Version June 2020

Sustainable Energy Authority of Ireland

National Energy Research, Development & Demonstration Funding Programme

FINAL REPORT TEMPLATE

SECTION 1: PROJECT DETAILS – FOR PUBLICATION

Project Title	Robust Real-Time **Wind** Power **P**rediction and **Earl**y, **A**ccurate **E**stimation of **D**owntime for Irish Wind Farms in an Integrated Single Electricity Market (**Wind-PEarlAED**)
Lead Grantee (Organisation)	University College Dublin (UCD)
Lead Grantee (Name)	Vikram Pakrashi
Final Report Prepared By	Vikram Pakrashi
Report Submission Date	07/10/2022

	Name	**Organisation**
Project Partner(s)	Bidisha Ghosh	Trinity College Dublin
Collaborators	John Kinsella Edward McGarrigle	WFSO Ltd., Cork Electroroute

Project Summary (max 500 words)
This project improved operations & maintenance (O&M) of onshore wind turbine farms in Ireland through bespoke data analytics, focusing on early and accurate downtime prediction and improved short term wind forecasts. The results are transformative and allows for real-time capabilities. The methods are adaptable to uncertain, imperfect or poor data and signifies a philosophical shift from individual numbers of probabilistic estimates. The project combines bespoke fundamental methods, their feasibility study and demonstration using authentic, real-data from several wind farms in Ireland. Improved methodologies developed were calibrated and implemented via novel software tools and a wide range of scenarios of implementation and data conditions were considered. Guidelines and recommendations for selecting, implementing and interpreting the methods and their results were presented. *The results form the most authoritative evidence base around the topic for Ireland and is also a global benchmark. Errors, performance metrices and uncertainties were calibrated and investigated extensively for appropriate comparison of different methods and approaches, along with limitations. It also allows for transparency of methods. The results lead to better O&M, with impact on addressing increased wind turbine availability, reduction in operational costs and reduction in uncertainties around short term energy prediction. The results also link with evolving and bourgeoning aspects around monitoring of wind turbines and create a multi-disciplinary*

approach leading to a wider impact on such challenges. Finally, the project demonstrates how such industry-aware and contemporary solutions and insights can be developed within a 'public good' framework through National funding.

Keywords (min 3 and max 10)	Wind Turbine, Forecast, Power Curve, Downtime, Integrated Single Electricity Market, Uncertainty, Operations and Maintenance, Time-Series, Anomaly Detection, Bayesian Statistics, Machine Learning

NB – Both Section 1 and Section 2 of this Final Report will be made publicly available in a Final Technical Report uploaded online to the National Energy Research Database.

In the following Section, please provide a clear overview of your project, including details of the key findings, outcomes and recommendations. The section headings below are provided as a guide, please update or add to these as best suits your project.

By submitting this project report to SEAI, you confirm you are happy for Section 1 and Section 2 of this report to be made publicly available. If you wish to request edits to this section in advance of publication, please contact SEAI at EnergyResearch@seai.ie.

SECTION 2: FINAL TECHNICAL REPORT – FOR PUBLICATION (max 10 pages)

2.1 Executive Summary

This project improved operations & maintenance (O&M) of onshore wind turbine farms in Ireland through bespoke data analytics, focusing on early and accurate downtime prediction and improved short term wind forecasts. The results are transformative and allows for real-time capabilities. The methods are adaptable to uncertain, imperfect or poor data and signifies a philosophical shift from individual numbers of probabilistic estimates. The project combines bespoke fundamental methods, their feasibility study and demonstration using authentic, real-data from several wind farms in Ireland. Improved methodologies developed were calibrated and implemented via novel software tools and a wide range of scenarios of implementation and data conditions were considered. Guidelines and recommendations for selecting, implementing and interpreting the methods and their results were presented.

The results form the most authoritative evidence base around the topic for Ireland and is also a global benchmark. Errors, performance metrices and uncertainties were calibrated and investigated extensively for appropriate comparison of different methods and approaches, along with limitations. It also allows for transparency of methods. The results lead to better O&M, with impact on addressing increased wind turbine availability, reduction in operational costs and reduction in uncertainties around short term energy prediction. The results also link with evolving and bourgeoning aspects around monitoring of wind turbines and create a multi-disciplinary approach leading to a wider impact on such challenges. Finally, the project demonstrates how such industry-aware and contemporary solutions and insights can be developed within a 'public good' framework through National funding.

2.2 Introduction to Project

Improved and real-time power curve forecasts along with updating for site-specific and turbine specific information can lead to O&M improvements. Additionally, early and accurate detection of deficiencies leading to downtime along with classification of downtime signatures can further improve the efficiency of wind farms. Quantitative estimates around the performance of these work improve contracts or agreements where vague definition might be present. Better power forecast and downtime estimate can reduce epistemic uncertainties around availability data. Demands for short term wind power forecasting remain relevant including forecasts for site-specific and turbine-specific conditions and there are needs for wind power predictions with improved confidence levels and estimates of uncertainties. There is a need to create appropriate benchmarks using Irish data around such topics. Until this project, there was no such evidence base on this topic for Ireland. On the other hand, several scientific novelty presented in the project was not available globally. The project thus addresses the needs of:

- Early, accurate downtime detection and improved short term power forecasting dedicated towards Irish conditions and using data from Irish wind-farms.
- Adequate benchmarking of methodologies for site-specific Irish conditions.
- Adaptation of numerical algorithms from other fields for prediction and downtime detection by exploiting their full potential

- Mapping the unexplored area of errors and performance metrices on field data.
- Understanding of uncertain, missing and poor datasets for various scenarios and their impact on
- detection/forecasting and downtime detection and classification.
- Creating evidence based guidelines and recommendations for choice of methods of analysis and related performance metrices or features.

2.3 Project Objectives

[O1] Development of bespoke, robust and demonstrable better methodology for accurate, early detection of wind farm downtime and accurate wind turbine power curve forecasts.

[O2] Comprehensive calibration of the developed models using real wind-farm data.

[O3] Direct use of authentic wind-farm data for development of methodologies and implementation of the methods for operational wind-farms in Ireland in the form of a software.

[O4] Creation of a comprehensive evidence base for the developed methodologies with estimates of errors, inaccuracies and limitations of implementation.

[O5] Creating guidelines, recommendations and solutions for transferability and scalability of developed methods for site-specific Irish conditions and for availability of data, including solutions for handling poor data, missing data and unknown patterns in data.

[O6] Developing insights of the impact of developed solutions on the business operations and maintenance of wind turbines

2.4 Summary of Key Findings/Outcomes

The key findings of the projects and its outcomes are summarised below.

Science

- ***Innovation 1: A comprehensive short-term wind power forecasting repository for Ireland***

Summary: The project developed the most comprehensive and authoritative evidence base for short-term forecasting for Ireland. While achieving this, the project used wind farm data from multiple locations in Ireland and implemented current and bespoke, improved suite of methods. A comprehensive study was carried out in this regard and the methodological detail was shared publicly with full clarity for others to use, encouraging replicability and transparency of methods.

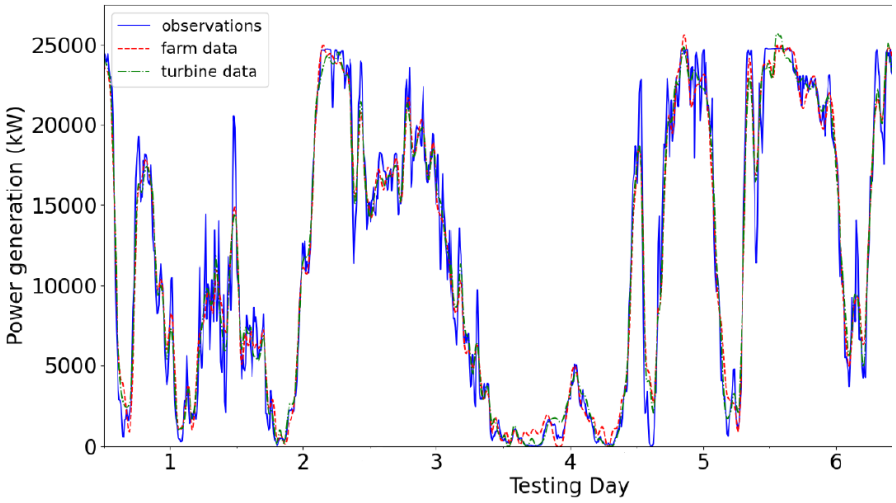

Figure 1. Short Term Wind Power Prediction: Irish Data

The work demonstrates innovations and applications in time-series and AI in such data in a globally novel manner.

- ***Innovation 2: Creation of a novel early downtime detection and classification framework***

Summary: A novel high-order eigenperturbative framework was created and demonstrated on multiple wind farms on how early downtime detection can be achieved in a real-time paradigm. This innovation was subsequently augmented with machine learning approaches to classify the downtime detection signatures.

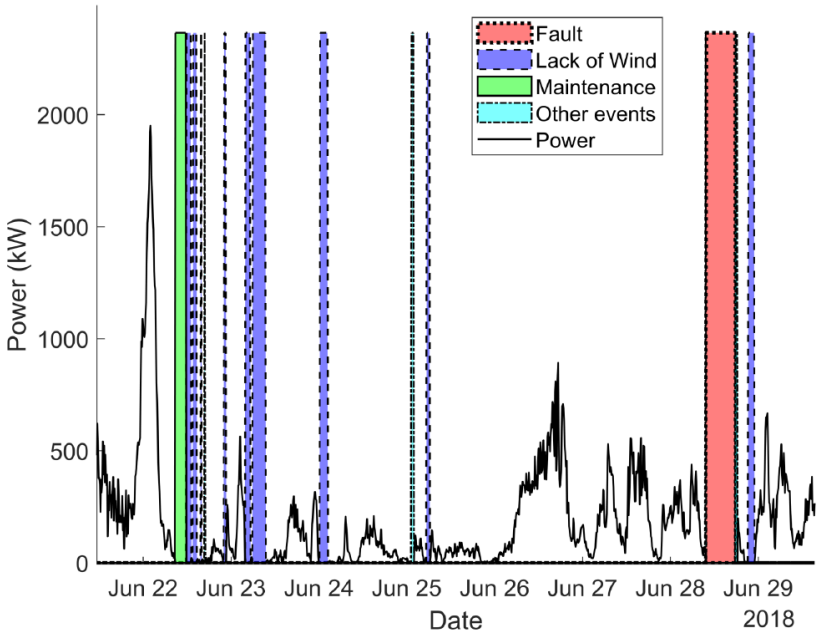

Figure 2. Real-Time Wind Power Downtime Detection and Classification

- ***Innovation 3: Creation of a comprehensive performance benchmark of developed methods***

Summary: The work highlighted the importance of understanding errors and performance metrices of developed methods and created the most comprehensive benchmark for Ireland and one of the most detailed benchmarks globally. The quantified performances, a movement towards probabilistic estimates, the limits of performance and the interpretation of errors provide a clear and fair way of choosing and comparing methods. This emphasis on errors and performance makes the project particularly robust, important and better aligned to ground realities of wind power data as compared developing new methods for methodological novelty alone.

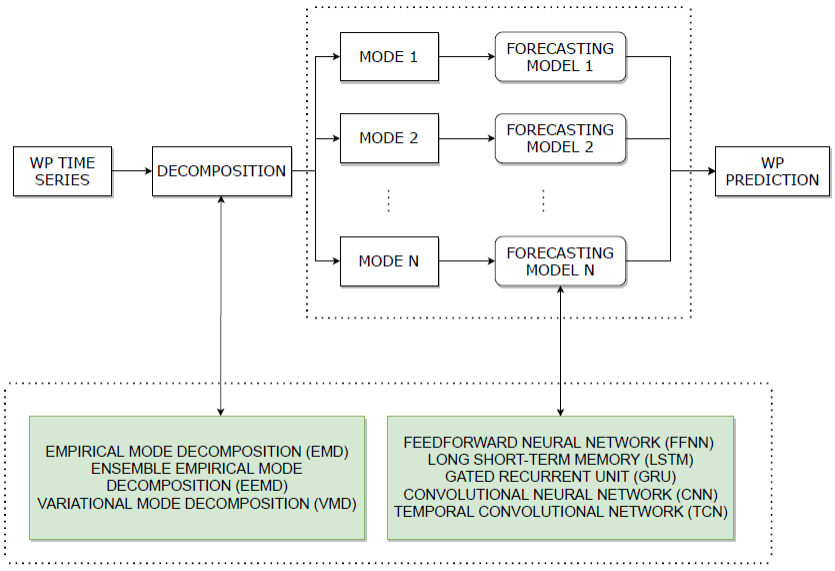

Figure 3. An example of decomposition based hybrid models for short term prediction.

Technology

- ***Innovation 1: A software suite for short-term time series prediction***

Summary: The project developed a software suite for short-term prediction of wind power along with related errors and performance metrices for comparison of different methods. This software suite can be implemented for any new dataset and guidelines and recommendations for its implementation are also developed.

- ***Innovation 2: A software suite for early downtime detection and characterisation***

Summary: The project developed a software suite for early downtime detection and characterisation along with related errors and performance metrices. This software suite can be implemented for any new dataset and guidelines and recommendations for its implementation are also developed. The tools allow for real-time and near real-time detection.

Figure 4. A turbine downtime detection and classification software tool

- ***Innovation 3: Adaptation to a neuromorphic framework for computing***

Summary: The project adapted short-term energy forecasting applications within a neuromorphic framework for computing. This was carried out in collaboration with Intel Neuromorphic Research Community. Apart from this implementation, the innovation paves way for future edge computing solutions in this area.

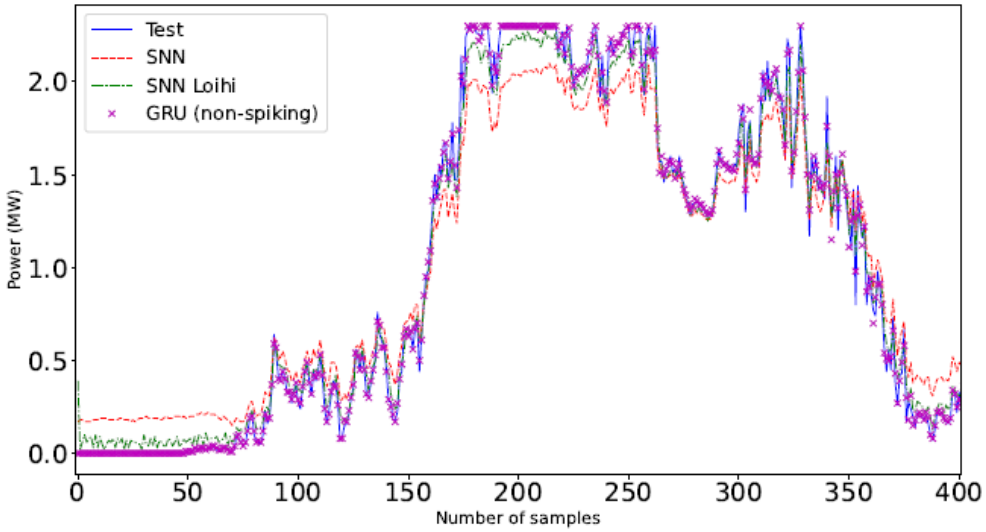

Figure 5. Adaptation of short term forecasting to a neuromorphic computing paradigm

Practice

- ***Innovation 1: A movement towards probabilistic estimates***

Summary: The work established through its comprehensive repository of performance metrices and errors a philosophical move from individual numbers to probabilistic estimates. This will continue to be an important aspect globally and has been discussed in the International Energy Agency Task 51 meeting in Dublin in 2022.

- ***Innovation 2: Creating a case for robustness over best performance***

Summary: The work established how, within a group of models, methods and metrices the performance of the best is often a function of what dataset or what type of data is used. Under such circumstances, the search for best model can often be less useful than the search of a set of models, methods or metrices that are collectively robust and also provide overall similar performance. One prevails to a certain extent over the other based on the situation but following guidelines and recommendations presented in the project, this collective approach creates a stable and robust performance – which is a new way of approaching current practice where the search of a single and best method, model or metric is often popular.

Essential reading from the outcomes of the project include:

González-Sopeña, J. M., Pakrashi, V., & Ghosh, B. (2021). An overview of performance evaluation metrics for short-term statistical wind power forecasting. Renewable and Sustainable Energy Reviews, 138, 110515.

Srbinovski, B., Temko, A., Leahy, P., Pakrashi, V., & Popovici, E. (2021). Gaussian mixture models for site-specific wind turbine power curves. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 235(3), 494-505.

Mucchielli, P., B. Bhowmik, B. Ghosh, and V. Pakrashi. "Real-time accurate detection of wind turbine downtime-An Irish perspective." Renewable Energy 179 (2021): 1969-1989.

Sopeña, Juan Manuel González, Vikram Pakrashi, and Bidisha Ghosh. "A spiking neural network based wind power forecasting model for neuromorphic devices." Energies 15, no. 19 (2022): 7256.

Sopeña, JM González, C. Maury, V. Pakrashi, and B. Ghosh. "Turbine-level clustering for improved short-term wind power forecasting." In Journal of Physics: Conference Series, vol. 2265, no. 2, p. 022052. IOP Publishing, 2022.

Sopeña, Juan Manuel González, Vikram Pakrashi, and Bidisha Ghosh. "Can we improve short-term wind power forecasts using turbine-level data? A case study in Ireland." In 2021 IEEE Madrid PowerTech, pp. 1-6. IEEE, 2021.

2.5 Project Impact

Clearly position the impact of your project with reference to the needs of the Irish Energy Sector, national and international policy objectives, and SEAI's remit.
Discuss the key impacts of your project: societal, economic, technological or otherwise. Clearly identify and highlight the value of your project in the wider context.

The project creates the first benchmark in Ireland on the topic of short term wind power forecasting, its errors, performance metrics and downtime detection and classification of the turbine farms using field-data. The work provides a clarity in terms of their choice, use, implementation, interpretation and comparison and remains a reference for similar questions in a global context. To achieve this novel methods, algorithms, numerical models and approaches have been considered and the scientific rigour of such novelty is well established through extensive publications. A significant aspect of the project has been in its ability to extend to new horizons of technology through the demonstration of how neuromorphic computing can be an important aspect, paving way for future decentralised and edge applications. Also important is the interdependence of the algorithms which were adapted multidisciplinarily from other sectors, adapted for the current problem – and subsequently was improved to apply to further sectors. In this way, the project is also demonstrative of the potential of a multidisciplinary approach for such complex problems. The project trained some excellent individuals in this topic and the detailed impacts are discussed below.

The project addresses the need for wind farms to be more efficient, especially in O&M as per 2009 EU Renewable Energy Directive target and National Energy Efficiency Action Plan (NREAP) 2020 targets. Pandemic and international armed conflicts were unthinkable during the time of application, but these have also created newer focus towards trying to make wind energy more efficient. The work in this project can be used for improvement of services through O&M and in terms of contracts. Often, these contracts are managed by local companies (SMEs seem to be popular here) and can thus provide a boost to local businesses. The developed tools provide wind security support in lines with NREAP and does not require further instrumentation. The implementation is shown on real data from multiple wind farms. Consequently, on this topic the project creates a first national guideline with quantitative and qualitative measures of performance as a benchmark.

Economic Impact:

a) The project represents the most comprehensive and authoritative benchmark repository on the downtime detection and short term forecasting methods for wind farms in Ireland to date. This is useful for O&M in wind energy and related companies for creating, implementing, comparing and adapting such solutions freely, since this is a public good project.

b) The work demonstrates the benefit of significant O&M improvement for commercial viability of wind power and this has the potential to creation of jobs in this and related sectors. From this project alone, the trained members in the project has joined academia and industry focused around solutions developed in the project in EU and Asia. Subsequent interactions with one of the industrial destinations on wind power has already started in terms of collaborations in the next step. In the medium term, with such follow up projects, we will continue to influence this sector in terms of niche job creation and the solutions that are aligned to the rapidly evolving face of this subject.

d) The project demonstrates Ireland's capabilities in creating cutting-edge solutions for O&M consulting in the long term.

e) The project took a central role in attracting new funding on this topic. A number of calls around the topic was pursued and 2 new projects on this topic was recently funded.

Note: With the complexities of markets and the way energy trading is carried out, it is unwise to exactly denote a monetary equivalence to the results and their performance metrics as reported for various scenarios. However, for any analysis, these performance metrics can be used for assessing changes in O&M in monetary equivalent terms.

Societal Impact:

a) Improved efficiency of wind power is quantified and what can be achieved through data analytics or AI is now better understood, along with their limitations. These efficiencies can be passed to the society in the medium term.

b) In long term, better O&M approaches through what has been proposed and in the lines of their implementation will lead to the society using more wind energy at a competitive price.

Policy Impact:

The work is an example of how data and evidence-driven policy making in the wind energy sector can be carried out for O&M in Ireland for the wind sector. It also allows for a clear understanding of fair comparison of performances and limitations of various approaches.

a) The developed evidence base and repository, along with associated guidelines and recommendations for implementation and interpretation forms the most authoritative information source in Ireland on this topic and can be adapted for any national guideline purposes. The calibration and other parameters obtained from this project are the first set of calibration and national parameters, which can be subsequently updated as required.

b) The results can influence and resolve possible vagueness around availability contracts by linking back to the performance metrices and their comprehensive assessments for Irish datasets. This can impact how availability contracts and warranties are written for operators and will allow for clearer risk assignment. This can improve correct allocation of availability percentages.

c) The results reduce uncertainty around information and forecast and improve the handling of missing, vague or poor data qualities. This will lead to better risk assessment and substantial improvement in downtime detection and turbine performance forecasts. In medium term ths allows for removing barriers for short-term decision making and make wind energy more competitive.

d) The work will strengthen wind energy in the I-SEM by not only through the evidence base created in the project but also by allowing it to evolve and re-calibrate itself over time as more data is available. This can be achieved through the tools developed. This marks a movement towards dynamic

Figure 6. WindPearl finalist in SEAI Awards 2022

estimation of the wind energy sector close to a real-time basis. This automatically allows for evidence and data-driven policy decisions in the medium term.

e) The work made researchers, traders, policy-makers and asset owners aware of the combined rewards that is to be tangibly obtained from improvements in O&M along with trading advantages. This will influence how decisions are taken in future and the policy orientations for Ireland by involving academia and industry within a 'public good' framework in the long term.

Scientific Impact:

a) A significant number of cutting-edge scientific publications were done in leading journals and conferences establishing the rigour of the work along with its relevance to national, EU and global audiences. Details of publications are presented in this report separately. It also established Ireland as a strong contributor to the global efforts in this topic and put it on the map.

b) Bespoke software tools were developed for short term forecasting and downtime detection. An industrial training was developed and delivered for industry and academia for the various methods developed.

c) Guidance and recommendations were created with related quantitative calibrations for application and adaptation of the developed methods for newer datasets or wind farms. The current benchmark along with various scenarios and related performance metrics remains the most comprehensive work of its kind for this country.

e) The use of real-data from multiple Irish wind farms ensures the applicability of the methods in realistic conditions with associated complexities of real-life datasets.

h) The work led to strategic scientific collaboration with Intel Neuromorphic Research Community.

2.6 Recommendations

Based on the work of the project, a number of recommendations are proposed for researchers, policy makers and for the industry.

Researchers:

R1. There is a strong requirement for creating and maintaining performance metrics for new models of prediction and detection in wind energy context, especially since there is an explosion of such models in literature but not enough comparison.

R2. Rather than trying to go for the 'best model' or 'best feature', there seems to be a strong argument for assessing and identifying a set of robust models and features for prediction and detection whose overall performance are good and one may surpass another based on specific circumstances and datasets.

R3. Investigation of decentralised computing for downtime detection and short term forecasting is an important direction to delve into and it can also allow for early technology adaptation.

R4. Expectations around what AI can detect has to be bounded through benchmarking and extensive testing and the boundaries of their abilities must be clearly understood to establish what is detectable, to what extent and what claims might be brought under further scrutiny.

R5. Physics forms a key constraint in realistic systems like wind power and consequently multi-scale models in spatial and temporal domain, with a better awareness of physics will make the detections and predictions considered in the project more explainable and robust. It will also allow their applicability in different conditions in a wider context, without losing interpretability.

Policy Makers:

R6. Interpretation and understanding of probabilistic estimates for prediction and downtime is required for better O&M – this is a fundamental move from single numbers.

R7. Ireland can play a significant role in this topic globally through niche analysis techniques, especially in the context of International Energy Agency work and O&M sectors in EU and globally.

R8. Better specification of reporting structure and comparison of errors, methods and assumptions around analysis techniques will control and allow for fair performance measures, leading to correct selection, implementation and use of them leading to higher benefits in the O&M sector

Industry:

R9. There is a strong case to move from single numbers to probabilistic estimates. Interpretation of estimates and fair comparison of errors are key to understanding model or algorithm performance.

R10. The search for 'the best' model or feature can be futile and it is better to isolate 'reasonably good' models and features from a long list, along with their applicability to ensure that prediction and detection performances are robust and not sensitive to small changes.

R11. New technologies like edge computing are aligned to the prediction and detection problems but the accuracy levels need to improve before they can compete with centralised computing. However, this gap is being bridged fast.

2.7 Conclusions and Next Steps

The project highlighted the contemporary need from industry, academia and policy makers for the topics covered. It not only created a bespoke repository and benchmark for the topic for Ireland, but also created similar impact globally on these aspects. This public good project created tools around the topics and guidelines of how to use the tools. In terms of prediction, downtime detection and classification, the project not only highlighted the importance of choosing right models, error metrics, features and approaches towards analyses but also established a clear departure in philosophy from single numbers to probabilistic estimates. This is also the direction in which both industry and academia are moving forward as discussed by the IEA Wind Task 51 meeting recently held in Dublin by the Principal Investigator of the project. The project allows for extensive follow up with industry and this is already being pursued. In terms of technology, WindPearl highlighted the ability of the sector to link to edge computing. Also, the project demonstrated the abilities and limitations of being able to classify problems occurring. These error metrics and limitations allow for fair comparison of models, choice of models, choice of features of interest and also ensures that unreasonable results within realistic constraints can be questioned. In the next steps, there will be further work on classification aspects and prediction in the presence of other variables and the choice of groups of features of interest and models rather than a single 'best' model. Close interaction with IEA Wind Tasks will be maintained.

Note - Both Section 3 and Section 4 of this Final Report are required for SEAI review purposes only and will not be made publicly available.

SECTION 3: COMMUNICATION & DISSEMINATION (max 3 pages)

3.1 Communication, Dissemination and Exploitation

Dissemination Summary Tables

Please see tables. More papers under review. Note how structural/vibration related problems encouraged some of the methods for wind and how the improved methods for wind later influenced monitoring/mechanical problems.

3.2 Intellectual Property Management & Exploitation

N/A – Public Goods project

Table 3.1 – List of Scientific Publications

Title	Main Author	Journal Title	Number, Date or Frequency	Publisher	Year of Publication	Is/Will open access be provided? If you marked "will", provide an estimate of the date	Peer-reviewed (Y/N)?
A spiking neural network based wind power forecasting model for neuromorphic devices	González Sopeña J, Ghosh B and Pakrashi V	Energies	15(19), 7256	MDPI	2022	Is	Y
Turbine-level clustering for improved short-term wind power forecasting	Sopeña, JM González, C. Maury, V. Pakrashi, and B. Ghosh	Journal of Physics: Conference Series	2265,2, p. 022052.	IoP	2022	Is	Y
A review of modelling techniques for Floating Offshore Wind Turbines	Otter A, Murphy J, Pakrashi V, Robertson A and Desmond C	Wind Energy	25(5), 831-857.	Wiley	2021	Is	Y
Real-time accurate detection of wind turbine downtime - an Irish perspective.	Mucchielli P, Bhowmik B, Ghosh B and Pakrashi V.	Renewable Energy	179, 1969-1989	Elsevier	2021	Is	Y
An overview of accuracy estimation and uncertainty analysis of wind power forecasts.	González Sopeña JM, Pakrashi V and Ghosh B	Renewable and Sustainable Energy Reviews	138, 110515.	Elsevier	2021	Is	Y

Decomposition-Based Hybrid Models for Very Short-Term Wind Power Forecasting	Sopeña, JMG, Vikram Pakrashi, Bidisha Ghosh.	Engineering Proceedings	5, no. 1	MDPI, Proceedings of ITISE Conf.	2021	Is	Y
Higher-order stabilised perturbation for recursive eigen-decomposition estimation.	Mucchielli P, Bhowmik B, Hazra B and Pakrashi V.	Journal of Vibrations and Acoustics	142(6), 061010.	ASME	2020	Is	Y
Wind Power Prediction and Early Downtime Detection for Ireland.	Pakrashi V, Bhowmik B, González Sopeña JM, Mucchielli P and Ghosh B.	Proceeding on CERI/ITRN2020 Conf, Cork	https://sword.cit.ie /monographs/1/	MTU	2020	Is	Y
An integrated condition monitoring scheme for health state identification of a multi-stage gearbox through Hurst exponent estimates.	Inturi, V SV Balaji, P Gyanam, B Priya, V Pragada,Rajasekharan, Vikram Pakrashi.	Structural Health Monitoring	14759217221092828	Sage	2022	Is	Y
Gaussian Mixture Models for Site-Specific Wind Turbine Power Curves.	Srbinovski B, Temko A, Leahy P, Pakrashi V and Popovici E.	Journal of Power and Energy,	0957650920931729	Proceedings of the Institution of Mechanical Engineers, Part A:	2020	Is	Y
Can we improve short-term wind power forecasts using turbine-level data? A	Sopeña, Juan Manuel González, Vikram Pakrashi, and Bidisha Ghosh.	IEEE Madrid PowerTech Conf	https://ieeexplore.ieee.org/ document/9494805	IEEE Madrid PowerTech Conf	2021	Is	Y

case study in Ireland							
Real time structural modal identification using recursive canonical correlation analysis and application towards online structural damage detection.	Bhowmik B, Tripura T, Hazra B and Pakrashi V.	Journal of Sound and Vibration,	468,115101.	Elsevier	2020	Is	Y
Damping estimation of a pedestrian footbridge – An enhanced frequency-domain automated approach,	Bhowmik B, Hazra B, O'Byrne M, Ghosh B and Pakrashi V.	Journal of Vibroengineering,	23(1), 14-25.	JVE Journals	2021	Is	Y
Structural Design Implications of Combining a Point Absorber with a Wind Turbine Monopile for East and West Coast of Ireland	O'Kelly-Lynch P, Long C, Devoy-McAuliffe F, Murphy J and Pakrashi V.	Renewable and Sustainable Energy Reviews	109583.	Elsevier	2021	Is	Y
First order eigen perturbation techniques for real time damage detection of vibrating	Bhowmik B, Tripura T, Hazra B and Pakrashi V	Applied Mechanics Reviews	71(6): 060801.	ASME	2021	Is	Y

systems: Theory and applications.							
Real-Time Structural Health Monitoring of Vibrating Systems.	Basuraj Bhowmik, Budhaditya Hazra, Vikram Pakrashi	Book by CRC Press	ISBN 9780429351341	CRC Press	2022	No	All work in the book is but the book is not

Note: the papers are available via open access, CC-BY format or preprint in a Romeo-Green format, except for the book which is not a part of open access. However, the book is a welcome addition rather than a core outcome of the project.

Table 3.2 – List of Dissemination Activities

Type of Activity	Main Leader	Title	Date/Period	Location	Type of Audience*	Size of Audience
International Training	*Vikram Pakrashi*	*WindPearl Day*	*1 April 2021*	*Online (Zoom)*	*Researchers, Industry, Policy makers, SEAI (John McCann was there and linked us to the right IEA Wind Task)*	51
Technical Summary	*Paul Mucchielli*	*WindPearl Technical Summary*	3rd March 2022	Face to Face	Research, Higher Education	10

**Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).*