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The economy-wide implications of reaching the UK's 2030 offshore wind targets: The importance of grid flexibility

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ABSTRACT

The UK's 2030 offshore wind targets are central to its decarbonisation strategy. Understanding the wider economy impacts of meeting them, and the conditions that shape those impacts, matters for investors, policy-makers, and the energy regulator, which now carries a statutory duty to promote sustainable economic growth. Here, we consider the extent to which electricity system flexibility conditions the macroeconomic outcomes of offshore wind. We use UKENVI, a dynamic multi-sector computable general equilibrium model with a detailed representation of electricity generation technologies and of the flexibility with which the transmission system draws on generators of differing responsiveness. Offshore wind expansion is introduced through productivity improvements reflecting declining generation costs, combined with exogenous investment sufficient to meet capacity targets, and we compare two scenarios: (i) current grid flexibility, and (ii) enhanced flexibility through investment in storage and network infrastructure. We find that offshore wind expansion delivers positive macroeconomic outcomes under both scenarios, but that enhanced grid flexibility substantially amplifies these gains. Crucially, under the current flexibility constraints, curtailment and declining returns to capital limit utilisation and, in turn, the economy-wide benefits realised. Where flexibility is enhanced, greater utilisation of installed capacity is sustained alongside capital productivity, and we observe stronger increases in GDP, employment, wages and household consumption. These findings suggest that delivery of the capacity targets alone is unlikely to be sufficient, and that coordinated investment in grid flexibility is required if the full economic and environmental returns to deployment are to be secured.

1. Introduction

Accelerating the deployment of renewable energy technologies is essential to meeting climate goals. Among these technologies, offshore wind energy has emerged as a particularly strategic technology due to its capacity to deliver large volumes of low-carbon electricity at scale, while potentially also supporting economic growth and regional development in countries with favourable maritime conditions. In the United Kingdom (UK), offshore wind has become a central pillar of the government's net-zero strategy (UK Government, 2022). Over the next decade, offshore wind is expected to play a transformative role in the UK

electricity system, becoming the dominant source of clean power generation (NESO, 2025; UK Government, 2024a). The projected large-scale deployment is anticipated to displace fossil fuel-based generation, significantly reduce power sector emissions, and enhance long-term electricity cost stability by lowering marginal generation costs and reducing exposure to volatile gas prices (IEA, 2023).

Reflecting these strategic objectives, the UK Government's Clean Power Plan sets a target of 50 GW of installed offshore wind capacity by 2030, up from 15.9 GW in 2024 (NESO, 2025; UK Government, 2024a). This ambition consolidates the UK's position as a global leader in offshore wind deployment, currently ranking second worldwide by

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installed capacity. More broadly, it aligns with an integrated policy and regulatory agenda that links renewable energy and electricity network expansion to energy security, industrial competitiveness, and sustained economic growth¹ (CCC, 2025a; Ofgem, 2024; UK Government, 2025; UK Government, 2024b).

Over the past decade, offshore wind generation costs have declined significantly, largely driven by technological innovation, learning-by-doing, and economies of scale (Jennings et al., 2020; Shields et al., 2021). These cost reductions have underpinned the competitiveness of offshore wind relative to conventional generation technologies, which have experienced sharp price increases since 2020, partly as a result of heightened fuel price volatility following the Russian invasion of Ukraine.

More recently, however, developments across the sector have highlighted growing financial pressures. In the UK, the 2023 round of the Contracts for Difference (CfD) scheme (Allocation Round 5) failed to attract any offshore wind bids, reflecting rising capital costs, supply chain constraints, and higher financing costs (Watson and Bolton, 2024). Nevertheless, projections continue to indicate scope for renewed cost reductions as deployment expands and supply chains mature, with the Climate Change Committee projecting a 39% reduction in offshore wind generation costs by 2050 relative to 2025 levels (CCC, 2025b).

Consequently, both academic and policy literature (Jennings et al., 2020; Ghorbani Pashakolaie et al., 2024; Higgins and Foley, 2014; Lecca et al., 2017a) increasingly suggests that cost-effectively achieving renewable energy targets is becoming not only more feasible over the long term, but is also an increasingly pressing requirement to deliver desirable outcomes for consumers and to support activity across the wider economy.

However, a significant policy challenge persists: the limited flexibility of the UK electricity grid to integrate intermittent renewable generation, particularly offshore windfarms that are situated far from major demand centres. The existing infrastructure was not designed for large-scale renewable integration, necessitating substantial transmission upgrades to ensure efficient and reliable power delivery. Furthermore, the grid lacks the operational flexibility required to manage the variability and intermittency of offshore wind output, leading to curtailment and inefficiencies (Qadrdan et al., 2025).

This challenge is intensified by lengthy consenting procedures, planning and delays in securing grid connection approvals (CATAPULT, 2023). Consequently, the UK remains exposed to high and volatile international gas prices, which continue to set the marginal cost of wholesale electricity despite the growth in renewable capacity (Zakeri et al., 2023).

The grid-limited flexibility not only hinders progress towards renewable energy targets but can also have impacts on realising the potential economic benefits of offshore wind. Enhancing grid flexibility through measures such as interconnection between regions and nations, energy storage, demand-side response, and digital system management are all widely recognised as essential for the cost-effective integration of variable renewable generation and for maintaining system balance (Ofgem, 2024; CATAPULT, 2023; DESNZ, 2025; World

Economic Forum, 2025). Moreover, in addition to strategic Growth Duty requirements identified by Ofgem as the energy industry regulator, UK parliamentary committees have highlighted the need for strategic reforms to grid infrastructure and system operation to support large-scale clean power deployment and unlock associated economic growth benefits (UK HOUSE OF LORDS, 2025).

Against this backdrop, the objective of this study is to estimate the dynamic, economy-wide implications of meeting the UK's 2030 offshore wind target (which we take as given in the current policy landscape), and to establish the extent to which grid flexibility conditions those outcomes.

The study is accordingly guided by two related questions. First, what are the likely economy-wide implications of the planned offshore wind expansion, including for GDP as a key measure of income generation and growth? Second, and crucially, what role does grid flexibility play in determining these outcomes? In addressing these questions, we are concerned primarily with wider economy impacts rather than with electricity-system performance in isolation. System-level outcomes, and particularly the formation of wholesale electricity prices under differing degrees of grid flexibility, are treated as a primary channel through which the economic consequences of the target are transmitted. The analysis thereby moves beyond the established focus on generation costs and intermittency to examine how electricity system constraints propagate through wholesale pricing to influence activity across the wider economy in different timeframes. To this end, we adapt a dynamic multi-sector economy-wide computable general equilibrium (CGE) model to reflect the limited flexibility of the electricity system in balancing supply and demand between renewable and thermal generation.

The paper makes two key contributions. First, it develops a methodological framework that incorporates electricity sector capacity expansion into a CGE model, enabling more realistic and policy-relevant analysis of large-scale renewable deployment. Second, it applies this framework to the UK economy and that nation's planned offshore wind expansion, offering new insights into the potential structural and distributional consequences of meeting the current government's 2030 target.

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature on offshore wind and economy-wide energy modelling. Section 3 outlines the methodology and data. Section 4 presents the simulation results, including electricity system outcomes and broader economic impacts. Section 5 concludes.

2. Literature review

Early research on offshore wind energy focused predominantly on generation efficiency and system integration challenges. Studies such as the comprehensive spatial-economic analysis by (Beiter et al., 2016) have analysed offshore wind development pathways in terms of significant cost reductions, establishing the vast technical potential available. Similarly (Stephens and Walwyn, 2018), examined generation efficiency implications from increasing installed capacity, highlighting operational considerations for large-scale deployment. These technical studies established the fundamental viability of offshore wind but necessarily left economic implications less thoroughly explored.

The economic impacts of offshore wind development have been examined using various methodological approaches. Input-output (IO) models have been widely applied, with (Kahouli and Martin, 2018) utilising regional IO modelling for France to quantify employment impacts during both investment and operational phases. Similarly (Varela-Vázquez and Sánchez-Carreira, 2017), employed IO analysis for Spain, demonstrating significant job creation potential even with limited installed capacity. More recent applications include demand-driven IO multiplier analyses (Allan et al., 2020, 2021) which are widely used to quantify gross supply-chain effects and gross employment supported by offshore wind investment and operation. However, IO models, are generally demand-driven and lack

¹ In addition to UK national and devolved governmental aims and ambitions around economic growth associated with net zero actions and pathways, numerous national regulators are subject to a statutory Growth Duty, which came effect in 2017 under the Deregulation Act 2015, and was extended to include the energy regulator Ofgem in 2024. The Growth Duty requires regulators to have regard to the desirability of promoting economic growth alongside their core regulatory functions. Thus, in the case of Ofgem and solutions like offshore wind, consideration of Growth Duty delivery becomes important in terms of delivering the grid flexibility need to efficiently and cost-effectively deliver electricity generated to end and intermediate users (via design of market frameworks, removal of barriers, and encouraging investment in storage and other solutions). See <https://www.gov.uk/government/publications/growth-duty> for details.

simultaneous consideration of price mechanisms and substitution possibilities, limiting their usefulness to contexts where resource scarcity is negligible (Dietzenbacher, 1989; Galbusera and Giannopoulos, 2018; Miller and Blair, 2009; Pichler and Farmer, 2022). For analysing price implications of meeting offshore wind targets in the UK context with constrained labour markets, IO methods are therefore inadequate.

Macro-econometric modelling extends IO analysis by embedding historical behavioural relationships and allowing for investigating demand-driven outcomes. Such models have been applied in the UK decarbonisation pathways (Arvanitopoulos and Agnolucci, 2020). While these models highlight investment and consumption dynamics, their reduced-form structure limits the explicit treatment of substitution possibilities between technologies, factors, and fuels.

Economy-wide computable general equilibrium (CGE) modelling provides an alternative framework where relative prices, factor markets, trade, and sectoral output adjust endogenously. This makes CGE models particularly suitable for analysing the dynamic and long-term implications of pursuing offshore wind targets, where resource constraints, technology substitution in the electricity network, and electricity price dynamics are central to all energy and economic system outcomes. This led to increased adoption of CGE modelling, as demonstrated by (Graziano et al., 2017) in their analysis of UK offshore wind development paths under different local content scenarios.

In this context, previous UK studies using CGE have explored various dimensions of offshore wind development (Lecca et al., 2017b). and (Qu et al., 2023a) have shown how technological learning in offshore wind reduces costs, supporting deployment targets while generating economy-wide welfare benefits. These cost reduction pathways are underpinned by technological innovation, learning-by-doing, and economies of scale, as documented by (Jennings et al., 2020; Shields et al., 2021), who have demonstrated significant declines in the levelised cost of electricity (LCOE) for offshore wind. Despite these advances, there remains a lack of dynamic economic modelling that combines investment ramp-up with cost reductions, particularly in understanding how these jointly affect both economic outcomes and system flexibility. Moreover, while previous CGE studies have examined cost trajectories, they did not consider the implications of achieving the current 2030 targets and, crucially, abstracted from the role of limited grid flexibility, a factor that may significantly alter economy-wide outcomes. Most existing studies treat these aspects separately, missing potential interactive effects.

Beyond cost considerations, the role of offshore wind in energy system flexibility has received increasing attention, as system integration becomes critical for achieving high renewable penetration (Sheykha and Madlener, 2020). analysed flexibility in the European electricity market, introducing a novel scoring concept and examining offshore wind's contribution to system flexibility. Similarly, studies have highlighted the importance of enhancing grid flexibility through interconnection, storage, demand-side response, and digital system management (Ahmed et al., 2025; Jerez and Nour, 2025). However, whilst these studies examine flexibility separately, there remains limited integration of flexibility considerations in economy-wide impact assessment. This requires overcoming the sectoral detail limitations of most CGE and other economy-wide frameworks, which generally rely on national (and/or regional) input-output accounting data that generally only identify a single electricity sector that aggregates across all generation, transmission, distribution and supply activity.

Furthermore, in exploring how offshore wind integrates within broader energy systems, the treatment of flexibility relates closely to the substitution possibilities between different energy sources in production structures of CGE modelling (Cui et al., 2020). investigated alternative nesting structures and substitution elasticities within the electricity generation mix in examining the impacts of technology learning on renewable curtailment (Qu et al., 2021, 2023a, 2023b). incorporated a disaggregated electricity sector that distinguishes offshore wind and other sub-sectors into the CGE modelling framework, allowing for

substitution and marine resource competition against other sectors in Scotland. However, different categories of renewables in terms of flexibility remain insufficiently explored in a wide economic modelling set, especially the substitution between flexible and inflexible renewables, and between renewables and fossil fuels. This gap is particularly important given the increasing role of renewable energy in power systems and the need to understand how different substitution elasticities affect the energy mix.

Our research aims to address these gaps by developing an integrated CGE framework that explicitly incorporates flexibility considerations while simulating investment ramp-up with increasing capital efficiency and implied cost pathways of a disaggregated offshore wind sector. The specification permits analysis of how substitution possibilities between different renewable and non-renewable electricity generation sources affect system flexibility and economic outcomes. This approach enables the provision of new insights into the relationship between offshore wind expansion, economic impacts, and energy system evolution, while accounting for technological progress and market development. By combining these elements within a single analytical framework, our research contributes to a more comprehensive understanding of the implications of reaching offshore wind development in the UK under different levels of flexibility of the electricity network.

3. Materials and methods

Here, we employ a dynamic CGE modelling framework to further contribute to and address some of the gaps set out above. This scenario simulation framework's dynamic structure permits an analysis that incorporates adjustment paths over time, including both the front-loaded investment requirements of offshore wind expansion and the subsequent cost reductions that support progress towards the UK's 2030 targets.

3.1. Developing a UK social accounting matrix (SAM) to focus on electricity generation and supply issues

As discussed above, analysing the long-term macroeconomic implications of offshore wind expansion requires a CGE model that can represent the electricity industry with sufficient technical detail. The building block of any CGE model is a social accounting matrix (SAM), which is usually constructed by building out from national or regional Input–Output (IO) tables (e.g., the ONS in the UK, or the Scottish Government in the devolved context) with fuller detail on income transfers (Miller and Blair, 2009). However, for a range of reasons, including data availability and collection costs, restrictions on disclosing firm-level information in sectors with few operators, and/or where there is extensive vertical integration, standard IO tables often feature high levels of sectoral aggregation (Chakraborty et al., 2010; Lindner et al., 2013). In the UK case, all electricity generation technologies, network distribution, and retail supply are grouped into a single sector.

Such over-aggregation introduces aggregation bias, a problem long recognised in the IO literature (Leontief and Leontief, 1951; Malinvaud, 1956; Morimoto, 1970). In environmental and/or energy studies, this hinders the construction of economy-wide models capable of isolating and investigating the role of specific technologies or assessing the impacts of policies targeted at them. Prior research has demonstrated that aggregation choices significantly affect results (Ara, 1959; Gale, 1995; Su et al., 2009). For example (Gale, 1995), shows that aggregation of the electricity sector constrains the ability to evaluate generation-specific policies. The issue arises because different generation technologies exhibit distinct input structures, which diverge further from those of the network distribution and retail supply elements of the electricity industry. In short, over-aggregated sectors are forced to share identical (upstream) input–output coefficients, despite clear technological differences in production technologies and requirements (Ara, 1959). Similarly, downstream differences are also masked, for instance, in how electricity generation activities primarily supply wholesale markets

through network operators, while retail suppliers sell directly to end-users. In short, such structural differences mean that aggregation into a single electricity industry mask important economic linkages. Consequently, several authors (Lenzen, 2011; Wiedmann et al., 2011) recommend disaggregating the electricity sector in economy-wide studies relying on IO databases.

In response, the present study undertakes a detailed disaggregation of the electricity sector within the 2018 UK IO tables (the most recent available at the time the research was conducted, here assumed to represent a starting year of 2025 in real terms in the absence of structural change), thereby constructing a more granular electricity block in the IO-based SAM that the UKENVI CGE model is calibrated on. Following methodologies established by (Lindner et al., 2013; Fei, 1956; Wolsky, 1984), the electricity sector is first separated into three sub-sectors: generation, network distribution, and retail supply, where the first delivers output only to the second, which then delivers to final consumers. Crucially, the network distribution sub-sector features a range of different generation technologies within its input structure, as reflected in Fig. 1 (see Section 3.2.1 below), where it substitutes between generation types in delivering its own output. Here, the generation subsector is composed of ten distinct technologies, including nuclear, wind power and solar as non-flexible technologies in the absence of storage and other flexibility options. The electricity trade sector ensures that the demand and supply are balanced all the time. This decomposition uses the UK's Annual Business Survey (ONS, 2024), fuel input allocations, and cost-based weighting factors to generate technology-specific representations of generation activities. Supplementary data from (DECC. Electricity generation costs, 2012) and (Hanna et al., 2022) provide cost and employment split factors, enabling the construction of a ten-subsector generation matrix embedded within the SAM.

The resulting refined electricity SAM enhances our model's ability to simulate technology-specific policies, investment scenarios, and structural transitions in the electricity system. In particular, it provides the necessary detail to evaluate how offshore wind interacts with network distribution and supply, and how additional flexibility investments alter macroeconomic outcomes. By overcoming the aggregation bias of standard IO tables, this SAM offers a more accurate representation of sectoral linkages and distributional effects in the context of large-scale

renewable deployment and grid infrastructure expansion.

3.2. The UKENVI CGE model

The CGE model employed in this analysis is UKENVI, a dynamic, multi-sector, economy-wide model of the UK economy designed to assess the impacts of energy and environmental policies. UKENVI captures interactions between three domestic economic agents, households, corporations, and government, and one external trade partner, the rest of the world (ROW). The dynamic structure of the model allows for adjustment paths over time, including investment cycles and technological learning. It explicitly represents the UK electricity sector through calibration on a purpose-built SAM described above, enabling detailed modelling of generation technologies, transmission, and system costs. This feature is critical for analysing scenarios where resource constraints and grid flexibility influence electricity prices and economy-wide outcomes. The full set of model equations is provided in the Appendix. Here, we focus on describing key elements of model specification for the current study.

3.2.1. Production

Each production sector in UKENVI (including each of the electricity generation, network distribution and trade sub-sectors) operates on a cost-minimisation basis, with output generated through a nested constant elasticity of substitution (CES) production function. A KLEM structure is adopted, where capital (K), labour (L), energy (E), and materials (M) are combined in a multi-level nesting framework, with import substitution possibilities for each commodity output within the E and M blocks (apart from the use of the domestic network distribution) as explained in Section 3.2.5 below. Capital and labour are first combined in a value-added nest, while energy and non-energy intermediates are grouped in a parallel nest. At the top level, these two composite inputs are aggregated to produce sectoral output. We note that it is common in CGE models to nest energy in the value-added block; however, given the produced nature of electricity in particular (the focus of this paper), we consider it more appropriate to nest within the intermediates (produced inputs) block (Lecca et al., 2017b).

For the block of the electricity sector, further refinements are introduced, where other electricity sub-sectors are located within the E

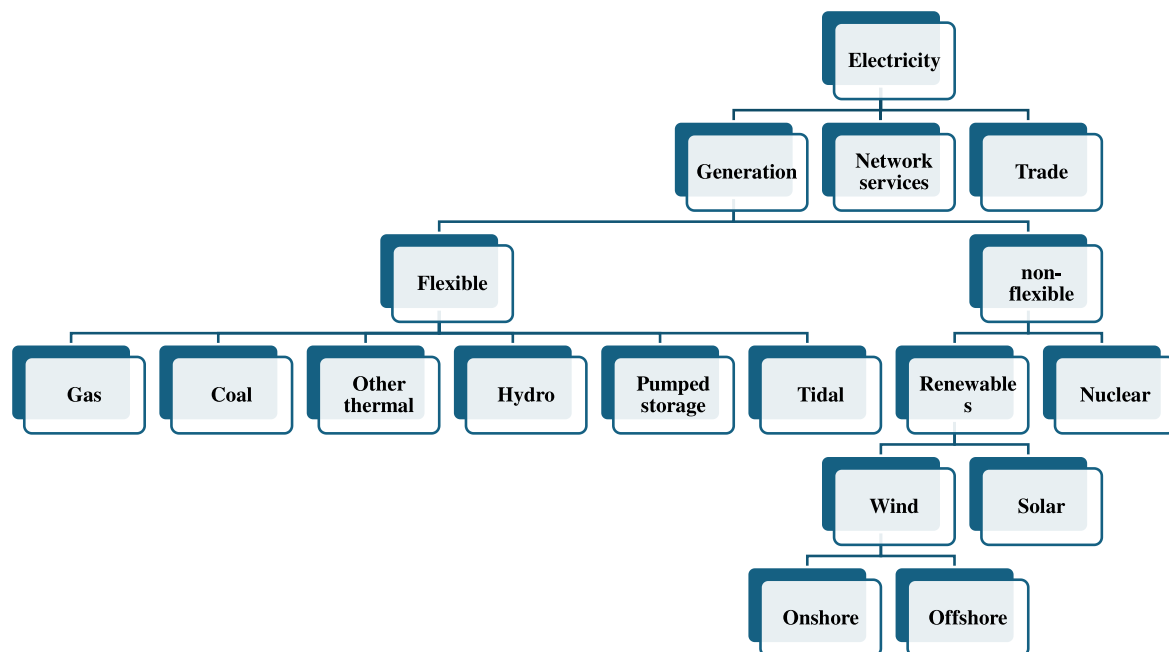


Fig. 1. The Network Distribution Generation Mix nesting structure.

block, but are introduced as complementary inputs to other energy use required by the sector in question. That is, both network distribution and electricity trade will have their own operational energy requirements are not substitutable for the latter's use of the former, or the former's drawing on the generation sub-sectors, rather varying with the overall output level.

In terms of how the electricity network distribution sector calls on the output of the 10 generation sub-sectors, the relevant nesting structure within the E block of the KLEM function of the network distribution sector is shown in Fig. 1. Here, rather than treating electricity generation as a homogeneous activity, generation is explicitly separated by technology and by functional role within the power system. This Distribution Network Generation Mix is further nested into flexible and non-flexible generation technologies.

- Flexible generation technologies comprise gas, coal, other thermal, hydro, pumped storage, and tidal. These are grouped because they can provide balancing services and system flexibility through dispatchability or storage capacity.
- Non-flexible technologies consist of nuclear and renewables. Renewables are further disaggregated into solar and wind, with the wind category divided into onshore wind and offshore wind.

A schematic of this crucial element nesting structure is shown in Fig. 1. This specification captures both the technological heterogeneity of generation activities and the systemic distinction between flexible and non-flexible sources. By explicitly representing offshore wind alongside onshore wind and other renewables, while differentiating technologies that provide flexibility, the model can analyse how offshore wind expansion interacts with system constraints and flexibility measures, and how these interactions propagate through the wider economy.

In the absence of econometric estimates of UK-specific substitution elasticities, the model adopts parameters from previous applications of UKENVI for the main KLEM elements of each sector's production function (e.g. (Alabi et al., 2022)). This ensures methodological consistency with the existing CGE literature on the UK. For the generation mix element of the distribution network's production function, substitutability is a central focus of the scenario simulation work conducted here (see Section 3.3 below).

3.2.2. Investment

Capital accumulation in UKENVI follows a recursive dynamic structure, with the capital stock updated through annual investment responses to changing activity levels. For all the sectors but the offshore wind sector (the subject of the UKENVI scenario simulations), investment is determined endogenously to both replace depreciated capital and partially close the gap between the existing capital stock and the desired level. The desired level of capital stock is defined not endogenously through not only activity requirements but current-period investment conditions, while depreciation rates and interest rates are specified exogenously. Consistent with the recursive dynamic nature of the model, producers are assumed to be myopic: investment decisions are based exclusively on current prices, costs, and demand conditions, rather than on forward-looking expectations or intertemporal optimisation (Lecca et al., 2017a; Alabi et al., 2022). In the long run, equilibrium conditions require that the actual capital stock converge to the desired level, with investment sufficiently large to offset depreciation.

Investment in the offshore wind sector is introduced exogenously through a sector-specific investment function. Offshore wind investment is calibrated to follow a predetermined trajectory consistent with meeting the 2030 capacity targets. This function specifies annual additions to the capital stock, allowing the model to impose the scale and timing of capacity expansion required under the policy scenario. At the same time, the approach accommodates endogenous cost reductions over time, reflecting learning-by-doing and technological progress

embedded in the sector's production structure. Further details on the construction of this investment path and its role within the broader simulation strategy Section 3.3, where the simulation strategy is set out.

3.2.3. Labour market

In this study, we assume a fixed national labour supply, abstracting from any natural population changes to reflect the current UK labour supply constraints and the existing migration limitations. This fixed labour supply comprises both employed and unemployed workers for the required base year of 2018, with the initial full-time equivalent (FTE) unemployment rate set at 4.1% in the base year, informed by data from the UK Office for National Statistics.² In the absence of data on specific work skills or competencies, we assume perfect labour mobility across sectors.

In the model setup, the real wage is determined through a bargaining function, which is inversely related to the unemployment rate (Blanchflower and Oswald, 1990):

$$\ln\left(\frac{w_t^b}{cpi_t}\right) = \omega - \varepsilon \ln(u_t) \quad (1)$$

In equation (1), w_t^b is the bargained nominal wage rate, cpi_t is the Consumer Price Index (CPI) in period t , u_t is the unemployment rate in period t , while ε is the elasticity with which wages adjust to changes in the unemployment rate, set at 0.113 (Blanchflower and Oswald, 2005; Layard et al., 1991). As equation (1) implies, the UK workers' bargaining power over their real wages increases as the unemployment rate falls and vice versa.

Note that our imperfectly competitive labour market specification allows for the presence of unemployed labour in the long run. Therefore, there can be net employment gains or losses in all transitory and long-run equilibria.

3.2.4. Government

The government balance GB is determined via:

$$GB_t = GY_t - GEXP_t \quad (2)$$

In (2), GY reflects the government revenue and $GEXP_t$ is total government expenditure (comprising government consumption and transfer). Government revenue is given by:

$$GY_t = \left(d^g \cdot \sum_i rk_{i,t} \cdot K_{i,t} + \sum_i IBT_{i,t} + \tau_t \cdot \sum_j L_{j,t} \cdot w_t + \overline{FE} \cdot \varepsilon_t \right) \quad (3)$$

Government revenue comprises the share of capital revenue directed to the government, determined by the share d^g , the indirect business tax (IBT), tax on labour income L at rate τ and foreign remittances FE at a fixed exchange rate ε . In the model, key parameters such as the government's share of capital revenue and the income tax rate are fixed.

3.2.5. Trade

We assume the UK engages in trade with a single external region, referred to as the rest of the world (ROW). Exports and imports are sensitive to changes in relative domestic and foreign prices, although foreign prices are assumed to remain constant across all time frames. Export demand is then inversely related to domestic prices, with a default export price elasticity of 2.0 used within the constant elasticity of transformation (CET) function.

In terms of imports, UK producers and consumers utilise a combination of domestic and foreign goods and services, which are regarded as imperfect substitutes (Armington, 1969). The default Armington

² The annual unemployment rate for the UK can be found at: <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/unemployment/timeseries/mgsx/lms>.

elasticity in UKENVI is set at 2.0. As we treat the ROW as being exogenous (and the UK treated under the small open economy assumption, where any change in activity will not feedback through interaction with the international sector), we do not include the production of imported goods and services in our model.

3.3. Simulation strategy

The UK Clean Power 2030 plan sets a target of 50 GW of installed offshore wind capacity by 2030, up from 15.9 GW in 2024. To evaluate the macroeconomic implications of achieving this target, the planned expansion is introduced into the UKENVI CGE model through two channels.

3.3.1. Cost reduction

Historical data (CCC, 2024) indicate a decline in the levelised cost of electricity (LCOE) for offshore wind from £167.77/MWh in 2018 to a projected £44/MWh by 2025, representing a reduction of approximately 74%. In the model, this is implemented as an exogenous increase in total factor productivity (TFP) in the offshore wind sector, reducing its effective unit cost. The TFP improvement is phased in gradually over 12 years (2018–2030) to reflect the observed trajectory of technological progress.

3.3.2. Capital expansion

Reaching the 2030 target requires a substantial increase in the sectoral capital stock. Based on capacity estimates, offshore wind capital must rise by 139% relative to its 2018 level. This is modelled as an exogenous investment shock representing the required additional capital formation. As with TFP, the capital expansion is introduced progressively at an equal path from 2018 to 2030, ensuring that the model captures the transitional dynamics associated with scaling up offshore wind capacity and that the required stock is achieved by the target year.

3.3.3. Simulation scenarios

We then develop two simulation scenarios to examine the long-term macroeconomic consequences of offshore wind expansion under alternative assumptions about electricity grid system flexibility.

3.3.3.1. Scenario 1: current flexibility. The UK electricity grid is assumed to maintain its current level of flexibility. Following (Papageorgiou et al., 2017), the elasticity of substitution between flexible and inflexible generation technologies within the distribution network generation nest (Fig. 1) is set to 2. Under these conditions, integration challenges persist, and constraint payments continue to be required to ensure the sector's financial viability.

3.3.3.2. Scenario 2: enhanced flexibility. This scenario assumes enhanced system flexibility arising from investments in grid infrastructure, energy storage, and broader system-integration measures. Within the model, this is operationalised by increasing the elasticity of substitution between electricity generation technologies. The elasticity is raised to the minimum (2.89) level required for the expanded offshore wind capacity to be absorbed efficiently by the power system, while ensuring that the electricity generation sector continues to earn non-negative economic returns.

This modelling approach is intended to represent a power system in which enhanced flexibility alleviates network constraints, thereby eliminating the need for constraint payments and facilitating the cost-effective integration of large volumes of offshore wind generation. Rather than modelling individual flexibility technologies explicitly, the higher substitution elasticity serves as a reduced-form representation of improved dispatchability and system responsiveness.

It is important to note that the costs associated with enhancing network flexibility, such as investments in transmission and distribution

networks, storage capacity, or system-balancing services, are not modelled explicitly in this scenario. As a result, the analysis focuses on the system-wide economic implications of increased flexibility on generation outcomes, abstracting from the direct capital and operational costs required to achieve such flexibility in practice.

3.3.3.3. Sensitivity analysis. We conduct three sets of sensitivity analyses to test the robustness of the main results to key modelling assumptions: the first on the elasticity of substitution, which governs the system's capacity to absorb offshore wind generation; the second on the trajectory of offshore wind costs; and the third on the labour-market specification.

The central comparison between Scenario 1 and Scenario 2 hinges on a single parameter, the elasticity of substitution between flexible and inflexible generation technologies within the distribution network generation nest (Fig. 1). This parameter is set to 2 under current flexibility and raised to 2.89 under enhanced flexibility. Given its centrality to the results, we examine how the economy-wide outcomes respond as it varies across a range of values representing progressively more- and less-flexible network states. Specifically, we re-run the analysis for elasticities of 0.8, 1.5, 2.25 and 2.5, alongside the two scenario values of 2 and 2.89. Values below unity place the generation technologies in a complementary relationship, representing a network more rigid than the current system; the value of 2 corresponds to the current calibration following (Papageorgiou et al., 2017); and 2.89 represents the minimum elasticity at which the expanded offshore wind capacity can be absorbed efficiently, without recourse to constraint payments and while the generation sector continues to earn non-negative returns. Outcomes are expressed relative to the current system (an elasticity of 2), to isolate the economic dividend associated with improving system flexibility. This allows us to establish whether the gains accumulate smoothly as flexibility increases toward the absorption threshold and, crucially, whether the magnitude of the dividend depends on the starting point, that is, whether a more constrained initial network implies a larger economic gain from enhanced flexibility.

The second analysis varies the assumed trajectory of offshore wind costs. The central case implements the historical LCOE decline of approximately 74% (Section 3.3.1). In light of the upward pressure on offshore wind costs evident in the 2023 Contracts for Difference allocation round, we examine a less favourable trajectory in which the LCOE is 10% higher than in the central case. Consistent with the simulation strategy, in which meeting the target is represented jointly by a TFP improvement and the investment required to reach 50 GW, the higher-cost case is implemented through a correspondingly smaller TFP improvement in the offshore wind sector together with the larger investment outlay required to deliver the same capacity at the elevated cost.

The third analysis concerns the labour-market specification. As noted above in section 3.2.3, our central case setting in UKENVI assumes fixed labour supply and bargaining over real wages, reflecting current labour-market constraints in the UK, where multiple planned net-zero projects compete for a limited pool of skilled workers, putting upward pressure on wages and moderating the economic benefits of offshore wind expansion. As a robustness check, we replace this with a fixed real-wage specification to isolate the macroeconomic implications of meeting the offshore wind target under a less constrained labour market.

4. Results and discussion

4.1. Electricity sector outcomes

Meeting the UK's 2030 offshore wind targets induces substantial changes in the electricity sector, affecting offshore wind output, capital returns, wholesale electricity prices, and the broader generation mix. These impacts depend critically on grid flexibility, which determines

how effectively offshore wind capacity can be integrated and translated into sustained economic benefits.

Under the existing level of flexibility (Scenario 1), offshore wind expansion delivers substantial gains but is constrained by system integration limits. As shown in Fig. 2 (orange solid line), meeting the 2030 deployment target requires a 139% increase in offshore wind capital stock, resulting in output levels that are 223% above baseline by 2050 (blue solid line). Consequently, Offshore wind's share of electricity supply increases from 8% to 22% over this period, displacing fossil-based generation, although natural gas remains the dominant source at 34% (Fig. 3, blue bars).

The increased availability of low marginal-cost offshore wind generation places downward pressure on wholesale electricity prices. However, returns to offshore wind capital decline over time, reflecting increasing underutilisation of installed capacity. This outcome is consistent with higher curtailment rates arising from limited grid capacity and balancing constraints, which reduce effective utilisation and dampen investment efficiency.

When grid capacity is expanded (Scenario 2), the electricity system is able to absorb substantially higher levels of offshore wind generation. Offshore wind output reaches 311% above baseline by 2050, around 90% higher than under current flexibility (Fig. 2, blue dashed lines). Returns to capital remain stable, indicating that enhanced grid infrastructure allows offshore wind investments to remain productive and economically viable. Offshore wind's share of the generation mix rises to 27% by 2050 (Fig. 3, orange bars), accelerating the displacement of fossil-based generation and reinforcing the decarbonisation of the UK electricity sector.

The contrast between the two scenarios underscores the path-dependent nature of electricity sector transitions. Without timely grid investment, offshore wind deployment risks being constrained by declining utilisation and returns, limiting its contribution to affordable and low-carbon electricity. By contrast, enhanced flexibility supports a reinforcing dynamic of higher renewable output, sustained investment incentives, and faster decarbonisation. These results highlight the importance of coordinating offshore wind deployment with grid expansion to fully realise the benefits of the UK's renewable energy transition.

4.2. Economy-wide impacts

4.2.1. Economy-wide impacts under current grid flexibility (scenario 1)

Meeting the UK's 2030 offshore wind generation target generates positive but moderate economy-wide effects, operating through changes in electricity prices, investment dynamics, and sectoral competitiveness. These impacts are relevant for policy debates on affordability, employment creation, and the broader economic implications of the energy transition.

As outlined in the simulation strategy in Section 3.3, achieving the 2030 target necessitates a substantial increase in offshore wind capital stock. This initially stimulates economic activity through higher investment demand, particularly in manufacturing, engineering services, and construction. The present analysis, however, focuses on the long-run economic effects that emerge once the additional capacity is fully deployed and operational.

The economy-wide effects displayed in Fig. 4 operate through three main channels. First, indirect production linkages strengthen upstream and downstream activities, supporting industrial competitiveness. Second, labour market effects arise as higher sectoral activity increases employment and real wages, raising household income and consumption. Third, electricity prices decline as offshore wind displaces higher-cost fossil-based generation, reducing energy costs for producers and households.

Table 1 summarises how these mechanisms translate into long-term percentage changes in key macroeconomic indicators relative to the benchmark by 2050. Under current grid flexibility, GDP increases by £4.14 billion (0.22%) relative to the baseline, while total employment rises by 18,018 full-time equivalent (FTE) positions (0.06%), including 2114 jobs within the offshore wind sector. Employment growth is less than proportionate to GDP growth, reflecting the capital-intensive nature of offshore wind deployment and its supply chain. The construction sector (Fig. 5) records the largest employment gains, supported by sustained investment activity to maintain the installed capital, while modest employment growth is also observed in service sectors such as wholesale and retail trade and accommodation, driven by higher household consumption, which increases by £1.78 billion (0.14%).

At the same time, some sectors experience small contractions. Fossil fuel-based electricity generation declines as offshore wind output expands, while sectors such as public administration and health and social work record marginal competitiveness losses. These later effects reflect rising wage and price pressures in a tightening labour market, which

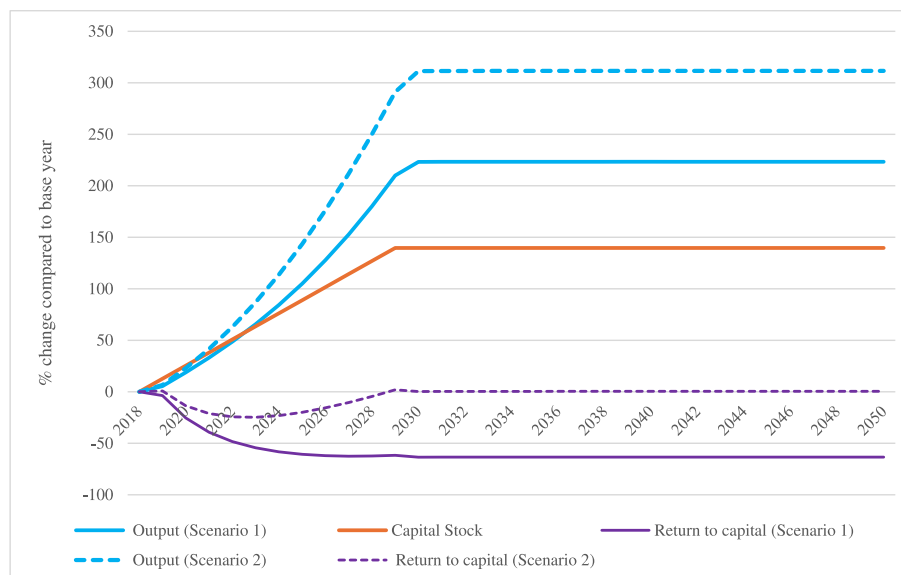


Fig. 2. Percentage change in offshore wind output, capital stock, return on capital, and output price under Scenario 1, relative to the 2018 baseline.

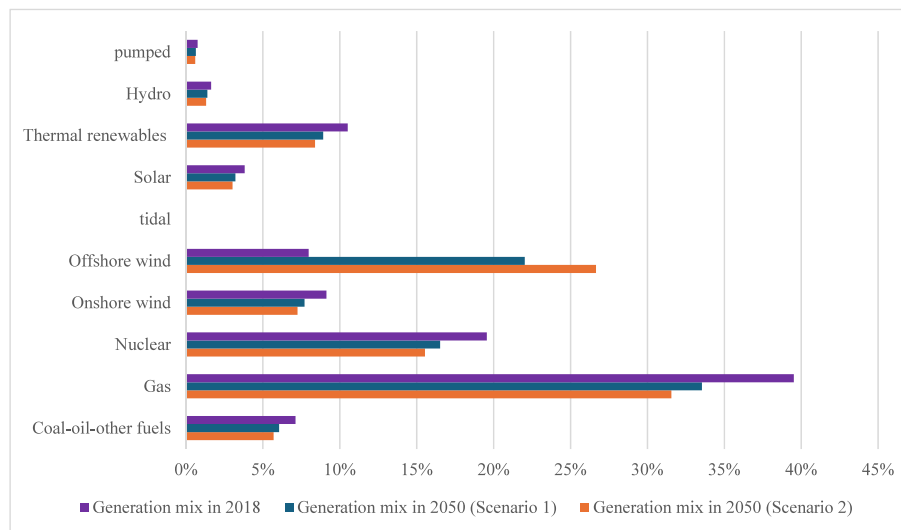


Fig. 3. Comparison of the UK electricity generation mix in 2018 and projected for 2050 under Scenario 1.

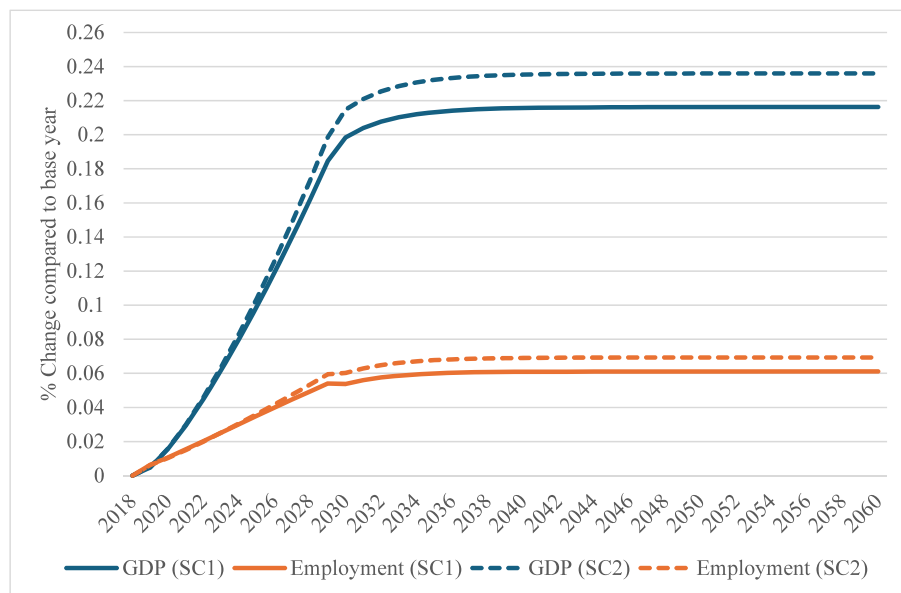


Fig. 4. GDP and employment change as a result of reaching the offshore wind target.

Table 1

Key macroeconomic impacts in the UK of reaching the UK 2030 offshore wind target.

	Scenario 1		Scenario 2	
	Absolute change	% change	Absolute change	% change
GDP (£million)	4142	0.22	4520	0.24
Employment (FTE)	18,018	0.06	20,434	0.07
Unemployment (% change)	NA	-1.43	NA	-1.62
Nominal wage - index to 1 (% change)	NA	0.17	NA	0.25
Real wage - index to 1 (% change)	NA	0.16	NA	0.18
CPI - index to 1 (% change)	NA	0.01	NA	0.06
Exports (£million)	-249.04	-0.04	-751.59	-0.13
Imports (£million)	839	0.14	1662	0.27
Real household consumption (£million)	1775	0.14	2503	0.19

increase production costs in labour-intensive activities. For instance, under Scenario 1, although electricity prices fall by 0.74%, average real wages increase by 0.16%, contributing to a modest CPI increase of 0.01%.

In summary, under current grid flexibility, offshore wind expansion delivers clear but constrained economy-wide benefits. GDP and employment increase, household consumption rises, and electricity prices decline as renewable generation replaces fossil-based supply. However, labour market tightness and limited grid flexibility restrict full utilisation of new capacity, dampening the overall macroeconomic impact. These results, therefore, represent a conservative baseline against which the potential gains from enhanced grid flexibility can be assessed in the following scenario.

4.2.2. Economy-wide impacts under an enhanced grid flexibility (scenario 2)

Enhanced grid flexibility substantially alters the economy-wide implications of meeting the UK's 2030 offshore wind target. As shown in Section 4.1, electricity sector outcomes improve significantly when the



Fig. 5. Sectoral employment impact of reaching the offshore wind 2030 target.

electricity system can more efficiently accommodate offshore wind generation. A similar pattern emerges at the macroeconomic level.

Under Scenario 2, real GDP increases by £4.52 (0.24%) billion, substantially higher than the gain observed under current grid flexibility. This stronger performance reflects more efficient utilisation of offshore wind capacity, which enhances the productivity of investment in the sector. Employment effects also intensify, with total employment increasing by 20,434 full-time equivalent (FTE) jobs (0.07%), including 3832 positions within the offshore wind sector, compared with 2114 jobs under current flexibility. The construction industry remains the largest contributor to job creation, supported by continued infrastructure deployment and capital inflows, while additional employment gains are observed across manufacturing and service sectors. Household

consumption rises by £2.50 billion (0.19%), driven by higher real wages and lower electricity prices, which together strengthen purchasing power.

Despite these gains, the macroeconomic response is less than proportionate to the improvements observed in the electricity sector. Relative to Scenario 1, real GDP increases by 9.1%, whereas offshore wind output and related electricity sector indicators improve by a considerably larger margin. This divergence reflects labour market constraints within the UK economy, which limit the extent to which sectoral productivity gains translate into broader economic expansion.

As grid flexibility improves, higher offshore wind output increases demand for both direct and indirect labour across the renewable energy supply chain. Under conditions of limited labour availability,

unemployment declines, and workers' bargaining power strengthens, exerting upward pressure on wages. In Scenario 2, real wages increase by 0.18%, compared with 0.16% under current flexibility. At the same time, while electricity prices continue to fall as grid expansion enables greater absorption of offshore wind generation, the reduction is smaller than in Scenario 1, declining by 0.52% compared with 0.74%. As a result, production and living costs rise slightly relative to Scenario 1, with the CPI increasing by 0.06%, moderating competitiveness gains for sectors not directly linked to offshore wind activity.

Overall, enhanced grid flexibility creates a more favourable macroeconomic environment, delivering higher GDP growth, stronger employment effects, and greater welfare improvements than under current flexibility. These findings underscore the strategic importance of coordinating offshore wind deployment with timely investments in grid flexibility, ensuring that electricity sector gains translate more effectively into broader economic benefits and maximising the economic dividends of the UK's clean energy transition.

4.3. Sensitivity analysis to the results

We subject the main results to three sets of sensitivity analyses: the elasticity of substitution governing the system's capacity to absorb offshore wind generation, the trajectory of offshore wind costs, and the labour-market specification.

The first sensitivity analysis varies the elasticity of substitution between flexible and inflexible generation technologies across the range 0.8 to 2.89, spanning a network more rigid than the present system (an elasticity below unity), the current calibration of 2, and the enhanced-flexibility value of 2.89 at which the expanded capacity is absorbed efficiently. Table A1 reports the outcomes. The economy-wide effects rise smoothly and monotonically with the elasticity: the GDP contribution of the offshore wind expansion increases from £2358 million at an elasticity of 0.8, through £4142 million at the current system, to £4520 million under enhanced flexibility, with employment and household consumption following the same ordered path. The absence of any discontinuity across the range indicates that the contrast between the two headline scenarios is representative of an underlying continuous relationship.

Crucially, the magnitude of the economic dividend from improving flexibility depends on the starting point. Measured from the current system, raising the elasticity to the absorption threshold of 2.89 adds some £378 million to GDP, the difference between Scenario 1 and Scenario 2. Measured instead from the more constrained network represented by an elasticity of 0.8, the same improvement adds around £2160 million, nearly six times as large. The mechanism is visible in the offshore wind output itself, which the rigid network is largely unable to absorb at an elasticity of 0.8; the expansion raises offshore wind generation by only £576 million, against £5248 million under the current system and £7321 million under enhanced flexibility. The more constrained the existing network, the higher the volume of curtailed generation that enhanced flexibility prevents, and the larger the resulting economy-wide gain.

The second sensitivity analysis addresses the trajectory of offshore wind costs. We examine a less favourable cost path in which the levelised cost of offshore wind is 10% higher than in the central case. This is implemented through assuming a smaller total-factor-productivity improvement together with the larger investment outlay required to reach the 50 GW target at the elevated cost. Table A2 reports the results under both grid-flexibility scenarios. A more costly programme commits more resources to achieving the same installed capacity. The impacts on macroeconomic indicators rise accordingly: under current flexibility the GDP contribution increases from £4142 million to £4508 million, with corresponding increases in employment and household consumption. These larger impact results reflect the higher volume of investment and activity required to deliver the target at higher cost. The key finding remains unchanged: the economic contribution of meeting the target

remains positive under a less favourable cost trajectory, and the dividend from enhanced grid flexibility is larger. The Scenario 1 to Scenario 2 GDP gain rises from £378 million in the central case to £548 million under higher costs, since the more expensive the generation, the greater the value of absorbing its output efficiently rather than curtailing it. The case for grid flexibility is therefore robust to, and indeed reinforced by, a less optimistic view of offshore wind costs.

The third sensitivity analysis concerns the labour market. As shown in Section 4.2, wage pressures offset part of the potential gains from offshore wind expansion under a constrained UK labour market, as increased labour demand in the offshore wind supply chain raises real wages and, in turn, production costs across the economy. To isolate this effect, we replace the central-case bargaining specification with a fixed real-wage closure, representing a less constrained labour market, and report the results in Table A3. The offshore wind sector outcomes are virtually identical under the two closures; offshore wind output increases by 223% under current flexibility and by 311% under enhanced flexibility in both cases, confirming that, once installed, the operation of offshore wind capacity is governed by technological parameters and the degree of grid flexibility rather than by wage-setting behaviour. The effects on the wider economy, however, differ substantially. Under the fixed real-wage closure, the GDP contribution under current flexibility rises to £7.35 billion, some 77% above the £4.14 billion recorded under endogenous wage setting, accompanied by markedly higher employment (71,199 FTE jobs, against 18,018) and, in the absence of wage-induced cost pressures, a lower cost of living, with the CPI falling by 0.13% and household consumption rising correspondingly. The dividend from enhanced flexibility also widens under the relaxed closure, to around 11% relative to its constrained counterpart, against 9% under bargained wages. Labour supply, therefore, dampens both the absolute gains from offshore wind expansion and the relative benefit of integrating it efficiently; relaxing that constraint allows the productivity gains from a flexible electricity system to pass through more fully to the wider economy.

5. Discussion

The analysis of offshore wind expansion under the UK's Clean Power 2030 target reveals a complex interaction between sector-specific dynamics and broader macroeconomic responses, underscoring the critical role of electricity system flexibility in shaping economic outcomes. Across all scenarios, the transition involves substantial structural change within the offshore wind sector, alongside measurable economy-wide effects. These findings highlight both the opportunities and the trade-offs associated with a large-scale shift towards renewable electricity.

A central result is that offshore wind deployment generates positive macroeconomic outcomes under both grid flexibility regimes, but that enhanced flexibility substantially amplifies these gains. Under current flexibility constraints, offshore wind expansion contributes to GDP and employment growth. However, declining capital returns signal increasing curtailment and underutilisation of installed capacity. This pattern is consistent with recent evidence from the UK power system, which points to rising constraint payments and network congestion in the absence of timely grid investment.

Enhanced grid flexibility fundamentally alters this outcome. By allowing offshore wind output to be absorbed more efficiently, improved system flexibility sustains capital productivity, stabilises sectoral returns, and enables greater displacement of fossil-based electricity generation. The resulting reductions in electricity prices strengthen economy-wide competitiveness and household purchasing power, leading to larger gains in GDP and employment. These results support the view that offshore wind deployment and grid investment are economic complements rather than substitutes. Policy frameworks that treat generation expansion and network development as separate or sequential challenges therefore risk underperforming in terms of both decarbonisation objectives and economic benefits.

At the same time, the results should be interpreted with some qualification and in the context of what can be achieved in an economic impact study. While enhanced flexibility delivers clear economic advantages in the model, the costs associated with achieving this flexibility, through investments in transmission and distribution networks, storage technologies, and system integration, are not modelled explicitly. As a result, the reported gains represent the benefits of flexibility net of generation costs but not net of the full system costs required to deliver flexibility in practice and should be read as an upper bound on the net economic benefit. The qualitative conclusion is unlikely to reverse since the cost of delivering flexibility would have to exceed the dividend it unlocks for the case to overturn. However, because the grid-reinforcement systems that underpin flexibility are represented in reduced form rather than explicitly, the analytical framework developed here is better suited to informing the economic case for flexibility than to prescribing the engineering means of achieving it. Quantifying net economy benefits more precisely, by incorporating the capital and operational costs of flexibility-enhancing investments, is an important direction for future research.

The second limitation concerns system resilience. Our representation of flexibility captures the improved economic capacity to absorb variable generation. What it does not incorporate is the physical resilience and adequacy of the resulting system, the maintenance of security of supply during periods of low wind, the provision of firm capacity, and the frequency and balancing services on which a high-renewables system depends. Our results should accordingly be read as conditional on adequate system reliability being maintained.

The third limitation concerns the scope of the technology assessment. The paper evaluates the economy-wide implications of a specific adopted policy, the UK government's 50 GW offshore wind target. It does not compare offshore wind against alternative low-carbon technologies such as nuclear or solar photovoltaics. Whether a different generation mix would deliver superior economy-wide outcomes is an important question that the present model and scenario specification cannot answer. The multi-sector economy-wide modelling and scenario simulation framework developed here is, however, readily transferable to other technologies, offering a route to precisely such comparative analysis in future work.

The analysis also highlights the importance of labour market conditions in mediating economy-wide benefits. Even under enhanced grid flexibility, tighter labour markets moderate GDP gains through rising real wages and higher production costs. The sensitivity analysis shows that relaxing wage pressures substantially increases employment and output effects, indicating that skills availability, workforce planning, and migration policy will play a crucial role in determining the realised economic benefits of the UK's clean energy transition. This insight is particularly salient given emerging evidence of skills bottlenecks and supply-chain constraints in offshore wind development.

From a methodological perspective, the paper contributes to the CGE literature by explicitly distinguishing between flexible and inflexible electricity generation technologies within a system-level framework. This approach provides a tractable means of representing integration constraints and flexibility investments without relying on fully detailed power-system dispatch models, making it well-suited to long-term policy analysis. This abstraction also implies limitations. The model does not, however, explicitly capture short-term balancing markets, locational constraints, project-level financing risks, or recent supply-chain cost pressures in offshore wind deployment. Relatedly, the central analysis introduces the required capital along a linear path to 2030; while the long-run outcomes reported here are anchored to the 2050 capital stock and so are robust to the deployment profile, the timing of investment shapes the transitional dynamics between now and the target year, which a fuller treatment of alternative deployment schedules would illuminate. These factors may dampen short-run investment responses and should be addressed in future work through hybrid modelling approaches or improved data integration.

Overall, the results underline that achieving offshore wind targets is not simply a matter of installed capacity, but of system readiness. Without parallel investment in grid flexibility and workforce capacity, the UK risks incurring higher system costs while foregoing a substantial share of the potential economic gains from its clean energy transition.

6. Conclusion

This paper has examined the economy-wide implications of achieving the UK's 2030 offshore wind targets, with a particular focus on the role of electricity system flexibility. Using a dynamic CGE model with a disaggregated representation of the electricity sector, the analysis finds that the expansion supports positive gains in the wider economy under current system flexibility: by 2050, GDP, employment, and household consumption all rise relative to the baseline, while electricity prices fall as offshore wind displaces higher-cost fossil generation.

Crucially, the scale of these gains depends on the extent to which the system can absorb variable renewable generation. Where grid flexibility is enhanced, higher utilisation of the same installed capacity raises the return to deployment and delivers larger gains across the board, in GDP, employment and consumption alike. That an identical capacity target yields a larger economy-wide dividend once the system can absorb the generation it produces is the central result of the analysis. The macro-economic response nonetheless remains less than proportionate to the improvement in electricity-system outcomes, because of labour supply constraints.

As reported in Section 4.3, sensitivity analysis confirms the role of the labour market. Under an alternative closure in which the real wage is fixed, the economy-wide gains roughly double, accompanied by substantially higher employment and a lower cost of living, while offshore wind output itself is unchanged; once capacity is installed, its operation is governed by grid flexibility rather than by wage-setting. The additional dividend from enhanced flexibility also widens. Labour supply, in other words, dampens both the absolute gains from offshore wind and the relative benefit of integrating it efficiently; relaxing that constraint allows the productivity gains from a flexible electricity system to pass through more fully to the wider economy.

The findings carry policy implications. Meeting offshore wind capacity targets alone is insufficient to maximise economic returns to deployment: the same installed capacity yields larger gains once the system can absorb the generation, and larger still once labour supply is eased. Coordinated investment in grid infrastructure is therefore essential, alongside measures to relax labour market and skills constraints in the offshore wind supply chain. Future research should extend this framework to incorporate supply-chain constraints and interactions with other net-zero investments. Nevertheless, the present analysis provides evidence that grid flexibility is a decisive factor in realising the economic potential of offshore wind in the UK.

CRedit authorship contribution statement

Doungahire Abdoul Karim Zanhoun: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Karen Turner:** Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Long Zhou:** Writing – review & editing, Writing – original draft, Methodology, Data curation.

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grant reference EP/W027879/1).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Karen Turner reports financial support was provided by UK Engineering and Physical Sciences Research Council. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1

Sensitivity to generation mix elasticity

	Elasticity of substitution between flexible and inflexible generation sources					
	0.8	1.5	2	2.25	2.5	2.89
Offshore wind generation (£million)	575.83	2846.35	5247.91973	6059.03	6657.52	7320.63
GDP (£million)	2358	3389	4142	4315	4421	4520
Employment (FTE)	14,385	15,751	18,018	18,889	19,586	20,434
Real household consumption (£million)	1119	1318	1775	2006	2216	2503

Table A2

Sensitivity to LCOE

	Default LCOE		10% Higher LCOE	
	Scenario1	Scenario2	Scenario1	Scenario2
Offshore wind generation (£million)	5247.92	7320.63	5603.57	8071.38
GDP (£million)	4142.32	4520.18	4508.48	5056.02
Employment (FTE)	18017.67	20434.28	19301.22	22608.55
Real household consumption (£million)	1775.18	2502.70	1892.98	2746.03

Table A3

Sensitivity to wage

	BRW		FRW	
	Scenario1	Scenario2	Scenario1	Scenario2
Offshore wind generation (£million)	5247.92	7320.63	5254.35	7324.96
GDP (£million)	4142	4520	7348.82	8147
Employment (FTE)	18,018	20,434	71198.52	80,654
Real household consumption (£million)	1775	2503	2225.96	3011

Appendix A. The mathematical presentation of the UKENVI model

Appendix A presents the mathematical structure of the UKENVI model applied in this study. The equations are organised by economic function, beginning with the determination of prices and production decisions, before turning to demand, institutional accounts, investment, dynamic adjustment and model closure. Unless an alternative closure is stated explicitly, the equations correspond to the recursive dynamic specification described in Section 3.

Prices

Equation (A.1) - (A.23) define the model's endogenous price system. They link output, composite input, electricity, capital and consumption prices to production costs and the fixed exchange rate, providing the price signals through which changes in offshore wind generation and electricity system flexibility are transmitted to the wider economy.

$$PM_{i,t} = \overline{PM}_i \quad (A.1)$$

$$PE_{i,t} = \overline{PE}_i \quad (A.2)$$

$$PQ_{i,t} = \frac{PR_{i,t} \cdot R_{i,t} + PM_{i,t} \cdot M_{i,t}}{R_{i,t} + M_{i,t}} \quad (A.3)$$

$$PIR_{j,t} = \frac{\sum_i VR_{ij,t} \cdot PR_{j,t} + \sum_i VI_{ij,t} \cdot \overline{P}_j}{\sum_i VI_{ij,t}} \quad (A.4)$$

$$PY_{j,t} \cdot a_j^Y = \left(PR_{j,t} \cdot (1 - btax_j - sub_j - dep_j) - \sum_i a_{ij}^Y \cdot PQ_{j,t} \right) \quad (A.5)$$

$$UCK_t = PK_t \cdot (r + \delta) \quad (A.6)$$

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(continued)

Prices

Equation (A.1) - (A.23) define the model's endogenous price system. They link output, composite input, electricity, capital and consumption prices to production costs and the fixed exchange rate, providing the price signals through which changes in offshore wind generation and electricity system flexibility are transmitted to the wider economy.

$$P_{C,t}^{1-\sigma^c} = \sum_j \delta_j^c \cdot PQ_{j,t}^{1-\sigma^c} \quad (A.7)$$

$$P_{G,t}^{1-\sigma^g} = \sum_j \delta_j^g \cdot PQ_{j,t}^{1-\sigma^g} \quad (A.8)$$

$$PNE_t = \frac{\sum_{zne} PQ_{zne,t} \cdot \bar{V}_{zne}}{\sum_{zne} PQ_{zne} \cdot \bar{V}_{zne}} \quad (A.9)$$

$$PE_t = \frac{\sum_{ze} PQ_{ze,t} \cdot \bar{V}_{ze}}{\sum_{ze} PQ_{ze} \cdot \bar{V}_{ze}} \quad (A.10)$$

$$PNELE_t = \frac{\sum_{znele} PQ_{znele,t} \cdot \bar{V}_{znele}}{\sum_{znele} PQ_{znele} \cdot \bar{V}_{znele}} \quad (A.11)$$

$$PELE_t = \frac{\sum_{zele} PQ_{zele,t} \cdot \bar{V}_{zele}}{\sum_{zele} PQ_{zele} \cdot \bar{V}_{zele}} \quad (A.12)$$

$$POG_t = \frac{\sum_{zno} PQ_{zno,t} \cdot \bar{V}_{zno}}{\sum_{zno} PQ_{zno} \cdot \bar{V}_{zno}} \quad (A.13)$$

$$PGN_t = \frac{\sum_{zg} PQ_{zg,t} \cdot \bar{V}_{zg}}{\sum_{zg} PQ_{zg} \cdot \bar{V}_{zg}} \quad (A.14)$$

$$PIN_t = \frac{\sum_{zin} PQ_{zin,t} \cdot \bar{V}_{zin}}{\sum_{zin} PQ_{zin} \cdot \bar{V}_{zin}} \quad (A.15)$$

$$PNIN_t = \frac{\sum_{znin} PQ_{znin,t} \cdot \bar{V}_{znin}}{\sum_{znin} PQ_{znin} \cdot \bar{V}_{znin}} \quad (A.16)$$

$$PWN_t = \frac{\sum_{zwn} PQ_{zwn,t} \cdot \bar{V}_{zwn}}{\sum_{zwn} PQ_{zwn} \cdot \bar{V}_{zwn}} \quad (A.17)$$

$$PLC_t = \frac{\sum_{zlc} PQ_{zlc,t} \cdot \bar{V}_{zlc}}{\sum_{zlc} PQ_{zlc} \cdot \bar{V}_{zlc}} \quad (A.18)$$

$$w_t^b = \frac{w_t}{(1 + \tau_t)} \quad (A.19)$$

$$\ln\left(\frac{w_t^b}{cpl_t}\right) = b - 0.068 \ln(u_t) + 0.4 \ln\left(\frac{w_{t-1}^b}{cpl_{t-1}}\right) \quad (A.20)$$

$$rk_{j,t} = PY_{j,t} \cdot \delta_j^k \cdot A^{Y_{\phi_j}} \cdot \left(\frac{Y_{j,t}}{K_{j,t}}\right)^{1-\phi_j} \quad (A.21)$$

$$pk_t = \frac{\sum_j PQ_{j,t} \cdot \sum_i KM_{ij}}{\sum_i \sum_j KM_{ij}} \quad (A.22)$$

$$\dot{\lambda}_{i,t} = \lambda_{i,t}(r_t + \delta) - R_{i,t}^k \quad (A.23)$$

Production technology

Equation (A.24) - (A.50) describe cost-minimising production through the nested constant elasticity of substitution (CES) structure. Within the electricity block, this structure distinguishes generation technologies and governs substitution between flexible and non-flexible sources in supplying the electricity distribution network.

$$X_{i,t} = A_i^X \cdot \left[\delta_i^V \cdot Y_{i,t}^{\rho_i^X} + (1 - \delta_i^V) \cdot V_{i,t}^{\rho_i^X} \right]^{\frac{1}{\rho_i^X}} \quad (A.24)$$

$$Y_{j,t} = \left(A^{X\rho_j^X} \cdot \delta_j^Y \cdot \frac{PQ_{j,t}}{PY_{j,t}} \right)^{\frac{1}{1-\rho_j^X}} \cdot X_{j,t} \quad (A.25)$$

$$V_{j,t} = \left(A^{X\rho_j^X} (1 - \delta_j^V) \cdot \frac{PQ_{j,t}}{Pv_{j,t}} \right)^{\frac{1}{1-\rho_j^X}} \cdot X_{j,t} \quad (A.26)$$

$$V_{j,t} = A^V \cdot \left[\delta_i^V \cdot E_{i,t}^{\rho_i^V} + (1 - \delta_i^V) \cdot NE_{i,t}^{\rho_i^V} \right]^{\frac{1}{\rho_i^V}} \quad (A.27)$$

$$\frac{E_{j,t}}{NE_{j,t}} = \left[\left(\frac{\delta_j^V}{1 - \delta_j^V} \right) \cdot \left(\frac{PNE_t}{PE_t} \right) \right]^{\frac{1}{1-\rho_j^V}} \quad (A.28)$$

$$E_{j,t} = A^E \cdot \left[\delta_i^E \cdot ELE_{i,t}^{\rho_i^E} + (1 - \delta_i^E) \cdot NELE_{i,t}^{\rho_i^E} \right]^{\frac{1}{\rho_i^E}} \quad (A.29)$$

$$\frac{ELE_{j,t}}{NELE_{j,t}} = \left[\left(\frac{\delta_j^E}{1 - \delta_j^E} \right) \cdot \left(\frac{PNELE_t}{PELE_t} \right) \right]^{\frac{1}{1-\rho_j^E}} \quad (A.30)$$

$$NELE_{s,t} = A_s^N \cdot \left[\delta_s^N \cdot COAL_{s,t}^{\rho_s^N} + (1 - \delta_s^N) \cdot OG_{s,t}^{\rho_s^N} \right]^{\frac{1}{\rho_s^N}} \quad (A.31)$$

$$\frac{COAL_{s,t}}{OG_{s,t}} = \left[\left(\frac{\delta_s^N}{1 - \delta_s^N} \right) \cdot \left(\frac{POG_t}{PQ_{coal,t}} \right) \right]^{\frac{1}{1-\rho_s^N}} \quad (A.32)$$

$$OG_{s,t} = A_s^G \cdot \left[\delta_s^G \cdot OIL_{s,t}^{\rho_s^G} + (1 - \delta_s^G) \cdot GAS_{s,t}^{\rho_s^G} \right]^{\frac{1}{\rho_s^G}} \quad (A.33)$$

$$\frac{OIL_{j,t}}{GAS_{j,t}} = \left[\left(\frac{\delta_s^G}{1 - \delta_s^G} \right) \cdot \left(\frac{PGAS_t}{PQ_{oil,t}} \right) \right]^{\frac{1}{1-\rho_s^G}} \quad (A.34)$$

$$ELE_{elec,j,t} = A^{TR} \cdot \left[\delta^{TR} \cdot GN_t^{\rho^{TR}} + (1 - \delta^{TR}) \cdot TR_t^{\rho^{TR}} \right]^{\frac{1}{\rho^{TR}}} \quad (A.35)$$

$$\frac{GN_t}{TR_t} = \left[\left(\frac{\delta^{TR}}{1 - \delta^{TR}} \right) \cdot \left(\frac{PQ_{ele,t}}{PGN_t} \right) \right]^{\frac{1}{1-\rho^{TR}}} \quad (A.36)$$

$$GN_t = A^I \cdot \left[\delta^I \cdot IN_t^{\rho^I} + (1 - \delta^I) \cdot NIN_t^{\rho^I} \right]^{\frac{1}{\rho^I}} \quad (A.37)$$

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Prices

Equation (A.1) - (A.23) define the model's endogenous price system. They link output, composite input, electricity, capital and consumption prices to production costs and the fixed exchange rate, providing the price signals through which changes in offshore wind generation and electricity system flexibility are transmitted to the wider economy.

$$\frac{IN_t}{NIN_t} = \left[\left(\frac{\delta^I}{(1-\delta^I)} \right) \cdot \left(\frac{PNIN_t}{PIN_t} \right) \right]^{\frac{1}{1-\rho^I}} \quad (A.38)$$

$$IN_t = A^{IT} \cdot \left[\delta^{IT} \cdot MR_t^{IT} + (1-\delta^{IT}) \cdot WN_t^{IT} \right]^{\frac{1}{\rho^{IT}}} \quad (A.39)$$

$$\frac{MR_t}{WN_t} = \left[\left(\frac{\delta_s^{IT}}{(1-\delta^{IT})} \right) \cdot \left(\frac{PWN_t}{PQ_{mar,t}} \right) \right]^{\frac{1}{1-\rho^{IT}}} \quad (A.40)$$

$$WN_t = A^{WN} \cdot \left[\delta^{WN} \cdot WNS_t^{oWN} + (1-\delta^{WN}) \cdot WNO_t^{oWN} \right]^{\frac{1}{\rho^{WN}}} \quad (A.41)$$

$$\frac{WNS_t}{WNO_t} = \left[\left(\frac{\delta^{WN}}{(1-\delta^{WN})} \right) \cdot \left(\frac{PQ_{wmo,t}}{PQ_{wms,t}} \right) \right]^{\frac{1}{1-\rho^{WN}}} \quad (A.42)$$

$$NIN_t = A^C \cdot \left[\delta^C \cdot HC_t^C + (1-\delta^C) \cdot LC_t^C \right]^{\frac{1}{\rho^C}} \quad (A.43)$$

$$\frac{HC_t}{LC_t} = \left[\left(\frac{\delta^C}{(1-\delta^C)} \right) \cdot \left(\frac{PLC_t}{PQ_{gcoal,t}} \right) \right]^{\frac{1}{1-\rho^C}} \quad (A.44)$$

$$LC_{zlc\<i,t} = \left(A_{zlc}^{lc} \cdot \delta_{zlc}^{lc} \cdot \frac{PLC_t}{PQ_{zlc,t}} \right)^{\frac{1}{1-\rho_{zlc}^{lc}}} \cdot LC_t \quad (A.45)$$

$$VV_{z\<i,j,t} = \left(A^{z\rho_j^j} (1-\delta_j^{EN}) \cdot \frac{PNE_t}{PQ_{z,t}} \right)^{\frac{1}{1-\rho_j^j}} \cdot NE_{j,t} \quad (A.46)$$

$$VV_{zn,j,t} = \begin{cases} COAL_{j,t} & \text{for } zn = coal \\ GAS_{j,t} & \text{for } zn = gas \\ OIL_{j,t} & \text{for } zn = oil \end{cases} \quad (A.47)$$

$$VV_{ze,ele,t} = \begin{cases} LC_{zlc\<ze,t} & \text{for } zg = gnlrf, gnuc, ggaz, gbio, ghyd \\ WNO_t & \text{for } ze = wno \\ WNS_t & \text{for } ze = wns \\ MR_t & \text{for } ze = mar \\ TR_t & \text{for } ze = ele \end{cases} \quad (A.48)$$

$$Y_{i,t} = A^Y \cdot \left[\delta_i^{K^Y} \cdot K_{i,t}^{Y^Y} + \delta_i^{L^Y} \cdot L_{i,t}^{Y^Y} \right]^{\frac{1}{\rho_i^Y}} \quad (A.49)$$

$$L_{j,t} = \left(A^{Y\rho_j^Y} \cdot \delta_j^{L^Y} \cdot \frac{PY_{j,t}}{w_t} \right)^{\frac{1}{1-\rho_j^Y}} \cdot Y_{j,t} \quad (A.50)$$

Trade

Equation (A.51) - (A.55) specify trade with the rest of the world under the small open economy assumption. Domestic and imported commodities are treated as imperfect substitutes through the Armington structure, while export demand responds to domestic prices relative to fixed external prices.

$$VV_{ij,t} = \gamma_{ij}^{vv} \cdot \left[\delta_{ij}^{vm} VM_{i,t}^{vA} + \delta_{ij}^{vr} VIR_{i,t}^{vA} \right]^{\frac{1}{\rho_i^A}} \quad (A.51)$$

$$\frac{VM_{i,t}}{VIR_{i,t}} = \left[\left(\frac{\delta_{ij}^{vm}}{\delta_{ij}^{vr}} \right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}} \right) \right]^{\frac{1}{1-\rho_i^A}} \quad (A.52)$$

$$VIR_{i,t} = \gamma_{ij}^{vr} \cdot \left[\delta_{ij}^{vi} VI_{i,t}^{vA} + \delta_{ij}^{vr} VR_{i,t}^{vA} \right]^{\frac{1}{\rho_i^A}} \quad (A.53)$$

$$\frac{VR_{i,t}}{VI_{i,t}} = \left[\left(\frac{\delta_{ij}^{vr}}{\delta_{ij}^{vi}} \right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}} \right) \right]^{\frac{1}{1-\rho_i^A}} \quad (A.54)$$

$$Exp_{i,t} = \overline{Exp}_i \cdot \left(\frac{PE_{i,t}}{PQ_{i,t}} \right)^{\sigma_i^e} \quad (A.55)$$

$$\text{Regional Demand} \quad (A.56)$$

Equation (A.56) maps demand for each commodity into demand for domestically supplied output, consistently with the domestic and imported composition of commodity use specified in the trade block.

$$R_{i,t} = \sum_j VR_{ij,t} + \sum_h QHR_{i,h,t} + QVR_{i,t} + QGR_{i,t} \quad (A.57)$$

Total absorption equation

Equation (A.57) imposes the commodity-market accounting condition, requiring total absorption to be consistent with intermediate, household, government and investment demand.

$$X_{i,t} + M_{i,t} = \sum_j VV_{ij,t} + \sum_h QH_{i,h,t} + QV_{i,t} + QG_{i,t} + E_{i,t}$$

Households and other Domestic Institutions

Equation (A.58) - (A.82) determine institutional income allocation, transfers, saving and household consumption demand. The nested household consumption structure allows expenditure to respond to relative price changes, including changes in electricity prices arising from the offshore wind scenarios.

$$\sum_{t=0}^{\infty} (1+\rho)^{-t} \frac{C_t^{1-\sigma} - 1}{1-\sigma} \quad (A.58)$$

$$\frac{C_t}{C_{t+1}} = \left[\frac{P_{C,t} \cdot (1+\rho)}{P_{C,t+1} \cdot (1+r)} \right]^{-\left(\frac{1}{\sigma}\right)} \quad (A.59)$$

$$W_t = NFW_t + FW_t \quad (A.60)$$

$$NFW_t(1+r_t) = NFW_{t+1} + (1-\tau_t)L_t^s(1-u_t)w_t + Trf_t \quad (A.61)$$

$$FW_t(1+r_t) = FW_{t+1} + \Pi_t - S_t \quad (A.62)$$

$$Trf_t = P_{C,t} \cdot Trf \quad (A.63)$$

$$S_t = mps \cdot [(1-\tau_t)L_t^s(1-u_t)w_t + \Pi_t + Trf_t] \quad (A.64)$$

$$\Pi_t = d^h \cdot \sum_i r_{k,i,t} K_{i,t} \quad (A.65)$$

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Prices

Equation (A.1) - (A.23) define the model's endogenous price system. They link output, composite input, electricity, capital and consumption prices to production costs and the fixed exchange rate, providing the price signals through which changes in offshore wind generation and electricity system flexibility are transmitted to the wider economy.

$$C_t = [\delta^E (\gamma E C_t)^{\rho^E} - (1 - \delta^E) N E C_t^{\rho^E}]^{\frac{1}{\rho^E}} \quad (A.66)$$

$$E C_t = \left[\gamma^{\rho^E} \delta^E \cdot \left(\frac{P C_t}{P E_t} \right) \right]^{\frac{1}{1-\rho^E}} C_t \quad (A.67)$$

$$E C_t = [\delta^{CO} C O C_t^{\rho_s} + (1 - \delta^{CO}) E G C_t^{\rho_s}]^{\frac{1}{\rho_s}} \quad (A.68)$$

$$\frac{C O C_t}{E G C_t} = \left[\left(\frac{\delta^{CO}}{1 - \delta^{CO}} \right) \cdot \left(\frac{P E G_t}{P C O_t} \right) \right]^{\frac{1}{1-\rho_s}} \quad (A.69)$$

$$C O C_t = [\delta^{CL} C L C_t^{\rho_o} - (1 - \delta^{CO}) O I L C_t^{\rho_o}]^{\frac{1}{\rho_o}} \quad (A.70)$$

$$\frac{C L C_t}{O I L C_t} = \left[\left(\frac{\delta^{CL}}{1 - \delta^{CL}} \right) \cdot \left(\frac{P Q_{oil,t}}{P Q_{coal,t}} \right) \right]^{\frac{1}{1-\rho_o}} \quad (A.71)$$

$$Q H_{z,t} = \delta_z^{\rho_z} \cdot \left(\frac{P C_t}{P Q_{z,t}} \right)^{\rho_z} \cdot N E C_t \quad (A.72)$$

$$E G_t = [\delta^{Ele} E l e C_t^{\rho_{el}} - (1 - \delta^{el}) G A S C_t^{\rho_{el}}]^{\frac{1}{\rho_{el}}} \quad (A.73)$$

$$\frac{E l e C_t}{G A S C_t} = \left[\left(\frac{\delta^{GAS}}{1 - \delta^{GAS}} \right) \cdot \left(\frac{P Q_{GAS,t}}{P Q_{Ele,t}} \right) \right]^{\frac{1}{1-\rho_{el}}} \quad (A.74)$$

$$Q H_{ele,t} = E C_t \quad (A.75)$$

$$Q H_{GAS,t} = G A S C_t \quad (A.76)$$

$$Q H_{coal,t} = C L C_t \quad (A.77)$$

$$Q H_{oil,t} = O I L C_t \quad (A.78)$$

$$Q H_{i,t} = \gamma_i^f \cdot \left[\delta_i^{hir} \cdot Q H I R_{i,t}^{\rho_i^A} + \delta_i^{hm} \cdot Q H M_{i,t}^{\rho_i^A} \right]^{\frac{1}{\rho_i^A}} \quad (A.79)$$

$$\frac{Q H I R_{i,t}}{Q H M_{i,t}} = \left[\left(\frac{\delta_i^{hir}}{\delta_i^{hm}} \right) \cdot \left(\frac{P M_{i,t}}{P I R_{i,t}} \right) \right]^{\frac{1}{1-\rho_i^A}} \quad (A.80)$$

$$Q H I R_{i,t} = \gamma_i^{fir} \cdot \left[\delta_i^{fir} \cdot Q H R_{i,t}^{\rho_i^A} + \delta_i^{hi} \cdot Q H I_{i,t}^{\rho_i^A} \right]^{\frac{1}{\rho_i^A}} \quad (A.81)$$

$$\frac{Q H R_{i,t}}{Q H I_{i,t}} = \left[\left(\frac{\delta_i^{fir}}{\delta_i^{hi}} \right) \cdot \left(\frac{P I_{i,t}}{P R_{i,t}} \right) \right]^{\frac{1}{1-\rho_i^A}} \quad (A.82)$$

Government

Equation (A.83) - (A.85) define government revenue, expenditure and the government balance. Government income is determined from the relevant tax and income-flow components described in Section 3.2.4, with the principal fiscal parameters held fixed in the simulations.

$$F D_t = G_t P g_t + \sum_{dngins} T R G_{dngins,t} \cdot P C_t - \left(d^8 \cdot \sum_i r k_{i,t} \cdot K_{i,t} + \sum_i I B T_{i,t} + \tau_t \cdot \sum_j L_{j,t} \cdot w_t + \overline{F E} \cdot e_t \right) \quad (A.83)$$

$$Q G_{i,t} = \delta_i^g \cdot G_t \quad (A.84)$$

$$Q G R_{i,t} = Q G_{i,t}; \quad Q G M_{i,t} = 0 \quad (A.85)$$

Investment Demand

Equation (A.86) - (A.90) determine demand for investment goods and their allocation across domestic and imported supply. For sectors other than offshore wind, investment responds endogenously to the desired capital stock, while the offshore wind capital expansion is imposed through the scenario path described in Section 3.3.

$$Q V_{i,t} = \sum_j K M_{i,j} \cdot J_{j,t} \quad (A.86)$$

$$Q V_{i,t} = \gamma_i^v \cdot \left[\delta_i^{qvm} \cdot Q V M_{i,t}^{\rho_i^A} + \delta_i^{qvtr} \cdot Q V I R_{i,t}^{\rho_i^A} \right]^{\frac{1}{\rho_i^A}} \quad (A.87)$$

$$\frac{Q V M_{i,t}}{Q V I R_{i,t}} = \left[\left(\frac{\delta_i^{qvm}}{\delta_i^{qvtr}} \right) \cdot \left(\frac{P I R_{i,t}}{P M_{i,t}} \right) \right]^{\frac{1}{1-\rho_i^A}} \quad (A.88)$$

$$Q V I R_{i,t} = \gamma_i^{vir} \cdot \left[\delta_i^{qvi} \cdot Q V I_{i,t}^{\rho_i^A} + \delta_i^{qvr} \cdot Q V R_{i,t}^{\rho_i^A} \right]^{\frac{1}{\rho_i^A}} \quad (A.89)$$

$$\frac{Q V R_{i,t}}{Q V I_{i,t}} = \left[\left(\frac{\delta_i^{qvr}}{\delta_i^{qvi}} \right) \cdot \left(\frac{P I_{i,t}}{P R_{i,t}} \right) \right]^{\frac{1}{1-\rho_i^A}} \quad (A.90)$$

Time path of investment

Equation (A.91) - (A.94) govern the dynamic adjustment of investment over time, including the costs associated with changes in capital stocks. This recursive dynamic specification captures gradual sectoral adjustment based on current economic conditions rather than perfect foresight.

$$J_{i,t} = I_{i,t} \left(1 - b b - t k + \frac{\beta}{2} \frac{\left(\frac{I_{i,t}}{K_{i,t}} - \alpha \right)^2}{\frac{I_{i,t}}{K_{i,t}}} \right) \quad (A.91)$$

$$\frac{I_t}{K_t} = \alpha + \frac{1}{\beta} \left[\frac{\lambda_{i,t}}{P k_t} - (1 - b b - t k) \right] \quad (A.92)$$

$$\theta(x_t) = \frac{\beta}{2} \frac{(x_t - \alpha)^2}{x_t}; \text{ and } x_t = \frac{I_t}{K_t} \quad (A.93)$$

$$R_{i,t}^k = r k_t - P k_t \left[\frac{I_{i,t}}{K_{i,t}} \right]^2 \theta'_t(I/K) \quad (A.94)$$

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Prices	
Equation (A.1) - (A.23) define the model's endogenous price system. They link output, composite input, electricity, capital and consumption prices to production costs and the fixed exchange rate, providing the price signals through which changes in offshore wind generation and electricity system flexibility are transmitted to the wider economy.	
Factors accumulation	
Equation (A.95) - (A.97) update factor stocks between periods. In particular, capital stocks evolve through new investment net of depreciation, linking current investment decisions to productive capacity in subsequent periods.	
$KS_{i,t+1} = (1 - \delta) \cdot KS_{i,t} + I_{i,t}$	(A.95)
$K_{i,t} = KS_{i,t}$	(A.96) A
$LS_t \cdot (1 - u_t) = \sum_j L_{j,t}$	(A.97) A
Indirect taxes and subsidies	
Equation (A.98) records indirect taxes and subsidies on production and commodities, ensuring that the relevant fiscal wedges are reflected consistently in producer and purchaser prices.	
$IBT_{i,t} = btax_i \cdot X_{i,t} \cdot PQ_{i,t}$	(A.98) A
Total demand for import and current account	
Equation (A.99) - (A.100) aggregate import demand and specify the current-account balance with the rest of the world. These equations close the external account consistently with the model's small open economy treatment.	
$M_{i,t} = \sum_j VI_{j,t} + \sum_j VM_{i,j,t} + \sum_h QHM_{i,h,t} + QGM_{i,t} + QVI_{i,t} + QVM_{i,t}$	(A.99) A
$TB_t = \sum_i M_{i,t} \cdot PM_{i,t} - \sum_i E_{i,t} \cdot PE_{i,t} + \varepsilon \cdot \left(\sum_{dngins} REM_{dngins} + FE \right)$	(A.100) A
Assets	
Equation (A.101) - (A.103) describe the accumulation of institutional assets and liabilities associated with saving decisions and sectoral balance positions over time.	
$VF_{i,t} = \lambda_{i,t} \cdot K_{i,t}$	(A.101) A
$D_{t+1} = (1 + r) \cdot D_t + TB_t$	(A.102) A
$Pg_{t+1} \cdot GD_{t+1} = \left[1 + r + \left(\frac{Pc_{t+1}}{Pc_t} - 1 \right) \right] \cdot GD_t \cdot Pg_t + FD_t$	(A.103) A
Steady State conditions	
Equation (A.104) - (A.109) impose the conditions required for long-run equilibrium once dynamic adjustment is complete. They ensure consistency between capital stocks, investment and the associated income and balance-sheet positions in the terminal solution.	
$\delta \cdot KS_{i,T} = I_{i,T}$	(A.104) A
$R_{i,T}^k = \lambda_{i,T} (r + \delta)$	(A.105) A
$FD_T = - \left[r + \left(\frac{Pc_{T+1}}{Pc_T} - 1 \right) \right] \cdot Pg_T \cdot GD_T$	(A.106) A
$TB_T = - r \cdot D_T$	(A.107) A
$NFW_T r = (1 - \tau_t) L_t^s (1 - u_t) w_t + Trf_t$	(A.108) A
$FW_t \cdot r_T = \Pi_t - S_t$	(A.109) A

To produce short-run results, the model applies a closure in which productive capacity is constrained by the inherited capital stock and the economy has not yet completed its longer-run investment adjustment. The corresponding short-run conditions are given by equation (A.110) - (A.113).

$$KS_{i,t=1} = KS_{i,t=0} \quad (A.110)A$$

$$LS_{=1} = LS_{t=0} \quad (A.111)A$$

$$GD_{t=1} = GD_{t=0} \quad (A.112)A$$

$$D_{t=1} = D_{t=0} \quad (A.113)A$$

To run the myopic model from the consumption side, household behaviour is represented on the basis of current-period income and prices rather than forward-looking optimisation. Equation (A.58) and (A.59) are therefore replaced by equation (A.114).

$$C_t = (1 - \tau_t) L_t^s (1 - u_t) w_t + \Pi_t + Trf_t - S_t \quad (A.114)$$

To obtain the simulated path of investment, equation (A.46)–(A.49) are replaced by equation (A.115)–(A.116), which specify gradual adjustment towards the desired capital stock.

$$I_{i,t} = v \cdot \left[KS_{i,t}^* - KS_{i,t} \right] + \delta \cdot KS_{i,t} \quad (A.115)$$

$$KS_{j,t}^* = \left(A^{y_{\theta j}} \cdot \delta_j^k \cdot \frac{PY_{j,t}}{uck_t} \right)^{\frac{1}{1-\theta_j}} \cdot Y_{j,t} \quad (A.116)$$

In equation (A.115), v is the capital stock adjustment speed, set to 0.5 following prior UKENVI application (Lecca et al., 2017b) and $KS_{j,t}^*$ is the desired level of capital stock.

<i>Prices</i>	
$PY_{i,t}$	Value added price
$PR_{i,t}$	Domestic output price
$PQ_{i,t}$	Output price
$PIR_{i,t}$	EU commodity price (domestic + RUK)
$PI_{i,t}$	Price of RUK commodities
$rk_{i,t}$	Rate of return to capital
w_t	Unified nominal wage
w_t^h	Wage after tax
PK_t	Price of capital goods (composite)
$PE_{j,t}$	Price of Energy composite
$PNE_{j,t}$	Price of Non-Energy composite
$PELE_{j,t}$	Price of Electricity
$PNELE_{j,t}$	Price of Non-Electricity
$POG_{j,t}$	Price of Oil and Gas composite
PGN_t	Price of Electricity Generation
PTR_t	Price of Electricity Transmission
PIN_t	Price of Electricity generation Intermittent
PNI_t	Price of Electricity generation Non-intermittent
PMR_t	Price of electricity generation marine
PWN_t	Price of Electricity generation wind composite
PLC_t	Price of Electricity generation low carbon composite
$\lambda_{i,t}$	shadow price of capital
Pc_t	aggregate consumption price
Pg_t	aggregate price of Government consumption goods
ε	exchange rate [fixed]
<i>Endogenous variables</i>	
$X_{i,t}$	total output
$R_{i,t}$	regional supply
$M_{i,t}$	total import
$Exp_{i,t}$	total export (interregional + international)
$Y_{i,t}$	value added
$L_{i,t}$	labour demand
$K_{i,t}$	physical capital demand
$KS_{i,t}$	capital stock
$LS_{i,t}$	labour supply
$VV_{i,j,t}$	total intermediate inputs in i and j
$V_{i,t}$	Total intermediate inputs in i
$VR_{i,j,t}$	regional intermediate inputs
$VM_{i,j,t}$	ROW intermediate inputs
$VR_{i,j,t}$	RUK + domestic intermediate inputs
$VI_{i,j,t}$	RUK intermediate inputs
$E_{j,t}$	Energy
$NE_{j,t}$	Non-Energy
$ELE_{j,t}$	Electricity
$NELE_{j,t}$	Non-Electricity
$COAL_{j,t}$	Coal
$OG_{j,t}$	Oil and Gas composite
GN_t	Electricity Generation
TR_t	Electricity Transmission
IN_t	Electricity generation Intermittent
NI_t	Electricity generation Non-intermittent
MR_t	Electricity generation marine
WN_t	Electricity generation wind composite
ONS_t	Electricity generation onshore wind composite
OFS_t	Electricity generation offshore wind composite
HC_t	Electricity generation high carbon - coal
LC_t	Electricity generation low carbon composite
$G_{i,t}$	aggregate government expenditure
$QG_{i,t}$	total government expenditure by sector i
$QGR_{i,t}$	regional government expenditure
$QGM_{i,t}$	government expenditure(REU + ROW)
C_t	aggregated household consumption
Ec_t	household consumption of energy
NEC_t	household consumption of non-energy goods and services
COc_t	household consumption of Coal and and Oil
EGc_t	household consumption of Electricity and Gas
$Elec_t$	household consumption of Electricity
$GASC_t$	household consumption of Gas
CLc_t	household consumption of Coal
$Oilc_t$	household consumption of Oil
$QH_{i,t}$	total households consumption in sector i
$QHR_{i,t}$	regional consumption in sector i
$QHRI_{i,t}$	regional + UK consumption in sector i
$QHM_{i,t}$	import consumption in sector i
$QV_{i,t}$	total investment by sector of origin i

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Prices	
$QVR_{i,t}$	regional investment by sector of origin i
$QVM_{i,t}$	ROW investment demand
$QVIR_{i,t}$	National + RUK investment (Regional + RUK)
$QVI_{i,t}$	RUK investment demand
$I_{j,t}$	investment by sector of destination j
$J_{j,t}$	investment by destination j with adjustment cost
u_t	regional unemployment rate
$R_{i,t}^k$	marginal net revenue of capital
S_t	domestic non-government saving
Trf_t	households net transfer
$TRSF_{dngins, dnginsp,t}$	transfer among $dngins$
$IBT_{i,t}$	Indirect tax on production
TB_t	current account balance
FD_t	Government deficit
D_t	Foreign debt
GD_t	Government debt
W_t	Total Households wealth
FW_t	Household financial wealth
NFW_t	Household non-financial wealth
Exogenous variables	
$\overline{REM}_t$	Remittance for $dngins$
$\overline{FE}_t$	Remittance for the Government
$GSAV_t$	Government saving
$\overline{Exp}_{i,t}$	Base year export
r	Interest rate
$\overline{PM}_{i,t}$	Base year import price
$\overline{PE}_{i,t}$	Base year export price
Elasticities	
σ	constant elasticity of marginal utility
ρ	constant rate of time preference
ρ_i^x	elasticity parameter between intermediate inputs and value added
ρ_i^y	elasticity parameter between capital and labour
ρ_i^A	in Armington function
σ_i^x	of export with respect to term of trade
σ_i^e	Substitution between energy and non-energy in Household consumption
σ_i^g	Substitution elasticity between CO and EG in Household consumption
σ_i^o	Substitution elasticity between Coal and Oil in Household consumption
$\rho_i^{E,N,G,TR,I,IT,WN,C,lc}$	Elasticity parameters in energy nest CES function
Parameters	
α_{ij}^V	Input-output coefficients for i used in j
α_i^y	share of value added on production
$\delta_j^{Y,V}$	shares in CES output function in sector j
$\delta_j^{k,l}$	shares in value added function in sector j
$\delta_{ij}^{vir,vm,vr,vi}$	shares parameters in CES function for intermediate goods
$\delta_{ij}^{qvir,qvm,qvr,qvi}$	shares parameters in CES function for investment goods
$\delta_{i,h}^{E,co,cl}$	shares parameters in CES function for households consumption
$\delta_{i,h}^{hr,hm}$	shares parameters in CES function for households consumption
$\delta_i^{gr,gm}$	shares parameters in CES function for government consumption
$\delta_i^{E,N,G,TR,I,IT,WN,C,lc}$	shares parameters in energy nest CES function
$A_i^{E,N,G,TR,I,IT,WN,C,lc}$	shift parameters in energy nest CES function
$\gamma_{ij}^{vv,vir}$	shift parameter in CES functions for intermediate goods
γ_i^f	shift parameter in CES function for households consumption goods
γ_i^g	shift parameter in CES function for government consumption
$btax_i$	rate of business tax
KM_{ij}	physical capital matrix
mps	rate of saving in institutions $dngins$
τ	rate of income tax
ρ	pure rate of consumer time preference
bb	rate of distortion or incentive to investment
β	the adjustment-cost parameter
δ	rate of depreciation
γ	efficiency shock in household consumption
d^h	the household share of capital revenue

Set/sector correspondence

description	set i,j	sub sets			
Coal Mining and quarrying	coal	ze	znele		
Gas Mining and quarrying	gas			zog	
Coke ovens, refined petroleum and nuclear fuel	oil				
Electricity distribution and supply	ele		zele	ele	
Generation - Coal	gcoal			zg	znin
Generation -Gas + Oil	ggas				zlc
Generation - Nuclear	gnuc				
Generation - Hydro	ghyd				
Generation - Biomass	gbio				
Generation - Landfill gas and Other	glnf				
Generation - Onshore Wind	wno				zin
Generation - Offshore Wind	wns				zwn
Generation - Marine/solar	mar				
Agriculture; Forestry and fishing	pry	zne			
Water	wat				
Construction	con				
Other Manufacturing and wholesale retail trade	oth				
Air Transport	air				
Other Transport	tra				
Services	ser				
Other traded e.g. Food and drink	otf				
Pulp and Paper	ppt				
Glass and Ceramics	gec				
Clay, cement, lime and plaster	ccl				
Iron and Steel; non-ferrous metals	ies				

Data availability

Data will be made available on request.

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Glossary The glossary below defines the sets, endogenous and exogenous variables, elasticities and parameters used in **Appendix A**. The subsequent sector correspondence table identifies how the disaggregated electricity generation activities and other economic sectors are represented within the model

i, j ($i = j$): the set of goods or industries
 ins : the set of institutions
 $dins$ ($\subset ins$): the set of domestic institutions
 $dngins$ ($\subset dins$) the set of non-government institutions
 E ($\subset i$): the set of energy sectors {Coal, Ele, Gas and Oil}
 $z ne$ ($\subset i$): the set of non-energy sectors
 $z e$ ($\subset i$): the set of energy sectors
 $z nele$ ($\subset ze$): the set of non-electricity sectors
 $z ele$ ($\subset ze$): the set of electricity sectors
 $z og$ ($\subset znele$): the set of non-coal sectors (oil and Gas)
 $z g$ ($\subset zele$): the set of electricity generation sectors
 $z in$ ($\subset zg$): the set of intermittent electricity generation sectors
 $z nin$ ($\subset zg$): the set of non-intermittent electricity generation sectors
 $z wn$ ($\subset zg$): the set of wind electricity generation sectors (offshore and onshore wind)