Sustainable Energy Authority of Ireland

National Energy Research, Development & Demonstration Funding Programme 2018

FINAL REPORT

SECTION 1: PROJECT DETAILS

Table 1.1 – Summary of Project Details

Project Title	FREMI (Forecasting Renewable Energy with Machine Intelligence)
Lead Applicant (Organisation)	SSE Airtricity
Lead Applicant (Name)	David Noronha
Final Report Prepared By:	Dr. Ricardo Simon Carbajo,
Total Project Duration (months)	18

Approved SEAI Funding	€ 221,997

	Name	**Organisation**
Partner Applicant(s)	Dr. Ricardo Simon Carbajo	University College Dublin - CeADAR (Centre for Applied Data Analytics)
Collaborators		Met Eireann

Project Summary (max 500 words)
Ireland is arguably considered a world leader in the facilitation of renewables on the grid. FREMI is an 18-month project that brings together the largest developer and operator of renewable generation on the island of Ireland; SSE Airtricity, with leading renowned centre for excellence in advanced data analytics; UCD, CeADAR (Centre for Advanced Data Analytics Research). Through I-SEM the requirement to trade power more intensively whilst placing a balance responsibility on renewable generators, essentially gives rise to the largest market exposure for SSE of any market participant. FREMI will mitigate this risk through applying advanced data science to enhance the industry’s ability to forecast generation and match demand.

The significance of 'balance responsibility' cannot be overstated, financial exposure is likely to incur significant cost. This places decisive importance on forecasting with highest accuracy. FREMI uses Artificial Intelligence (AI) and will seek to apply state of the art Machine Learning tools to greatly enhance forecasting capabilities. CeADAR involvement will ultimately allow SSE to further optimise its renewable portfolio and with it reduce power prices for the end consumer and achieve even greater levels of decarbonisation. FREMI will take a holistic approach whereby forecasting will not be considered in isolation of plant availability; system demand and localised grid constraints.

FREMI will alleviate utilities' requirement to rapidly respond to alter generation which can be highly inefficient and expensive for energy providers and in turn for the consumer. FREMI can bring the industry closer to maintain a more cost effective and efficient means of participation in ISEM.

Keywords (min 3 and max 10)	Artificial Intelligence, Machine Learning, I-SEM, Wind Forecasting

SECTION 2: EXCELLENCE & INNOVATION (max 5 pages)

2.1 Innovation / Novelty – Beyond State-of-the-Art

- Rich Data: Combining many sources of data from wind turbines, multiple sources of weather data, historic windfarm measurements and curtailment data. We have analysed these different sources and also integrated them into predictive models.
- Latest AI Technology: The forecasting tool has been developed using the latest state of the art advancements in this field. This includes the application of deep learning algorithms with Long Short-Term Memory (LSTM) layers. In addition, we have performed large scale experimentation using advanced machine learning algorithms including ensembles and XGBoost.
- Novel Power Curve Cleaning: We have developed a power curve cleaning technique which produces an accurate estimation of a windfarm's power output given a particular windspeed. This power curve cleaning process is automated which is a significant improvement since power curves are often manually created or created by the manufacturer.
- Large Scale Modelling: We have built predictive models for 24 windfarms, each of which have data spanning years. The windfarms are built by 3 different manufacturers which increases the modelling complexity. In addition, we have modelled the turbine level behaviour and windfarms can have up to 32 turbines.
- Customized Predictive Modelling for I-SEM: The forecasting models that we have built make predictions from 12 hours up to 36 hours in the future. These predictions are made at 30-minute intervals. This entire prediction task is optimised for the I-SEM market.

2.2 Project Objectives

In the Table below, list all project objectives as detailed in your application, and provide on update on their status. Have these objectives been achieved? What were the key outcomes or deliverables associated with each?

Table 2.1 – Summary of Project Objectives

No	Objective Description	Objective completed (Y/N) Justify your answer	Key Outcomes/Deliverables
1.	**Definition of forecasting objectives** Define the technical objectives of the forecasting output, identifying the desired standard of the output of models around parameters such as: Frequency; Timing; Granularity; Duration and Accuracy	Yes. This objective was achieved early in the project. Appendix A contain the report.	Analysis of the forecasting output and accuracies in the energy sector previous to the application of this project. This analysis set-up forecasting errors for reference to improve with FREMI.
2.	**Scoping out of available forecasting options:** Review and evaluate forecasting tools available to assess techniques used, their accuracy, and suitability for use or adaptation to input into optimal modelling solution	Yes. Literature review covered in Appendix B	Review of the state of the art in energy forecasting methods, including the latest Machine Learning techniques.
3.	**Development of optimal forecasting model:** Build model to deliver the optimal forecast (given the requirements of Objective 1), with an ability to adapt to a variety of market (wind)	Yes. Extract of the final technical document provided. Data Architecture provided	Novel architecture to ingest SSE Wind Farm assets data has been designed, implemented and tested. A

	conditions, e.g. low/high wind, increasing wind, etc., utilising latest analytical/forecasting techniques.	as well as accuracy of Machine Learning models for power forecast. See Appendix C.	state-of-the-art ensemble machine learning system has been designed, implemented and thoroughly tested achieving accurate levels of prediction which outperform state of the art.
4.	**Deploy in a sustainable and functional format for commercial use:** Ensure ongoing operation of model is efficient, robust and adaptable to incorporating new information such as for new windfarms. Output should be in required format for effective use in business activity, and where possible flexible to meet evolving market requirements.	Yes. This phase started towards the end of the project where CeADAR transferred and help deploy the architecture and predictive models into SSE Airtricity private cloud infrastructure. Now is fully integrated.	Architecture of FREMI project is fully embedded in SSE Airtricity cloud infrastructure, has been tested and SSE Airtricity is leveraging these resources for different business goals, the primary one being I-SEM trading.
5.	**Communication, Dissemination and Exploitation:** Ensure key project learnings are disseminated in relevant industry / academic forums.	Yes. A range of communication activities have been conducted – see Table 3.3. A website was created and in a post-project phase, with all final results, a journal paper is being written.	Increase visibility of FREMI project, SEAI, SSE Airtricity and CeADAR in forums related to energy and machine learning, such as SEAI Energy Show, Predict Conference (Machine Learning), IWEA (postponed due to COVID-19 and poster and presentation is due. Publication in a top journal paper in progress.

SECTION 3: RELEVANCE & IMPACT (max 6 pages)

3.1 Relevance to the needs of the Irish Energy Sector and to SEAI

Clearly position the outcomes and impact of your project with reference to the needs of the Irish Energy Sector, national and international policy objectives, and SEAI's remit.

The new Integrated Single Electricity Market (I-SEM) was introduced on the island of Ireland 1st October 2018. I-SEM requires market participants to trade power more intensively whilst placing a balance responsibility on renewable generators. Renewable generation is a cornerstone for national sustainable energy strategy and, so, the successful participation of renewable generators in I-SEM is critical for the achievement of these strategic aims.

Due to the sizeable portfolio of its renewable generation, SSE Airtricity possesses a large amount of data related to renewable generation. This data presents an opportunity to use it to optimise the participation of renewable assets in I-SEM.
The objective of the FREMI (Forecasting Renewable Energy with Machine Intelligence) project was to work with our academic partners (CeADAR Ireland Centre for Applied AI www.ceadar.ie) to mitigate this renewable energy forecast risk in I-SEM through applying advanced data science.

If demonstrated to be beneficial in business as usual operations over time, the learnings from FREMI could be applied elsewhere in SSE Group to generate further benefit, and would have value in other markets.

3.2 Project Impact

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 FREMI project tackles a real need in the energy market with demands from the new I-SEM to accurately forecast the day ahead power generated by each wind farm. Tools exists in the EU market; however, companies have a large amount of data about the historical operations of their wind farms and meteorological data which can help them get a customised in-house solution to increase the accuracy and control of their trading strategies. This in turn will reduce the uncertainty factor in wind renewable generation, making this technology more economically competitive and reliable, having a higher impact in balancing the market and consequently accelerating the transition to a green energy landscape, by reducing carbon emissions and ultimately reduce the cost of energy for consumers.

Renewable generation is a cornerstone for national sustainable energy strategy, and so the successful participation of renewable generators in I-SEM is critical for the achievement of these strategic aims.

3.3 Communication, Dissemination and Exploitation

Please provide details of all dissemination activities undertaken throughout the project, providing references and links where applicable.

Dissemination Summary Tables

Please list details of any scientific publications in Table 3.1 on the next page. Please mention papers published in peer-reviewed journals or papers disseminated at conferences (e.g., on the conference website, etc.).

Please list details of all dissemination activities in Table 3.2 on the next page (e.g. publications, conferences, workshops, websites/applications, press releases, flyers, articles in press, videos, presentations, exhibitions, thesis, interviews etc.).

3.4 Intellectual Property Management & Exploitation

If applicable, please provide details of any patents or IP generated as a result of this research award, or patents/IP which you think may eventuate as a result of the 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", please provide an estimate of the date	Peer-reviewed (Y/N)?
IN PROGRESS: Forecasting Wind Farm Power Output with Deep Learning	Members of team	Applied Energy	https://www.journals.elsevier.com/applied-energy	Elsevier	2020-2021	Open access if we get the remaining funding in the budget to cover this cost	Yes

Table 3.2 – List of Dissemination Activities

Type of Activity	Main Leader	Title	Date/Period	Location	Type of Audience*	Size of Audience
Present FREMI at Conference	*David Noronha*	*SEAI Energy Show*	*27th and 28th March 2019*	*RDS, Dublin*	*Industry, Business, Energy*	*100+*
Attend Conference	*Ricardo Simon Carbajo, David Haughton, Andres Suarez-Cetrulo, Lauren Burnham-King*	*SEAI Energy Show*	*27th and 28th March 2019*	*RDS, Dublin*	*Industry, Business, Energy*	*300+*
Present FREMI at Stand	*Lauren Burnham-King*	*Learning at Work*	*17th May 2019*	*SSE Offices, Dublin*	*SSE Employees*	*50+*
Present FREMI at Seminar	*Andres Suarez-Cetrulo*	*SMARTlab PhD Seminar*	*23rd July 2019*	*UCD, Dublin*	*Scientific Community*	*40+*
Attend Conference	*Lauren Burnham-King*	*Women in Tech*	*12th September 2019*	*Convention Centre, Dublin*	*Technical*	*100+*
Presentations and discussion	*CeADAR, SSE Trading, SSE Analytics, SSE Innovation teams*	*Interim Stakeholder Event*	*19th September 2019*	*SSE Offices, Dublin*	*Industry, Energy, Trading, Technical*	*20+*

KeyNote at Greener 2019 Conference	*Ricardo Simon Carbajo*	*AI in Energy*	*24 Sep 2019 - Dublin*	*Trinity College Dublin*	*Academia, Industry*	*80+*
Present FREMI at Conference	*Ricardo Simon Carbajo*	*Predict: Europe's Leading Data Conference*	*1st October 2019*	*RDS, Dublin Ireland*	*Technical, Industry, Business*	*200+*
Attend Conference	*Ricardo Simon Carbajo, David Haughton, Andres Suarez-Cetrulo, Lauren Burnham-King*	*Predict: Europe's Leading Data Conference*	*1st October 2019*	*RDS, Dublin Ireland*	*Technical, Industry, Business*	*100+*
Present FREMI at Conference	*Ricardo Simon Carbajo*	*AI Summit*	*5th of March 2020*	*Croke Park, Stadium , Dublin*	*AI Community in Ireland*	*200+*
Present/Attend at IWEA Spring Conference – Registered, Payed and to occur	*Ricardo Simon Carbajo, David Haughton, Andres Suarez-Cetrulo, David Noronha*	*IWEA Spring Conference 2020 (postponed due to COVID-19)*	*TBC*	*TBC*	*Energy Audience*	*400+*

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