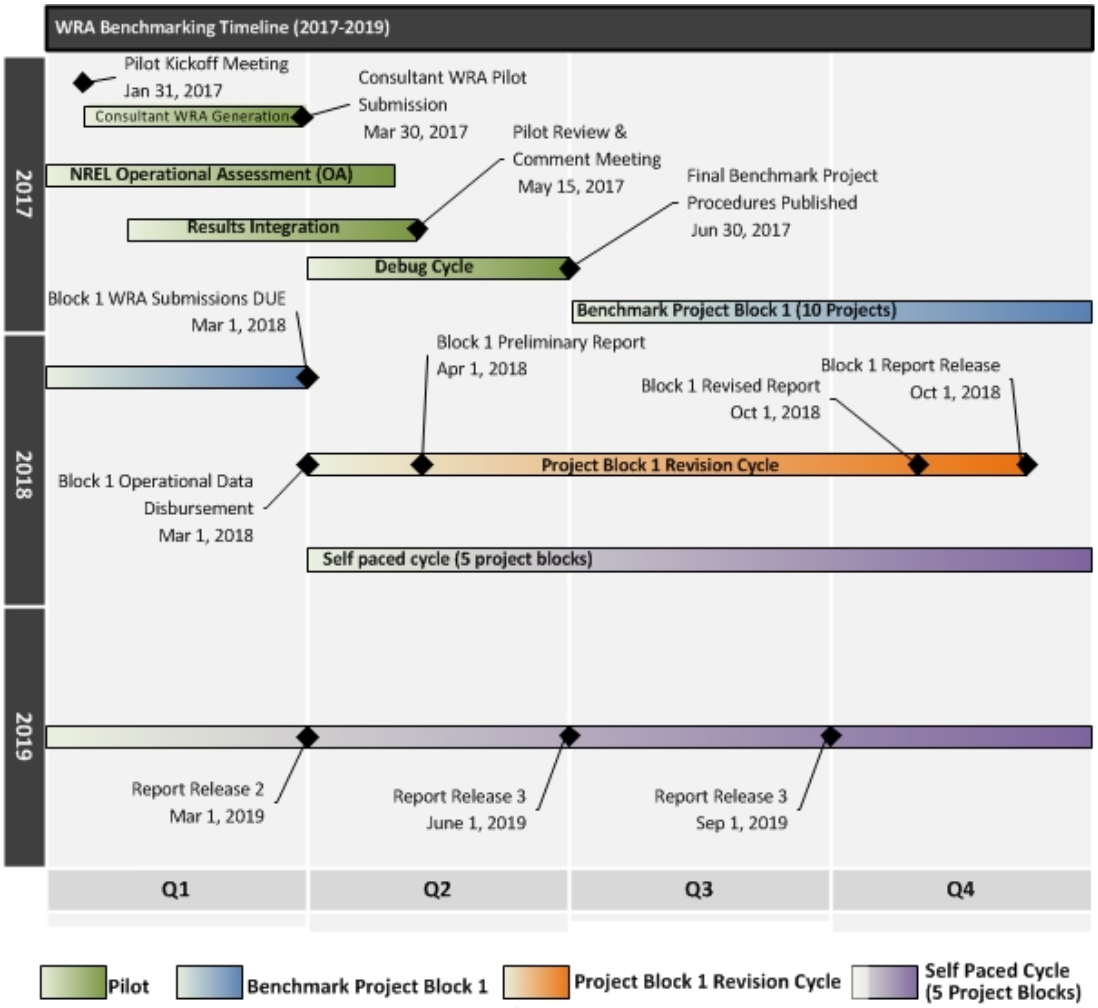

Figure 4. Wind plant performance prediction (WP3) benchmarking timeline

6 Deliverables

1. Industry Consortium
    a. Pre-construction and operational data sets delivered to NREL
    b. Participation in ongoing meetings and project work
2. Third-party participants
    a. Perform energy yield assessments
    b. Report on improved methods based on operational data
3. WP3 Benchmark Organizer (NREL)
    a. Operational assessment process
    b. Energy yield assessment aggregation process
    c. Public reporting.

Appendix A: WRA Benchmark Project Scope

This section describes the scope of the project and specific implementation details for how the benchmark initiative will operate.

1. Project Rules and Requirements
   a) Benchmark participant selection/qualification
      i) Requirements
         (1) TPP may not have financial stake in development/ownership of wind projects
         (2) Use of Energy Information Administration (EIA) or other available data sources regarding the operation of the facilities in question is strictly prohibited
      ii) IC to establish board to vote on participation; 80% rate to pass; "No" votes may withhold data from that TPP in question
      iii) Expectations of TPP
         (1) Consultants will provide results to NREL in a standard template provided by NREL
         (2) Consultants will provide methodology used for projects and information on repeatability of methods
   b) Wind Project Eligibility
      i) Owners provide list of projects that meet the following criteria:
         (1) Age: 2005 or later
         (2) Project size: 20 MW or larger (pending discretion from NREL and owner)
         (3) Geography: United States and territories (additional phases later may include other regions)
         (4) Hub height of at least 65 meters above ground
         (5) Turbine original equipment manufacturer: viable turbine technology is from original equipment manufacturers who are capable of actively supporting turbines from a warranty and O&M perspective (e.g., not Clipper) {NREL's discretion}
         (6) Project duration: 1 year minimum, 3 years preferred
         (7) Operations: documented O&M strategy including any upgrades or modifications (e.g., Power up)
         (8) Ten-minute turbine-level data (SCADA)
         (9) Curtailment: minimum monthly curtailment values; preferred is hourly or finer temporal resolution of curtailment signals from utility
      ii) NREL identifies the projects to be contributed to the study by the IC using the following criteria:
         (1) Proportional allocation by contributing IC member
         (2) Climate diversity
            (a) Define distinct climates (either through objective criteria or by regions)
            (b) Number and priority of projects in the regions; concepts for project selection:
               (i) Go through regions sequentially; 10 projects in plains, then 10 in east, then 10 in west, and so on
               (ii) Distribute projects weighted by future development activity or existing wind operation
               (iii) Distribute projects evenly by region
   c) Data Dissemination
      i) Data will be transmitted to partners in the following order:
         (1) Pilot project (single project)
         (2) Project block 1 (10 projects selected by WP3 members and NREL)
         (3) Self-paced blocks (five projects at a time)
         (4) See Figure for timeline

ii) Consultant must provide results (EYA) for existing project block data sets prior to receiving new data sets (pre-construction or operational)

iii) Pre-construction data package (Pacific Northwest National Laboratory to TPP)–
This should be considered as similar to a data package that would be used for project due diligence.

(1) Data delivery
  (a) Data transmission to TPP will be through the Atmosphere to Electrons Data Access Portal, which offers secure data transmission and management capabilities; (https://a2e.pnnl.gov/about/dap)

(2) Turbine information
  (a) Turbine model, rated capacity, hub height, rotor diameter
  (b) Power curves (if available)
  (c) Wind plant and turbine layout
  (d) Roads and electrical infrastructure

(3) Raw meteorological data files and metadata
  (a) Meteorological tower/device location, type, deployment duration
  (b) 10-min raw data

(4) Pertinent contractual information (as it impacts WRA prediction)
  (a) Turbine availability guarantee values
  (b) Turbine power curve guarantee values
  (c) Wind plant curtailment/interconnection guarantees

(5) Site and environmental characteristics
  (a) Terrain information
  (b) Land cover

iv) Operational data set (Pacific Northwest National Laboratory to TPP)

(1) Data delivery: data transmission to TPP will be through the Atmosphere to Electrons Data Access Portal, which offers secure data transmission and management capabilities; https://a2e.pnnl.gov/about/dap

(2) Shared as TPP returns completed EYA (e.g., block 1 projects EYA completed, TPP then receives the next 5 projects, and so on)

(3) 10-min park-level data
  (a) Meteorological towers/remote sensing (only if available)
    (i) Wind speed
    (ii) Direction
    (iii) Temperature (optional)
    (iv) Pressure (optional)
    (v) Humidity (optional)
    (vi) Vertical velocity (optional)
  (b) Plant output (substation or revenue meter)

(4) 10-min turbine-level SCADA
  (a) Nacelle wind speed (provide documentation on the transfer function applied to the anemometer signal)
  (b) Output
  (c) Yaw direction (optional)
  (d) Availability tags

d) Reporting

i) Guidelines and timing

(1) NREL to issue first report at 10 projects

(2) TPP will be provided with an advance copy of the report and be given an opportunity to provide an improved estimate based on operational data; both the original estimate (V1) and improved estimate (V2) will be reported
(3) After completion of first 10 projects, NREL will then begin a rolling report cycle; additional TPP results will be included as they complete EYA and submit prior to deadline
(4) Project-level performance feedback (can owners sign off?) with unique project ID's

ii) Report outline
(1) Benchmarking project goals and objectives
(2) Benchmark evaluation methodology
(a) Benchmarking metrics
(3) Benchmarking participant submission template
(4) Summary of pre-construction data sets and operational data sets (anonymized to protect IP considerations)
(a) Number of data sets
(b) Distribution of project size and turbine technology
(c) Distribution of project age
(5) Summary of IC and benchmark participants (anonymized)
(a) TPP will be given a random ID; TPP may choose to release the given ID
(b) Report shall indicate number of projects completed
(c) Report shall indicate the relative number of projects completed compared to other participants
(d)
(6) Results
(a) Detailed benchmarking test metrics
(i) P50 estimate for each project (anonymized) compared to baseline (per the NREL OA)
(ii) Distribution of results: P50 estimate vs. OA (classic histogram)
(iii) Loss category comparison to industry (i.e., consultant A average wake loss vs. others, electrical vs. others, and so on). Comparisons to be made for the same project grouping (10, 15, 20, and so on)
(7) Uncertainty estimate comparison to industry (same as loss concept above); comparisons to be made for the same project grouping (10, 20, 30, and so on)
(8) Variance vs. uncertainty plot of projects

2. Project Structure and Workflow
a) Project design of experiment
b) Pilot project
c) Project block 1
d) Self-paced project assessment.