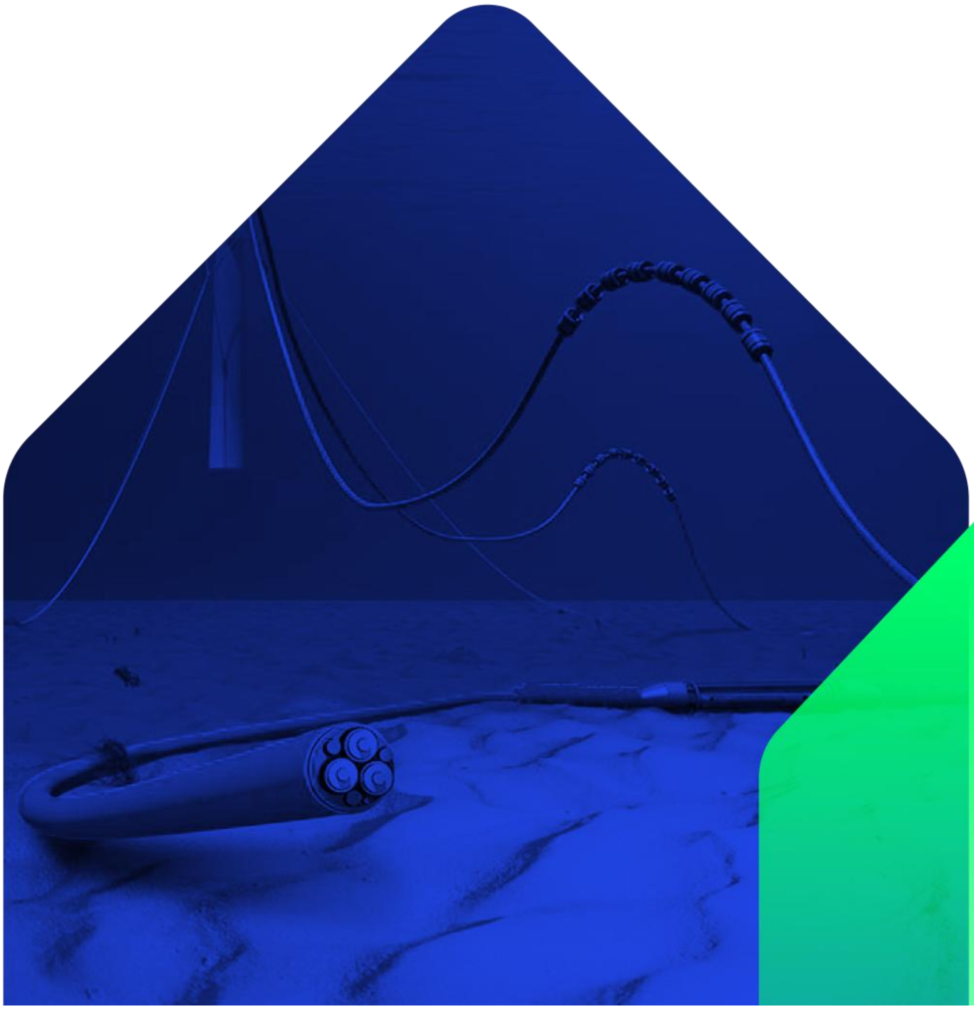
FLOATING WIND JOINT INDUSTRY PROGRAMME

Guidance for Dynamic Cables

April 2025



Contents

Authors:

Karolina Zieba
Associate, Carbon Trust
karolina.Zieba@carbontrust.com

Luisa Amorin
Manager, Carbon Trust
luisa.amorim@carbontrust.com

Luiza Ferreira
Principal Engineer, 2H Offshore

Acknowledgments

The Carbon Trust wrote this report based on an impartial analysis of primary and secondary sources, including expert interviews.

The Carbon Trust would like to thank everyone that has contributed their time and expertise during the preparation and completion of this report. Special thanks goes to: Hellenic Cables, JDR, Orient Cable, SINTEF, Marin, Aurora Offshore Engineering and Bureau Veritas.

Introduction

The Guidance for Dynamic Cables (GDC) project was delivered by 2H Offshore Engineering (2H) in collaboration with Vekta on behalf of the Floating Wind Joint Industry Programme (Floating Wind JIP).

Dynamic power cables are critical components in floating offshore wind projects and in offshore wind more broadly, power cable technology has not proved to be as reliable as design outcomes suggest. Subsea cable failures are one of the main contributors to financial losses in the global offshore wind industry. However, many of these incidents could be avoided with a better understanding of the risks of the system and associated mitigation techniques.

The aim of this project was to examine the existing guidelines, methodologies, and cross-industry standards for dynamic cable fatigue assessment. In addition, a guideline document has been developed for use by Floating JIP developers and their supply chain.

Project objectives

1. Understand and review, within the offshore wind and analogous industries, the existing guidelines for fatigue design in dynamic high voltage (HV) power cables.
2. Engage with the relevant stakeholders across offshore wind and analogous industries to better understand the design requirements of dynamic cables.
3. Develop a dynamic cable fatigue assessment and lifetime prediction guideline document to support the warranty and insurability of this equipment.

Methodology

Literature review

A comprehensive review of a range of literature sources, including design codes and academic papers was undertaken. The review captured:

- existing power cable fatigue prediction methods, including mechanical fatigue, electrical aging, thermal issues, and cyclical stressed on both the power cable as a whole, and the individual components that make up the high voltage power cable;
- design challenges, including the management of components especially sensitive to fatigue such as the conductor, metallic screen, and tensile armour, and extrapolating data from oil and gas to offshore wind;
- testing regimes proposed to perform fatigue and lifetime assessments for offshore wind dynamic power cables and in complementary industries such as oil and gas.

Preliminary guideline document

Based on the outcomes of the literature review, a draft guideline for dynamic power cable fatigue assessment was produced.

The guideline details the best practices and methods to perform fatigue assessment and lifetime prediction of dynamic power cables, covering both mechanical and electrical design aspects for inter-array and export cables. In addition, it provides guidance on the steps required to undertake a fatigue assessment.

Stakeholder engagement

A wide range of stakeholders including vendors, certification bodies and offshore wind developers were engaged during this project to give expert input on a range of topics regarding the fatigue of dynamic power cables.

These engagements helped refine the guideline for dynamic cable fatigue assessment and to address gaps and questions previously identified in the literature review.

Case studies for sample applications

To test the methodology proposed within the draft guideline document, and to identify areas for improvement in this methodology, a fatigue and lifetime case study of a HV floating wind power cable was undertaken.

The case study considered a small wind farm consisting of: four floating wind turbines connected in a daisy chain configuration; a generic 66 kilovolts (kV) power cable cross section; a reference 15 megawatt floating offshore wind turbine on an associated semi-submersible substructure; 200m water depth, and typical environmental conditions for the North Sea. Simulations were carried out using a range of tools - including SimScale UFLEX, Orcaflex, and Shear7 - to complete each of the steps in the fatigue and lifetime assessment guideline. Based on these studies, a range of improvements were identified and implemented in the guideline.

Final industry guideline document

The final version of the power cable fatigue assessment guideline was prepared considering inputs from the Floating Wind JIP partners and additional stakeholder engagement. This document is currently exclusively available for Floating JIP partners who may share it with their supply chains.

Key findings

1

Cable temperature is the predominant factor when considering electrical loading as a cause of mechanical fatigue.

- Assuming that the HV power cable is adequately designed (free from contaminants, manufacturing defects, installation damage, or operational damage) it is considered that there are no electrical-only failure modes that can cause cable fatigue damage or decrease its lifetime.
- The variation of effective wind speed over time is directly related to power production of the wind turbine generator. This, in turn, impacts the magnitude of electrical current transmitted through the power cable and therefore its temperature variation.
- Cable temperature fluctuations caused by these electrical phenomena impact cable properties and exacerbate the mechanical fatigue of cables.

2

Cable thermal analysis is an important step in assessing the mechanical fatigue of dynamic power cables for floating wind.

- The power cable properties are significantly affected by temperature and therefore cable thermal analysis should be carried out to establish the temperature in cable cross-section components and how these vary during the wind farm lifetime.
- Thermal analysis should be conducted to determine the cable's temperature under varying operational loads and environmental conditions, including in the impact of marine growth, presence of ancillary equipment and cooling from sea currents.
- Geometry, materials and modelling approach for ancillary equipment have an important effect on the cable temperature results, therefore project specific data should be used and care taken to model accurately as well as consider heat transfer along the cable. Examples of cable thermal analysis are shown in **Figure 1**.
- Results from the thermal analysis should be used as inputs to the cable local analysis (see **Figure 1** below).
- Load case matrices used for the assessment of cable fatigue should consider temperature associated with both the load case's environmental and operational conditions.

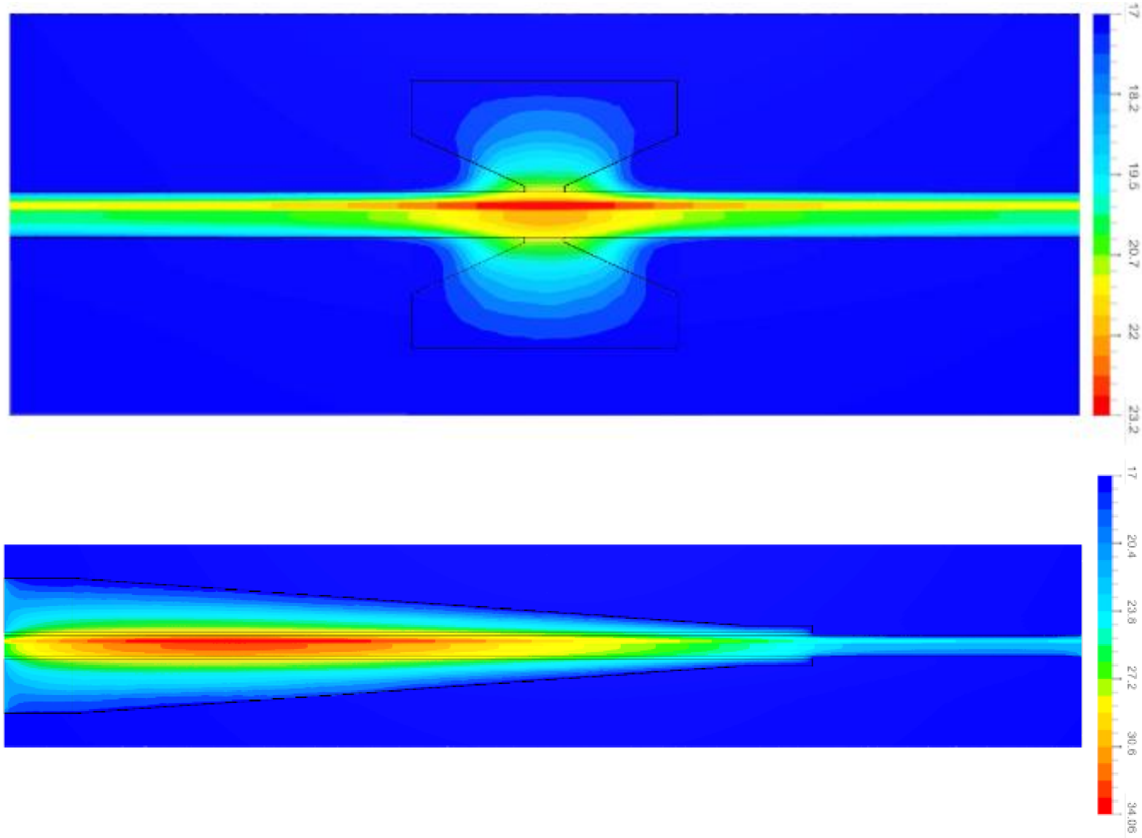


Figure 1. Example of Cable Thermal Analysis Results with Buoyancy Module and inside Bend Stiffener

3 There is a strong interaction between local and global analysis for mechanical fatigue calculation of dynamic power cables for floating wind.

- Local analysis that focuses on a specific region or component of the structure should be carried out to calculate cable properties such as bending and axial stiffness for input into a global analysis which, in turn, considers mechanical fatigue across the entire system.
- Local analysis can be used to obtain stress (or strain) transfer functions. These functions help in translating global curvature loads into detailed stress or strain distribution at the component level. This process helps to accurately predict fatigue damage in specific sections of the cable.
- Factors that influence local analysis outputs and that should be taken into account include temperature, pressure, tension and friction.

4 Project-specific data should be incorporated as early as possible in the fatigue calculation of power cables to minimise assumptions and uncertainties.

- Fatigue damage calculation of power cables is sensitive to inputs such as cable cross-section and fatigue details (e.g. SN curve, which shows the relationship between the stress applied and the number of cycles to failure the component can endure under cycling loading), marine growth profile, ancillary equipment, metocean conditions, and the overall floater system.
- Assumptions made during the input phase of fatigue analysis can alter conclusions and lead to results and designs that are either overly or under-conservative regarding a cables' resistance to fatigue loading.

- Although front-end engineering design and earlier stages are typically carried out with some assumed data, it is recommended that wind farm site-specific data is incorporated as early as possible in the design process.

5 Data gathering, thermal analysis and local and global property analysis should be followed to ensure accuracy in fatigue life calculation of high voltage power cables in floating offshore wind.

- The following key steps should be observed in for a fatigue assessment, as summarised in **Figure 2**:
    a. Input data gathering should be project-specific and provided by equipment vendors to minimise assumptions and reduce uncertainties. Assumed design data should be avoided since it can result in under and over-conservative fatigue results.
    b. Thermal analysis should be carried out to establish the temperature variation at the cable cross-section components for a range of electrical loadings (and wind speeds) expected during the wind farm life.
    c. Local analysis of cable properties should be developed for the range of temperatures established in the thermal analysis, including bending stiffness, axial stiffness, torsional stiffness, and stress and strain transfer functions.
    d. Global analysis should incorporate the cable properties developed in the local analysis and be carried out to calculate fatigue damage at the power cable due to global loads (e.g. wave and wind fatigue analysis and Vortex Induced Vibration (VIV) analysis).
- The inputs and outputs of the analysis listed above are all interdependent on each other. Managing data exchange between these analysis activities and the iteration of varied datasets is therefore essential to achieving a final design of the power cable.
- The level of detail of the fatigue analysis should increase as the project advances from feasibility to detailed design.

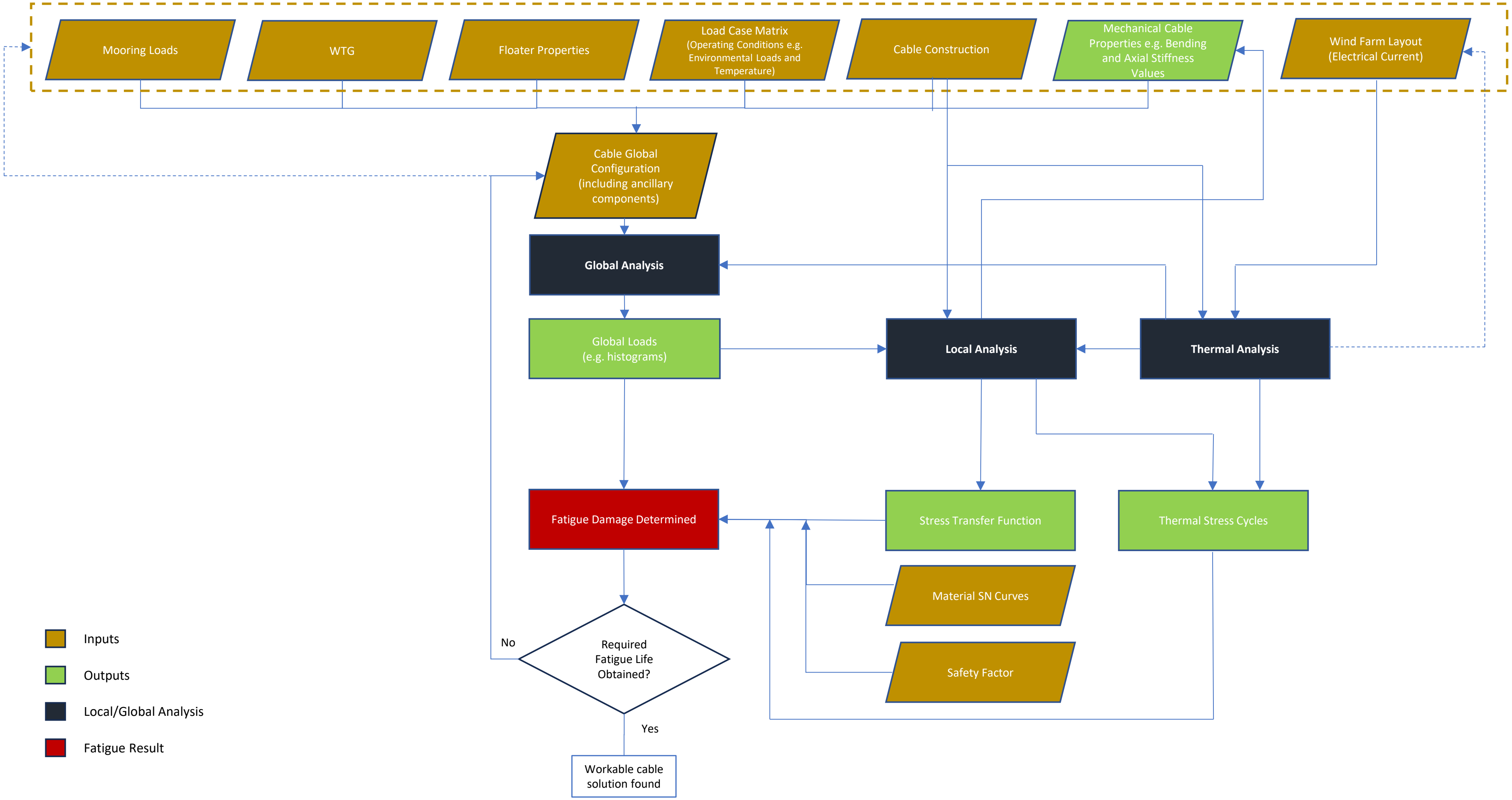


Figure 2. Global, Local and Thermal Cable Fatigue Analysis Flowchart

Industry needs/innovations

1 Further research is needed to quantify the extra heat generated by friction between cable components under dynamic motion.

- Cable temperature has an impact on the cable properties and fatigue damage accumulation, however there is limited publicly available research about the amount of heat generated by friction between the cable cross-section components due to dynamic motions.
- Calculations of cable temperature without taking into account the extra heat generated by friction between cable components due to dynamic motion can result in under-conservative temperature results, increasing cable failure risk.
- Understanding how much extra heat is generated by friction between cable comments is key for accurate cable design.

2 Guidance for conducting Vortex Induces Vibration (VIV) of dynamic power cables is needed in the industry.

- VIV is highly dependent on the parameters selected for analysis and there is currently uncertainty as to the set of parameters that give the most accurate results.
- There is limited published data concerning numerical analysis calibration based on VIV testing results for dynamic power cables.
- Specific guidance for VIV of dynamic power cables should be developed through further testing and calibration of design tools.

3 Development of best practices for assessing fatigue of individual components within the cable cross section is required.

- The fatigue assessment (e.g. SN Curves) of power cable conductors is very complex due to the presence of effects such as friction, abrasion, or the notch effect between wires.
- The metallic screen, a critical component of the cable cross section, also presents significant modelling challenges.
- Temperature is a critical variable when generating SN curves for power cables, and the inclusion of this parameter adds to the complexity of these fatigue assessments.
- The development of a standardised methodology for the assessment of fatigue in power cables is recommended to simplify the generation of SN curves (or similar).

4 Further research is needed for the calculation of fatigue damage specific to non-metallic components.

- The literature review and stakeholder feedback highlight that non-metallic components of the power cable are less sensitive to fatigue than the metallic components.
- There is no standard or recommended methodology for calculating the fatigue of non-metallic components such as cable insulation, however current methodologies proposed include SN curves and crack propagation.
- Fatigue calculation for non-metallic components of power cables is therefore an area that needs further research and guidance.

5 Benchmarking of all the software tools used in floating wind fatigue assessments must continue.

- Due to the early nature of floating offshore wind, there is a general need to continue the industry efforts to benchmark and validate the software tools, models, and methodologies used in HV cable fatigue design.
- It is recommended that this benchmarking and validation is conducted against test data (e.g. a hysteretic curve) and data collected from instrumentation installed on high voltage power cables (e.g. curvature in cable) to identify discrepancies and improve the precision of fatigue life predictions.

ABOUT THE FLOATING WIND JIP

The Floating Wind Joint Industry Programme (Floating Wind JIP) is a collaborative research and development (R&D) initiative between the Carbon Trust and 17 leading international offshore wind developers: bp, EDF Renouvables, EnBW, Equinor, Kyuden Mirai Energy, Ørsted, Ocean Winds, Parkwind, RWE Renewables, ScottishPower Renewables, Shell, Skyborn Renewables, SSE Renewables, TEPCO, Tohoku Electric Power Company, Total Energies and Vattenfall.

The primary objective of the Floating Wind JIP is to overcome technical challenges and advance opportunities for commercial scale floating wind. Since its formation in 2016, the programme scope has evolved from feasibility studies to specific challenges focusing on:

- Large scale deployment
- De-risking technology challenges
- Identifying innovative solutions
- Cost reduction

Stage 3 of the Floating Wind JIP commenced in 2022 and projects are expected to run until early 2027. With several commercial scale floating offshore wind farm projects in design phase and having the ambition to be commissioned by 2030, the industry needs to address several challenges. The 17 Floating Wind JIP partners agreed on six research areas where further understanding and advancement is required to reach full commercialisation of floating offshore wind projects.

Electrical systems	Mooring systems	Logistics	Windfarm optimisation	Foundations	Asset Integrity and monitoring

This Guidance for Dynamic Cables project addresses the ambitions of the Electrical Systems research area:

Electrical systems

1	Understand full electrical system design for commercial scale floating wind farms.
2	Define dynamic array and export cable architecture for commercial scale floating wind.
3	Advance understanding of dynamic cable failures to accelerate towards more reliable and insurable systems.

The Stage 2 summary reports can be found here: Phase I, Phase II, Phase III, Phase IV and Phase V.

ABOUT THE CARBON TRUST

Who we are

Our mission is to accelerate the move to a decarbonised future. We are your expert guide to turn your climate ambition into impact.

We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions to drive positive climate action. To date, our 400 experts globally have helped set 200+ science-based targets and guided 3,000+ organisations and cities across five continents on their route to Net Zero.

carbontrust.com

+44 (0) 20 7170 7000

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 04190230 with its Registered Office at: Level 5, Arbor, 255 Blackfriars Road, London SE1 9AX, UK.

Published in the UK: 2025