Publicly Available

Carbon Intensity
Regional Forecast Methodology

Authors: Dr Alasdair R. W. Bruce, Lyndon Ruff[a], James Kelloway, Fraser MacMillan, Prof Alex Rogers[b]

[a] St. Catherine's Lodge, Wokingham, NESO, [b] Department of Computer Science, University of Oxford

Issue: May 2024

National Energy System Operator (NESO), in partnership with Environmental Defense Fund Europe and WWF, has developed a series of Regional Carbon Intensity forecasts for the GB electricity system, with weather data provided by the Met Office.

Introduction

NESO's Carbon Intensity API has been extended to include forecasts for 17 geographical regions of the GB electricity system up to 48 hours ahead of real-time [1]. It provides programmatic and timely access to forecast carbon intensity. This report details the methodology behind the regional carbon intensity estimates. For more information about the Carbon Intensity API see here.

What's included in the forecast

The Regional Carbon Intensity forecasts include CO_2 emissions related to electricity generation only. The forecasts include CO_2 emissions from all large metered power stations, interconnector imports, transmission and distribution losses, and accounts for regional electricity demand, and both regional embedded wind and solar generation.

This approach considers the carbon intensity of electricity consumed in each region and uses peer reviewed carbon intensity factors of GB fuel types [2][3]. The carbon intensity factors used in this data service are based on the output-weighted average efficiency of generation in GB and DUKES CO_2 emission factors for fuels [4]. GB regions are divided according to Distribution Network Operator (DNO) boundaries, see Figure 1.

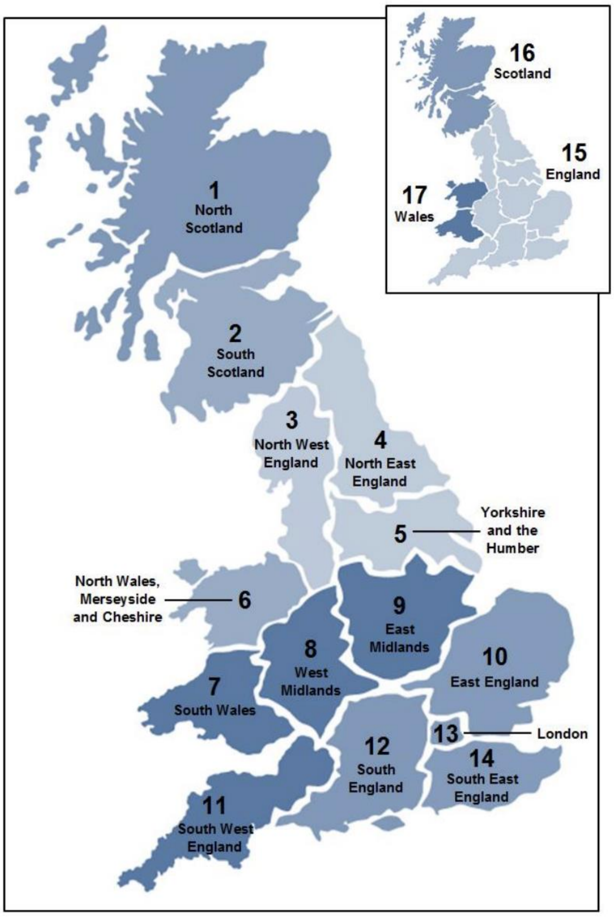

Figure 1: GB Regions and IDs for the API.

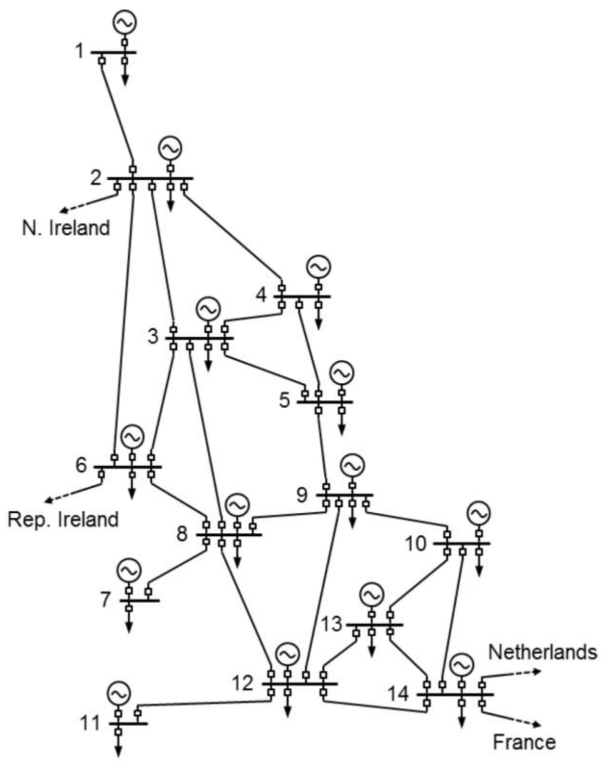

Figure 2: Electrical representation of reduced GB network.

Methodology

A reduced GB network model is used to calculate the CO_2transfers between importing/exporting regions, which takes into account the impedance characteristics of the network, constraints, and system losses. See Figure 2.

Estimating the carbon intensity of the electricity consumed in each region requires modelling the power flows between importing/exporting regions and the carbon intensity of those power flows. The estimated regional carbon intensity of generation uses metered data for each fuel type.

Step 1: Forecasting ahead

The demand (P_i^{dem}), generation (P_i^{gen}), and generation by fuel type for each region is forecast two days ahead at 30-min temporal resolution using an ensemble of state-of-the-art supervised Machine Learning (ML) algorithms. The forecasts are updated every 30 mins using a nowcasting technique to adjust the forecasts a short period ahead.

Step 2: Calculating the generation and CO_2 emissions at each node

The GB power system is divided into regions and represented as an N-bus network connected by lines. The power generation at bus is the sum of the generation in that region:

$$P_i^{gen} = \sum_{g=1}^{G} P_{i,g}^{gen}$$

The CO_2 emissions of each generator is estimated to calculate the CO_2 emissions from generation in each region:

$$E_i^{gen} = \sum_{g=1}^{G} P_{i,g}^{gen} \times c_g$$

Where $c_g$is the carbon intensity of generator's fuel type, see Table 1. Then, the carbon intensity of generation C_i^{gen} is calculated at each node:

$$C_i^{gen} = \frac{E_i^{gen}}{P_i^{gen}}$$

Step 3: Calculate power imbalance between exporting and importing regions

The power imbalance P_i at bus i is calculated by subtracting the regional power generation P_i^{gen} from the regional power demand P_i^{dem}:

$$P_i = P_i^{gen} - P_i^{dem}$$

A region is exporting power if $P_i > 0$ and importing power if $P_i < 0$.

Step 4: Three-phase Newton Raphson AC power flow

A network of N buses and L lines is described by an $L \times N$ incidence matrix A, such that $A_{l,i} = -1$ if line l ends at bus i, $A_{l,j} = -1$ if line l ends at bus j, and $A_{l,k} = 0$ if $k \neq i \neq j$. The power equations for the AC power flow in polar form are:

$$P_i = |V_i| \sum_{j=1}^{N} |V_j| \, |Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij})$$

$$Q_i = |V_i| \sum_{j=1}^{N} |V_j| \, |Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij})$$

Where $|Y_{ij}|$ is the admittance, $|V_i|$ and $|V_j|$ are the bus voltages, δ_i and δ_j are the phase angles at buses i and j respectively.

A three phase Newton Raphson iteration is performed to calculate the active and reactive power flows between buses i and j.

Step 5: Calculate the carbon intensity of power flows

Once the inter-regional power flows have been determined from the power flow analysis, it is possible to calculate the carbon intensity of power flows through every line.

The carbon intensity of power flows through lines L between N buses is represented as a matrix, where the carbon intensity of power flowing out of a bus is equal to the weighted average of the carbon intensity of power flowing into that bus.

Step 6: Calculate the carbon intensity of power consumed in each region

It is then possible to calculate the carbon intensity of electricity in each region. If the region is exporting power, then that region consumes electricity equal to its carbon intensity of generation. If the region is importing power, then the carbon intensity of the power that it consumes is equal to the weighted sum of its regional generation plus the power flow from the lines it is importing from.

Limitations

This work does not include any commercially sensitive market information about generator positions, outages, or price data. The forecasts only consider historic generation data and forecast weather data.

This work does not consider the CO_2 emissions of embedded generators that NESO does not have visibility of or access to metered data. Future work will look at estimate the contributions of these embedded generators to regional and national carbon intensity.

Interconnector carbon intensity factors

Daily at 6am, the average generation mix of each network the GB grid is connected to through interconnectors is collected for the previous 24 hours through the ENTSO-E Transparency Platform API [6].

The factors from Table 1 are applied to each technology type for each import generation mix to calculate the import carbon intensity factors. If the ENTSO-E API is down, the import carbon factors default to those listed in Table 1.

Fuel Type	Carbon Intensity gCO_2/kWh
Biomass[i]	120
Coal	937
Gas (Combined Cycle)	394
Gas (Open Cycle)	651
Hydro	0
Nuclear	0
Oil	935
Other	300
Solar	0
Wind	0
Pumped Storage	0
French Imports	~ 53
Dutch Imports	~ 474
Belgium Imports	~ 179
Irish Imports	~ 458

Contact

For any suggestions, comments or queries please contact: lyndon.ruff@nationalgrideso.com

References

[1] Carbon Intensity API (2017): www.carbonintensity.org.uk

[2] GridCarbon (2017): www.gridcarbon.uk

[3] Staffell, Iain (2017) “Measuring the progress and impacts of decarbonising British electricity”. In Energy Policy 102, pp. 463-475, DOI: 10.1016/j.enpol.2016.12.037

[4] DUKES (2017):
www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

[5] BM Reports (2017):
https://www.bmreports.com/bmrs/?q=generation/

[6] ENTSO-E Transparency Platform:
https://transparency.entsoe.eu/

---

[i] Using 'consumption-based' accounting, the carbon intensity attributable to biomass electricity is reported to be 120 ± 120 gCO_2/kWh [2]. The large uncertainty relates to the complex nature of biomass supply chains and the difficulty in quantifying non-biogenic emissions.