Written evidence submitted by Professor Sir John Aston, Dr Anastasia Borovykh, Professor Sylvain Laizet, Dr Luca Magri, Dr Georgios Rigas, Aarushi Shah, Professor Konstantina Vogiatzaki, and Professor Michèle Weiland

Submission to Environmental Audit Committee - Sustainable electrification of the UK economy

This submission is from the collaborators on the Engineering and Physical Sciences Research Council award: *Real-time digital optimisation and decision making for energy and transport systems.* The team consists of Georgios Rigas, Sylvain Laizet, Anastasia Borovykh (Imperial College London), Luca Magri (Imperial College London and the Alan Turing Institute), John Aston, Aarushi Shah (University of Cambridge), Michèle Weiland (University of Edinburgh) and Konstantina Vogiatzaki (University of Oxford).

To reduce global warming and meet the UK's ambitious objectives of zero emissions by 2050, we need to complement engineering solutions with strong involvement and engagement at a societal level. The engineering systems that underlie zero-emission technology involve multiple simultaneously interacting physical phenomena, which are turbulent and dynamic, and as such, technical solutions need to be adaptable. However, these solutions need to be acceptable not just in the abstract but also in practice to policymakers and potentially local communities. For example, optimisation of wind farms should aim to both maximise power output as well as minimise local communities' disruption – the optimisation needs to be technical and societal. This is the foundation for the recently funded UKRI for Net Zero award: *Real-time digital optimisation and decision making for energy and transport systems*. This project was funded as part of the recent UKRI call on Artificial intelligence (AI) research to enable UK's net zero target [UKRI, 2022]. It is currently well recognised that energy and transportation are two sectors that there is no silver bullet in terms of solutions in relation to net zero targets. AI is a modern tool that can help optimise and adjust engineering practice to a wide range real-life scenarios and thus support solutions tailored to the specific needs of local communities

During the first quarter of 2022, renewables' share of electricity generation was 45.5% in the UK [BEIS, 2022]. In 2020, wind turbines provided almost a quarter of electricity in the UK [ONS 2021]. To sustain this dramatic increase in wind energy production, while maintaining a competitive cost per watt, technological progress is needed to enable an order of magnitude increase in power, yet with only 100% more wind turbines likely by 2030 [EU report, 2023]. To achieve this aim, we need to factor in a physical reality – turbulent flows. Turbulent flows are those states in which a gas (or wind in our case) undergoes fluctuations – where the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction. While it is obvious that wind changes speed and direction, it has profound implications when designing and operating multiple turbines in a specific location in terms of power output.

Wind energy generation results from dynamic systems, and while we have come far in understanding them, through a now mature branch of mathematical engineering, Computational Fluid Dynamics, we are yet to harness the outputs of such knowledge in real-time. It is important to understand the turbulence around wind turbines and produce optimised control strategies, based on accurate simulations of wind farms during operations, to harness wind power effectively and increase power output. There is a clear need for reliable physics-based simulation methods that can faithfully replicate realistic scenarios during operational conditions. These tools are called wind farm simulators (WFS) and they heavily rely on supercomputers. A distinct advantage of WFS by comparison to wind tunnel experiments is the possibility of conducting studies at full scale, under operational conditions [Deskos et al, 2020]

Modern large–scale wind farms consist of multiple turbines clustered together, usually in well–structured formations. Such a clustering exhibits a number of drawbacks during the operation of the wind farm, as some of the downstream turbines will inevitably have to operate within the wake of the upstream ones. A wind turbine operating within a wake field is an issue for two reasons. First, the apparent reduction of its power output due to the wind speed de-acceleration and second an increase of the fatigue loads due to the upstream wake-laden turbulence. Power losses due to wake effects were recently reported to be in the order of 10–25 % [Nygaard et al, 2014] while the fatigue–related failures were reported to be around the same levels owing to a limited understanding of the offshore turbulence [Frandsen & Thøgersen, 1999]. To summarise, currently installed wind farms do not produce as much power as expected and break more quickly, ultimately either requiring more turbines or alternative power sources.

Computer based solutions to these problems are available through economical models that reduce the need for expensive experiments, but these solutions are not optimal and computationally effective when used in real-time real-scale simulations, as in the case for example of changing the angles of the turbine blades. To tackle these problems fast and efficiently, multi-disciplinarity becomes a necessity. This is at the heart of our project, that brings together state of the art mathematical models and modern tools of artificial intelligence.

We are combining two disciplines that have historically received considerable government and industrial funding: physics-based modelling, which is generalisable and robust but may require tremendous computational cost, and machine learning, which is adaptive and can be evaluated quickly but not easily made generalisable and robust. The intersection of the two areas yields scientific machine learning, which maximises the strengths and minimises the weaknesses of the two approaches individually. The data is provided by high-fidelity simulations and experiments, from the UK state-of-the-art facilities and software. Machine learning algorithms require minimal time and energy to run, once trained, and thus have the potential to be used in real-time. The most significant bottleneck of most scientific machine learning models is that they need time to be re-trained offline when new data becomes available. Currently, we are developing offline paradigms to deliver real-time approaches for the models to re-adapt and provide accurate estimates on the fly. Our project will culminate in the delivery of practical digital twins (defined as digital counterparts of real-world physical systems or processes that can be used for simulation, prediction of behaviour to inputs, monitoring, maintenance, planning and optimisation). These digital twins will help us to provide solutions for currently intractable problems in wind energy, hydrogen, and road transportation.

Of course, such approaches are important as they allow real-time engineering optimisation of energy systems to generate more power. However, an often-missed additional advantage is that dynamic AI algorithms also provide local stakeholders, policymakers, and governments with the opportunity to partner in the design and decision-making implications of different options and proposals. While in the past it was impossible to factor in local considerations due to the computational costs required to adapt designs, with real-time digital twins, it is possible to involve policymakers and communities when thinking about the implications of design choices on energy production (even up to a national grid level), rapidly iterating multiple scenarios in real time. This allows government and communities some agency in the infrastructure choices and implications of the energy system design.

Our research will create a multi-disciplinary framework and toolbox not only aimed at the engineers themselves but also at the local and national decision-makers who need to make such choices. The project will deliver real-time digital twins and energy-efficient AI algorithms.

Professor Sir John Aston (University of Cambridge), Dr Anastasia Borovykh (Imperial College London), Professor Sylvain Laizet (Imperial College London), Dr Luca Magri (Imperial College London and the Alan Turing Institute), Dr Georgios Rigas (Imperial College London), Aarushi Shah (University of Cambridge), Professor Konstantina Vogiatzaki (Universirty of Oxford), and Professor Michèle Weiland (University of Edinburgh) ESE0017

June 2023

References

[BEIS, 2022] Energy Trends Statistical Release, Department of Business, Energy and Industrial Strategy, UK Government, June 2022.

[ONS, 2021]
https://www.ons.gov.uk/economy/environmentalaccounts/articles/windenergyintheuk/june2021

[EU report, 2023] https://energy.ec.europa.eu/topics/renewable-energy/offshore-renewable-energy_en, retrieved 30-May-2023

[Deskos et al, 2020] Deskos, G., Laizet, S., & Palacios, R. (2020). WInc3D: A novel framework for turbulence-resolving simulations of wind farm wake interactions. *Wind Energy*, *23*(3), 779-794.

[Nygaard et al, 2014] Nygaard, N. G. (2014, June). Wakes in very large wind farms and the effect of neighbouring wind farms. In *Journal of Physics: Conference Series* (Vol. 524, No. 1, p. 012162). IOP Publishing.

[Frandsen & Thøgersen, 1999] Frandsen, S., & Thøgersen, M. L. (1999). Integrated fatigue loading for wind turbines in wind farms by combining ambient turbulence and wakes. *Wind Engineering*, 327-339.

[UKRI, 2022] https://www.ukri.org/opportunity/artificial-intelligence-research-to-enable-uks-net-zero-target/