Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total. Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

NIA Project Close Down Report Document

Date of Submission

May 2025

Project Reference Number

NIA2_NGESO027

Project Progress

Project Title

Carbon Intensity Modelling

Project Reference Number

NIA2_NGESO027

Funding Licensee(s)

NESO - National Energy System Operator

Project Start Date

January 2023

Project Duration

1 year and 9 months

Nominated Project Contact(s)

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Scope

This project for carbon intensity modelling will:

- Explore how to accurately model carbon output of carbon plant in different operational modes
- Use a combination of traditional statistical techniques and cutting-edge machine learning methods to increase accuracy beyond current peak efficiency assumption
- Build upon internal capability with external domain experts.
- If successful, provide recommendations for future development of carbon intensity tool into Carbon Intensity of Balancing Actions and Virtual Energy Systems (VES).

Objectives

- Identify key missing data items that will have the most impact on our understanding of the carbon intensity of gas/coal/biomass generation.
- Improve the carbon intensity modelling of CCGT/OCGT/Coal/Biomass plants in different states by creating models for when they are operating outside of peak efficiency, and by better understanding the relative efficiencies of BMUs where data is available.
- Develop a PoC tool to optimise the dispatch of the plants on the grid with respect to the carbon intensity of the energy produced (e.g. by generating a carbon merit order, providing recommendations for dispatch which factor in predicted upcoming BM requirements as well as peak / partial load efficiency of available BMUs, or other methods yet to be determined).

Success Criteria

The project will be deemed a success if:

- It delivers against objectives, timescales and budgets as defined in the proposal.
- WP1 models deliver higher accuracy when compared against actual gas usage (as provided by Major Power Producers (MPP) survey or the Gas System Operator if available) than the current fixed value being used.
- A PoC tool is developed for optimising dispatch based on carbon intensity as well as system requirements.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

Background information: The carbon intensity of fossil fuel plants depends on how they are running, whether they are starting up from cold or operating at less than full capacity. Currently a single value is used in the overall calculation of the carbon intensity of the grid. With the rise of renewables, increasingly the fossil fuel plants no longer run at a steady state, which means this single value is increasing less accurate. In addition, NESO has no sight of what the impact of both carbon intensity and cost would be if the grid was optimised based on carbon intensity rather than cost.

This project will improve the understanding on modelling of the carbon emitted by power plants in their different states and then use that to explore the optimisation of the grid based on carbon intensity.
Currently, NESO publish half-hourly information on the carbon intensity of the GB electricity system. This data is important in tracking the progress towards de-carbonising the electricity system. NESO worked with the project partner to improve the existing models for a couple of fossil fuel powered plants by refining the models that doesn't use a static value but more accurately reflects real world usage and emissions of these plants.

Problem statement: The single value for the carbon intensity of each type of fossil fuel plant is increasingly inaccurate. This prevents the accurate understanding of the carbon impact of optimisation and balancing actions. In addition, NESO would like to understand what the impact on cost and carbon emissions would be of optimising the grid based on carbon intensity rather than cost.

Progress against stated project plan

The project developed models to estimate the carbon intensity of gas, coal, and biomass plants using features derived from the plants' half-hourly operations. These features included whether the plants were on or off, whether they were operating at a constant power output, or if they were ramping up or down in energy production. The length of time a plant had been off was used to distinguish between warm and cold starts based on the data.

Monthly data on fuel usage for groups of power plants was sourced and served as the target variable for the modelling. This data was then translated into a carbon intensity value for the electricity generated by these groups of plants within a given month and compared against the figures currently in use.

Successfully developed a proof-of-concept model for producing and evaluating energy allocations that are optimised based on both price and carbon emissions. This came with additional recommendations for further work:

- Improve CO2 intensity model of individual generators
- Improve the model of energy demand forecast
- Implement and optimise energy storage
- Develop the model towards practical use cases

- Incorporate carbon tax into our model

Additional details can be found in the final project report, available on the ENA portal: https://smarter.energynetworks.org/projects/nia2_ngeso027/

Required Modifications to the Planned Approach During the Course of the Project

None

Lessons Learnt for Future Projects

Lessons learnt from this project indicate that the data, which was collected monthly and for groups of power plants, restricts the modelling techniques available for assessing the performance of these plants. This issue could be alleviated by collecting data at more frequent intervals, such as daily or weekly, or by focusing on individual plants. Future projects should extend this work to get predictions of carbon intensity per BM Unit per half hour with more granular data.

With improved modelling, detailed analysis of the impact of dispatch and flexibility services should be undertaken.

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

The initial work package developed models that improved upon the current single-value carbon intensity of a power plant, and produced models for gas, coal, and biomass. These models were compared against the single values currently used for carbon intensity.

The models demonstrated reasonable initial performance given the limited available data and were refined to optimise performance and reduce the risk of overfitting. They were built using features derived from the half-hourly operation of power plants, with various iterations and combinations of these features used as inputs—including interactions and nonlinear terms.

Due to the low volume of data and the emphasis on explainability, a linear regression approach was used. Only a small number of features were included in the final models to further mitigate the risk of overfitting.

The project suggested several activities as follow-on activities to further the impact of the project:

- NESO needs more access to more granular data on power plant inputs.
- With additional data, additional modelling techniques should be explored to improve the performance of the machine learning.
- Explore more nonlinear relationships between the variables and correlations between the variables
- The best performing model for CCGT plants is a Bayesian regression model using time spent on and time spent in ramp up as features.
- If data is available, look at the biomass plants separately to separate the behaviour of Drax from the other plants.
- Linear regression, using only the time the plant was on, is the best-performing model for biomass plants.
- The most predictive model for coal is that without an intercept that has the variables time spent on and % of time constant.
- Replace the current values in the grid carbon intensity calculation with the modelled ones for the different gas generators.
- Do not change the value used for coal in the grid carbon intensity calculation.
- Explore a project conducting full lifecycle analysis of carbon emissions for all the main fuel types.
- Calculate improved carbon intensity calculations for the non-wood pellet biomass plants

Data Access

Details on how network or consumption data arising in the course of NIA funded projects can be requested by interested parties, and the terms on which such data will be made available by National Grid can be found in our publicly available "Data sharing policy related to NIC/NIA projects" and www.nationalgrideso.com/innovation.

National Grid Electricity System Operator already publishes much of the data arising from our NIC/NIA projects at www.smarternetworks.org. You may wish to check this website before making an application under this policy, in case the data which you are seeking has already been published.

Foreground IPR

The following outcomes have been delivered by this project:

- Jupyter notebook built and tested preferred models
- Report on models built and their performance measured
- Report analysing the methodology used to create the control mechanism and corresponding Jupyter notebook demonstrating the control method developed
- Report providing overview of work completed, potential impact and limitations

Planned Implementation

The recommendations for future work are:

- **Improved CO2 intensity model of individual generators**: It was observed that generators can operate at different levels of CO2 intensities even when they use the same fuel type. Another observation was that the CO2 intensity of a generator can be different at different stages of its operation. These properties were implemented into the CO2 intensity model of the generators in our network. Nevertheless, the limited data means that the CO2 intensity model is still generic. Improving the CO2 intensity model of every generator in the network is important as it has a major impact on the dispatch optimization.
- **Improved the model of energy demand forecast**: The previous model had a straightforward energy demand forecast — the control room knows the exact demand two-time steps ahead. Improving this forecast model, preferably in collaboration with the NG-ESO demand forecast team, could further enhance the allocation model and optimization.
- **Implement and optimise energy storage**: The previous model didn't include energy storage such as batteries or pumped storage. However, it was noted that energy storage could be an important component for achieving net zero operation and, thus, should be implemented in subsequent versions of the model.
- **Develop the model towards practical use cases**: The previous model assumed central dispatch. However, other CO2-friendly dispatch strategies (e.g., implementing CO2 emissions premium or introducing incentives for flexible demand) could be explored. These strategies could be implemented on top of the base model and the different results could be analysed.

Net Benefit Statement

A successfully developed proof-of-concept model was delivered capable of estimating the benefits and costs of CO2-friendly energy allocations. The model explores central dispatching where the control room has full control over the generator operations. For simplicity, assumptions have been made about the network, generators, and demand scenario. Nevertheless, the model can still provide useful insights.

It also highlights the additional data and development required for an effective implementation of CO2-friendly energy dispatch. It further serves as the basis for the development of more complex models for analysing allocating policies beyond central dispatching --- e.g., adding CO2 emissions premium or introducing financial incentives for flexible demand.

Other Comments

The Project outcomes and results contain confidential information and intellectual property rights that cannot be disclosed in this Report due to their proprietary nature. Should the viewer of this Report ("Viewer") require further details this may be provided on a case by case basis following consultation of all Publishers. In the event such further information is provided each and any Publisher that owns such confidential information or intellectual property rights shall be entitled to request the Viewer enter into terms that govern the sharing of such confidential information and/ or intellectual property rights including where appropriate formal licence terms or confidentiality provisions. Dependent upon the nature of such request the Publishers may be entitled to request a fee from the Viewer in respect of such confidential information or intellectual property rights.

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