Article Title:

Modelling the long-term financial benefits of UK investment in wind energy generation

Author(s):

Colm O'Shea[1], Piers Horne[2], Mark Maslin[3]

Affiliations:

Department of Geography, University College London (UCL), UK and COMAC Capital LLP, UK [1] ; COMAC Capital LLP, UK [2] ; University College London (UCL), UK; The United Nations University, Institute for Water, Environment and Health, Canada [3]

ORCID IDs:

0000-0001-9957-3463[3]

Corresponding Author:

Colm O'Shea (colm.o'shea.23@ucl.ac.uk)

DOI:

https://doi.org/10.14324/ucloepreprints.290.v1

Preprint Version:

This is version 1 of this article.

Data Availability Statement:

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Keywords:

natural gas prices, renewable energy, national investment, net zero, financial modelling, energy modelling, climate change, energy security, UK energy, wind energy benefits, wind energy

Modelling the long-term financial benefits of UK investment in wind energy generation

Colm O'Shea[1,2], Piers Horne[2] and Mark Maslin[1,3]

1. Department of Geography, University College London, North-West Wing, Gower Street, London, WC1E 6BT
2. COMAC Capital LLP
3. The United Nations University, Institute for Water, Environment and Health, 225 East Beaver Creek Road, Richmond Hill, ON L4B 3P4, Canada

Abstract

This study presents new evidence of the financial impact of wind generation on the UK energy market, challenging the idea that sustainability, security, and affordability, are always in conflict. From 2010 to 2023, wind power delivered a net benefit of £104.3 billion to UK consumers—£14.2 billion from lower electricity prices and £133.3 billion from reduced natural gas prices, partially offset by £43.2 billion in wind energy subsidies. Our study takes a long-term modelling approach and considers the broader counterfactual of what would happen if the UK had continued to invest in gas instead of wind generation. In this scenario, the result is a significantly increased demand for gas in the regional European market, and therefore higher prices. Unlike previous short-term modelling studies, this approach highlights the longer-term financial benefit that wind has delivered to the UK consumer.

It is clear that wind generators reduce market prices, cannibalising their own revenues, creating value for others while limiting their own profitability. Wind power should be viewed as a public good—like roads or schools—where government support leads to national gains.

The current funding model, where electricity users bear the cost while gas users benefit, raises fairness concerns. Ultimately, wind investment has significantly lowered fossil fuel prices, underscoring the need for strategic, equitable energy policy that aligns with long-term national interests. Our study demonstrates that the energy transition is not a costly environmental subsidy, it is a compelling financial investment.

Introduction

The transition to low-carbon energy is a cornerstone of UK and European policy, driven by the need to balance sustainability, affordability, and energy security—the Energy Trilemma (World Energy Council, 2020). The UK has made significant progress in decarbonising its energy system by rapidly expanding wind capacity, which has had a significant impact on electricity markets and indirectly on natural gas markets, which remain the marginal cost supplier for UK electricity.

UK wind generation – Investment and Growth

Under the Kyoto Protocol (UNFCCC, 1998), the UK and EU adopted a burden-sharing agreement targeting an 8% emissions reduction, with a particular focus on electricity production and supply. In the UK, this led to the launch of the Renewables Obligation (RO) scheme in 2002, which provided 20 years of support for renewable energy generators through tradable certificates purchased by electricity suppliers (Grimwood & Ares, 2016).

UK Renewable Generation

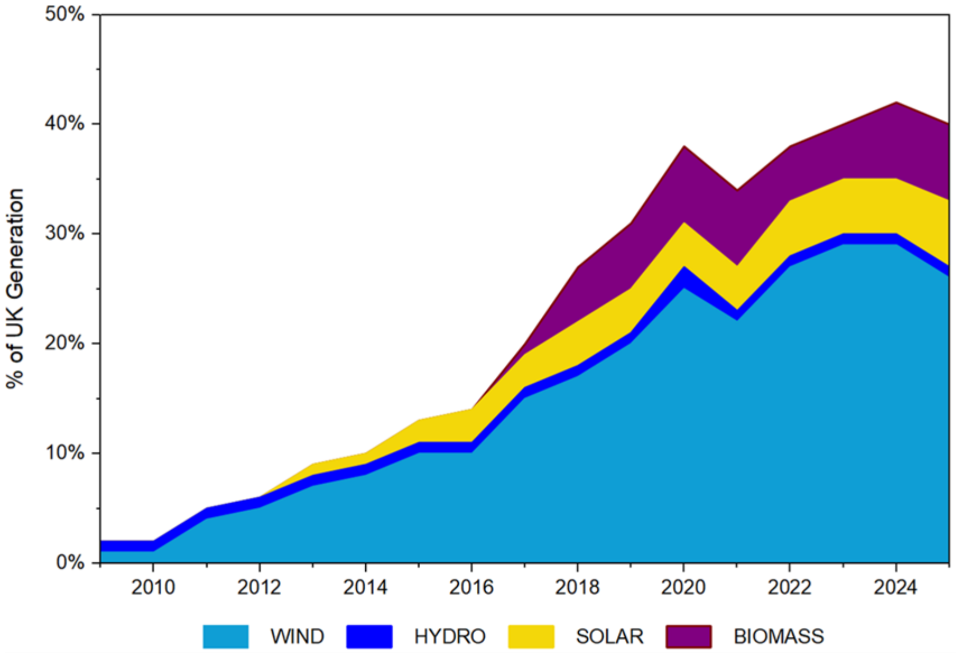

Fig. 1 Annual UK Renewable Generation by type 2009-2025

Source: NESO

The Climate Change Act 2008 prioritised the deployment of wind power over natural gas generation in the UK, leading to rapid growth of wind capacity shown in Figure 1 which was also seen across the EU (BNEF, 2025), with a concerted shift away from fossil fuels for electricity generation. From 2017, the Contract for Difference (CfD) replaced RO (Watson & Bolton, 2024), offering a 15-year inflation-indexed strike price set by competitive auctions, called Allocations Rounds (AR). Over the past decade, generation costs have fallen significantly, as shown in Figure 2.

UK CFD Allocation Round Results

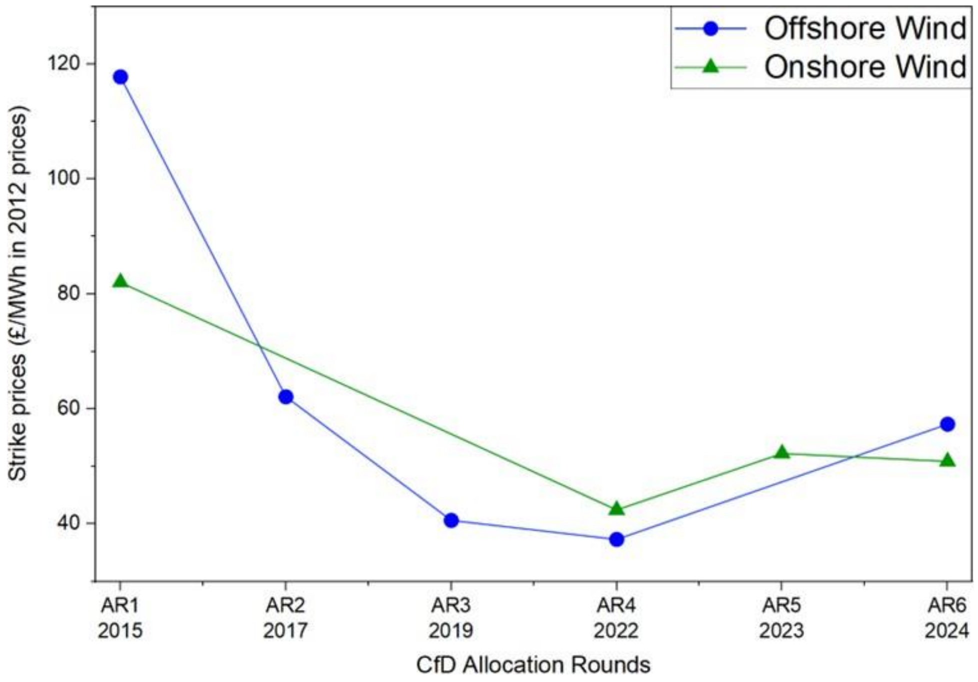

Fig. 2 Strike Prices (£/MWh in capacity-weighted 2012 prices) by Allocation Round (AR) year

Source: LCCC

Although described as government subsidies, these support schemes are paid entirely by electricity users via their bills. Since 2010, the total cost has reached £43bn, as shown in Table 1.

Table 1
UK Wind Subsidies

	CFD Scheme	RO Scheme	Total
	£ bn	£ bn	£ bn
2010		0.6	0.6
2011		0.8	0.8
2012		1.2	1.2
2013		1.6	1.6
2014		1.8	1.8
2015		2.4	2.4
2016		2.4	2.4
2017	0.2	3.2	3.3
2018	0.5	3.7	4.2
2019	1.1	3.8	4.9
2020	1.8	4.2	6.0
2021	0.6	3.7	4.3
2022	0.3	4.4	3.9
2023	1.4	4.4	5.9
Total	5.2	37.9	43.1

Source: LCCC, OFGEM

Structure of UK electricity market

Electricity generated is sold to retailers through the British wholesale market, where prices are set for each half-hour period. Trading occurs across exchanges (e.g. Nordpool, EPEX) and over the counter (OTC) markets. The day-ahead market is the primary venue and reference price for the market. Volumes are more than six times greater (NordPool, 2022) than the intraday market, whose main role is managing the mismatch between expected demand and supply.

Prices are determined via auctions where generators submit bids for a given period, specifying the price and quantity they are willing to supply. Bids are accepted in merit order i.e. lowest prices first - then sequentially until demand is fully met. All accepted generators receive the clearing price, set by auction, not their individual bid price which means that the most expensive marginal supplier becomes the price setter.

Gas generation is dispatchable, meaning supply quantity can be adjusted to meet demand, depending on the price signal. This dispatchability makes gas the marginal supplier and thus the dominant price setter of electricity prices in the UK (Gasparella & Zucker, 2023; Zakeri et al., 2023).

The marginal price of gas generation is primarily driven by the price of natural gas which operates within regional markets, due to transport limitations. Regions are connected by pipelines (e.g. Russia and Europe) or by liquified natural gas (LNG), which dominates in Asia (Filimonova et al., 2022). Globally, the gas market can be seen as consisting of two major regions of net exporters, the CIS and the Middle East, and two of net importers, Europe and Asia, whilst North America is both a large consumer and producer (Energy Institute, 2025).

These regional supply - demand differences lead to varied local gas prices (Filimonova et al., 2022). From 2000 to 2020, European markets (TTF) benefited from consistent supply from local production and cheap pipeline imports from the CIS (Ellersiek & Gnerre, 2023), alongside demand growth moderated by the shift to renewable energy. In contrast, North American prices (Henry Hub) were initially higher than in Europe but fell dramatically post 2010 with the development of the Permian Basin (Hauser et al., 2016). Asia, reliant on expensive LNG imports, has consistently significantly higher prices compared to both the US and Europe (Energy Institute, 2025).

Unlike gas, wind generation is non-dispatchable, in that there is no response to demand. As an effectively zero marginal cost supplier, wind generators will always supply electricity based upon wind strength, regardless of market conditions. It is this feature of wind generation that directly lowers electricity prices by the Merit Order Effect (MOE).

Merit Order Effect (MOE) Theory

A large body of academic literature has explored the impact of wind generation on lowering electricity prices (Cevik & Ninomiya, 2023; Cludius et al., 2013; Halttunen et al., 2020; Shao et al., 2022) by focusing on the Merit Order Effect (MOE), a concept first described in (Sensfuß et al., 2008).

The theoretical description of this effect is shown in Figure 3 where higher wind generation shifts the supply curve (Snw) to the right (Sw), lowering the price of electricity. The vertical demand curve assumes that demand is unaffected by price i.e. exogenous. The difference in electricity price with and without wind generation (Pw vs Pnw in Figure 3) is how much the price of electricity is impacted by renewable generation for a given supply curve, which is determined by the rising marginal cost of gas generation. This is often simply referred to as MOE, or sometimes as Specific Merit Order Effect (Cludius et al., 2013) commonly quoted in £/GW. In this paper the term Marginal Merit Order Effect has been used for this concept to make clear that this is the change in electricity price due to small changes in wind/renewable generation.

MOE Theory

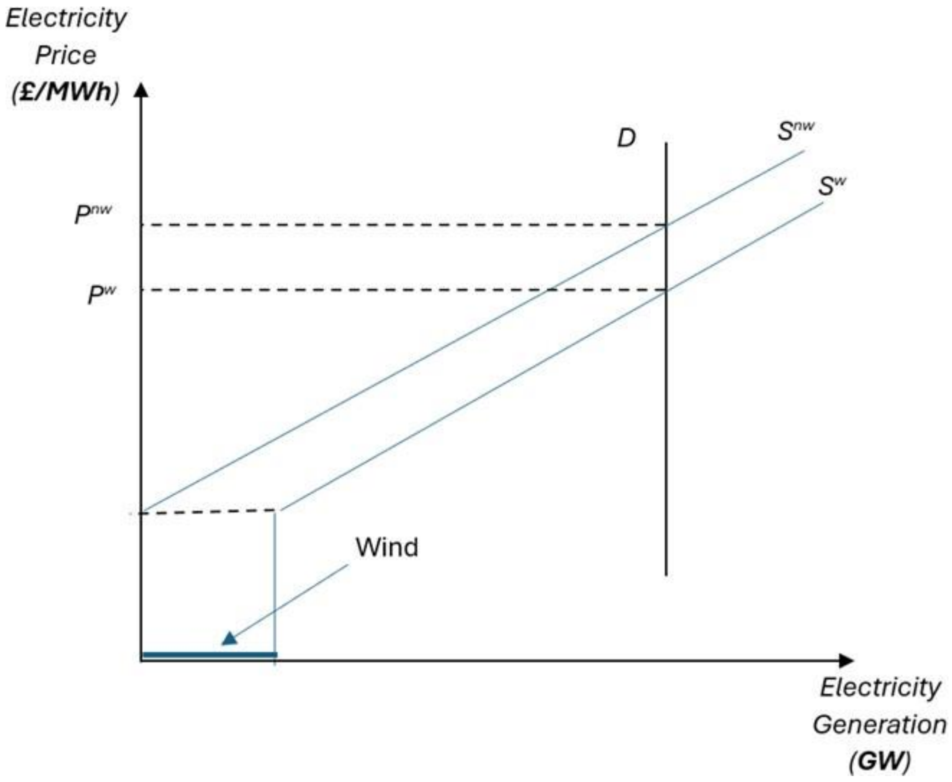

Fig. 3 Illustration of Marginal MOE effect due to wind generation

The effect is not just that wind generation lowers electricity prices overall, but that it particularly lowers the price electricity generators earn. As shown in Figure 4, wind generators receive a lower average price (called the “Capture Price”) than gas generators, and this difference has grown over the last decade. As wind penetration increases, it has led to lower relative prices for wind generators, in effect, a “cannibalisation” of its own market (Halttunen et al., 2020).

Capture Prices

Capture Price of Wind relative to Gas

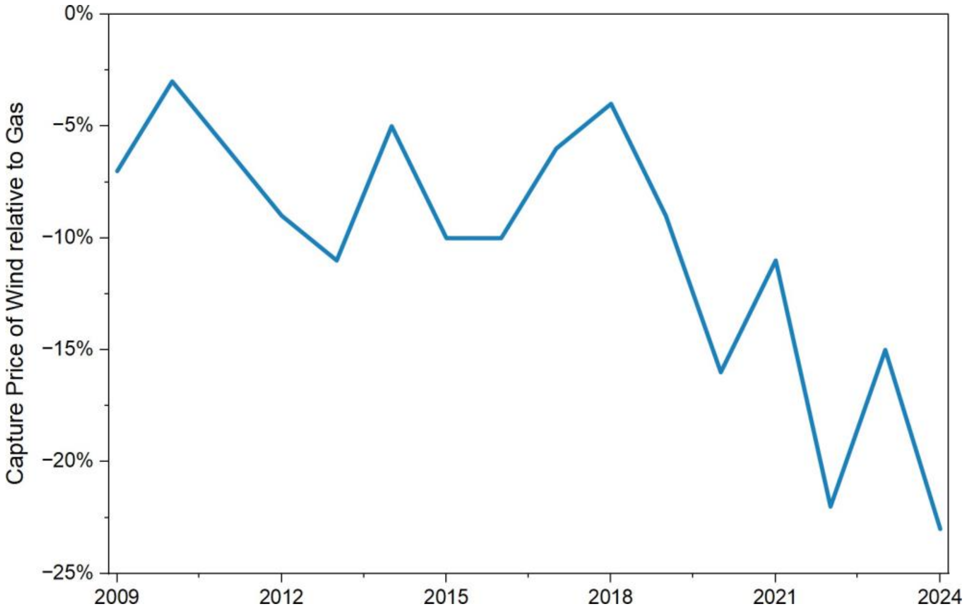

Fig. 4 Capture Price of Wind relative to Gas relative to average electricity prices
Source: Author calculations, NESO, LCCC/Elexon

In earlier research (Sensfuß, 2011), the most common approach to estimate the electricity supply curve was to simulate the entire energy system using engineering models. Over time however, most studies have shifted to empirical methods using regression analysis on historical time series data. (Denny et al., 2017) demonstrated that the results from these simpler empirical models are very similar to those more complex simulation-based approaches.

Table 2 shows a range of academic estimates for Marginal MOE over several periods and regions. OLS is by far the most popular method with Electricity Price as Dependent Variable, Generation Data as Independent Variable and a choice of Control Variables among Energy prices (Gas/Oil/Coal), Total Electricity (Demand/Load) and Time dummies (daily/monthly/ annual).

Table 2

MOE Literature Overview

(1) Name	(2) Method	(3) Region	(4) Period	(5) Units	(6) Technology	(7) MOE
(Cevik & Ninomiya, 2023)	E	24 European Countries	2014 - 2021	% price / % wind	R	-0.55
(Welisch et al., 2016)	E	Denmark	2013	€/GW	R	-4.70
(Jónsson et al., 2010)	E	Denmark	2006 - 2007	€/GW	W	-9.87
(Oestergaard et al., 2006)	E	Denmark	2004–2006	€/GW	W	(-5.28, -1.33)
(Bode & Groscurth, 2006)	S	Germany	2005	€/GW	R	-0.60
(Sensfuß et al., 2008)	S	Germany	2001 – 2006	€/GW	R	(-0.04, -0.1)
(Sensfuß, 2011)	S	Germany	2007 - 2010	€/GW	R	(-0.77, -0.55)
(Traber & Kemfert, 2011)	S	Germany	2007 - 2008	€/GW	W	-0.80
(Weber & Woll, 2007)	S	Germany	2006	€/GW	W	-1.15
(Weigt, 2009)	S	Germany	2006–2008	€/GW	W	(-2.83, -1.78)
(Ketterer, 2014)	E	Germany	2006–2012	% price / % wind	W	-0.10
(Cludius et al., 2013)	E	Germany	2008 - 2012	€/GW	R	-1.12
(Gürtler & Paulsen, 2018)	E	Germany	2010 - 2016	€/GW	R	(-0.3, -2)
(Kyritsis et al., 2017)	E	Germany	2015 - 2015	€/GW	R	-0.04
(Welisch et al., 2016)	E	Germany	2012	€/GW	R	-1.49
(Zipp, 2017)	E	Germany	2011 - 2013	€/GW	R	(-1.32, -1.4)
(Cludius et al., 2013)	E	Germany	2008 - 2012	€/GW	W	-1.30
(Neubarth et al., 2006)	E	Germany	2004 - 2005	€/GW	W	-1.89
(Würzburg et al., 2013)	E	Germany & Austria	2010 - 2012	€/GWh	R	-1.03
(Nieuwenhout & Brand, 2011)	E	Holland	2006 - 2009	€/GW	W	-6.17
(Denny et al., 2017)	E	Ireland	2009	€/GW	W	-3.40
(O'Mahoney & Denny, 2011)	E	Ireland	2009	€/GW	W	-9.90
(Clò et al., 2015)	E	Italy	2005 - 2013	€/GW	W	-4.20
(Sáenz de Miera et al., 2008)	S	Spain	2005 - 2007	€/GW	W	(-7.83, -2.99)
(Gelabert et al., 2011)	E	Spain	2005 - 2010	€/GW	R	-1.86
(Welisch et al., 2016)	E	Spain	2012	€/GW	R	-5.68
(Gil et al., 2012)	E	Spain	2007 - 2010	€/GW	W	-2.15
(Shao et al., 2022)	E	UK	2009 - 2021	£/GW	W	-1.28
(Halttunen et al., 2020)	E	UK	2010 - 2019	£/MWh /% renewables	R	-0.48
(Mills et al., 2021)	S	US	2008 - 2017	$/MWh/%	R	-0.14
(Quint & Dahlke, 2019)	E	US (MISO)	2008 - 2016	$/GW	W	(-3.1, -1.4)
(Ajanaku & Collins, 2024)	E	US (PJM)	2011 - 2019	$/MWh /% renewables	W	-0.72

Notes: Method Key: S – Simulation, E - Empirical Technology Key: R - Renewables; W - Wind

Source: Authors

Further, Figure 5 shows the wide variation in estimates across locations and time ranges, which makes it hard to draw general estimates on how wind generation affects electricity prices. As a result, this study only focuses on the UK for its analysis.

Marginal MOE Results

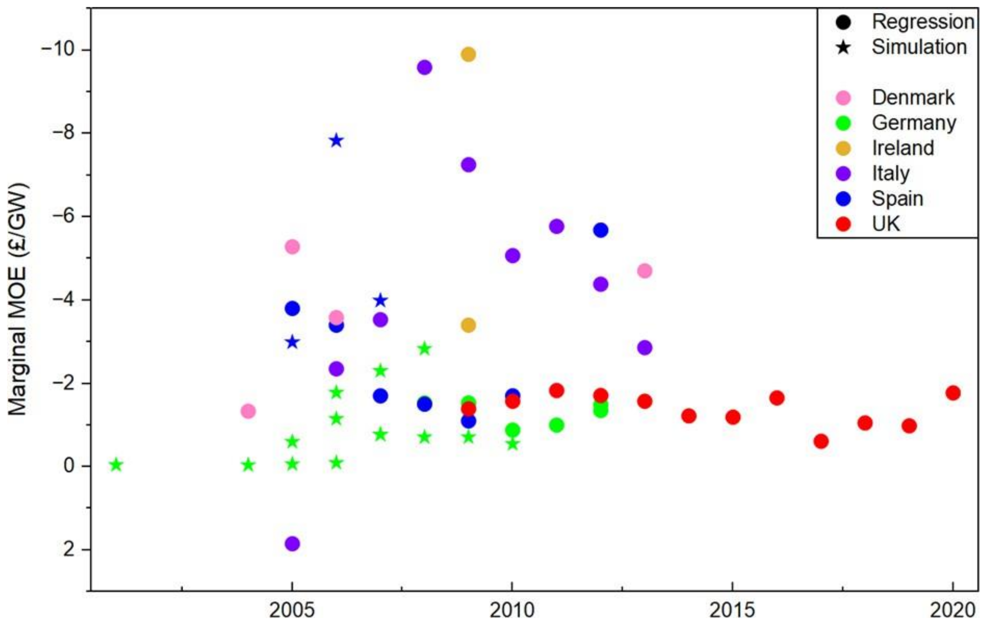

Fig. 5 Marginal MOE results from academic literature. Note that y axis has been flipped

Source: Table 2

While most studies only focus on Marginal MOE, some extend analysis to Total MOE in an effort to quantify the overall price impact of wind generation. For example, (Cludius et al., 2013) estimate the “Wind Specific Effect”, or Marginal MOE, as -1.53 EUR/MWh in 2008, combined with the “Wind feed-in”, or wind generation per hour as 4.61GW, producing a “Wind total effect”, or Total MOE, of -7.05 EUR/MWh. They conclude that electricity prices in Germany in 2008, were EUR 7.05/MWh cheaper due to impact of wind generation.

There have only been a small number of papers attempting to employ this MOE calculation to create an overall financial value to consumers. One example for Spain in 2011 where (Gil et al., 2012) conclude that the subsidies in Spain have been lower than the benefit gained from lower electricity prices. For the UK, (Shao et al., 2022), use the annual Marginal MOE to calculate the total consumer benefit from lower electricity prices, which they then compare with the annual cost of subsidies under the UK’s RO scheme. (Shao et al., 2022) conclude that the cost of subsidies was higher than the benefit from lower electricity prices by £7bn between 2009 and 2020. In (Shao et al., 2023) they updated their methodology by adding in the value of reduced carbon emissions, as priced by the EU Emission Trading Scheme, and conclude that there is an overall net benefit.

A recent paper has proposed a different method to estimate the value of offshore wind to the UK. (Ghorbani Pashakolaie et al., 2024) note that “adding offshore wind energy results (in) lower energy prices” but they accept the (Shao et al., 2022) result that “it has not been sufficient to offset the costs”. They instead turn to “broader sustainability co-benefits” including energy security (as measured by the impact on the trade deficit), employment and emission costs and conclude that these co-benefits offset 60% of the policy costs.

A key methodological issue has been highlighted by (Antweiler & Muesgens, 2021) who note “much of the literature ignores the dynamics of the system and assumes constant installed capacity of conventional generators”. There has been little done on what they term the “Long Term Merit Order Effect” (LTMOE) which accounts for resultant shifts in installed capacity over time. In this paper, we follow this LTMOE terminology and use Short-Term MOE (STMOE) for the most common approach with its ‘ceteris paribus’ assumptions of fixed capacity, current supply curves and exogenous gas pricing.

Their solution to this problem is to create a theoretical model which has the counter-intuitive conclusion that the Long-Term MOE is zero. We used a different approach to estimate the LTMOE because their result relies on two key assumptions on the market structure that should be questioned. Firstly, they assume marginal changes to the supply of renewables, where renewables “capacity is small relative to overall demand but large enough to displace peak load spikes”. However, the question we are addressing in this paper is not the long-term impact of a marginal change, but the impact of a large systemic change. Secondly, they assume that the addition of this marginal wind generation is a “supply shock” to a market in equilibrium even though, the development of wind generators takes years and would more realistically be fully incorporated into the decision-making of gas generators regarding their capacity.

Data

The data used in this study is shown in the tables. The monthly cost of Renewable Obligations (RO) is calculated as the product of certificates issued and the annual RO price, aggregated by calendar years.

For UK wholesale electricity prices, we used the system buy price and system sell price from Elexon for 2009 and 2016 and the Intermittent Market Reference Price (IMRP) from the Low Carbon Contracts Company for the period 2016 to 2025. For UK electricity generation, we used ‘Historic GB Generation Mix’ from the National Electricity System Operator (NESO) for the period 2009 to 2025 executing data transformations to convert into MWh units for hourly periods. ‘Generic 1st UK Natural Gas Futures (ICE)’ from Bloomberg were used as the data source for UK natural gas futures. Hourly data was used for the UK wholesale day-ahead electricity price, UK electricity generation and UK natural gas futures price.

Data sources

Subsidies Data Series

Times Series	Source - Description	Region	Time Range	Time Frequency	Units	Transformation Done
Contracts for difference payments	Low Carbon Contracts Company	UK	2016-2025	Daily	£	
Renewable Obligations Certificates (ROC) Issued	Department of Energy Security & Net Zero	UK	2010-2024	Monthly	no. of certificates	
Renewable Obligations Certificates (ROC) Value	OFGEM	UK	2010-2024	Financial year	£ per ROC	

MOE Data Series (Short Term and Long Term)

Times Series	Source - Description	Region	Time Range	Time Frequency	Units	Transformation Done
Day-ahead Electricity Prices	Low Carbon Contracts Company	UK	2016-2025	Hourly	£/MWh	
Intra-day Electricity Prices	Elexon	UK	2009-2016	Half-Hourly	£/MWh	Average buy & sell price Convert to hourly (generation-weighted)
Electricity Generation	National Electricity	UK	2009-2025	Half-hourly	MWh	Convert to hourly
Natural Gas Price	Bloomberg	UK	2009-2025	Daily	p/therm	

Gas Model Data Series

Times Series	Source - Description	Region	Time Range	Time Frequency	Units	Transformation Done
Electricity Generation by Gas	Bloomberg NEF	Connected Europe	2000-2023	Annual	GWh	
Gas used by Power Generation	Bloomberg NEF	Connected Europe	2016-2023	Monthly	Mcm per day	Convert to Annual
Wind Generation	Bloomberg NEF	Europe	2000-2023	Annual	GWh	
Gas Consumption	Statistical Review of World Energy	Europe ex Ukraine/Turkey	2001-2010	Annual	bcm	Convert to mcm per day
Russian Pipeline Imports	Statistical Review of World Energy	Europe ex Ukraine/Turkey	2010-2018	Annual	bcm	Convert to mcm per day
LNG Imports	Statistical Review of World Energy	Europe ex Ukraine/Turkey	2010-2018	Annual	bcm	Convert to mcm per day
EU Natural Gas Prices	Statistical Review of World Energy	Europe ex Ukraine/Turkey	2010-2018	Annual	$ per million Btu	Convert to £

Methods

To assess the financial impact of wind generation on the UK energy market, we employ two distinct modelling approaches, as outlined in the flowchart below, Figure 6.

Short-Term MOE (STMOE)

The STMOE model estimates the marginal Merit Order Effect (MOE) directly, using a regression-based approach, which is the most widely used method from the academic literature above and serves as a useful benchmark for comparison. This method calculates the immediate impact of wind generation on electricity prices, relying on implicit "ceteris paribus" assumptions of fixed wind and gas generation capacity and the use of contemporaneous gas prices as a control. While MOE Total Value can be derived using this method, the reliance on extrapolation of a regression along with the above assumptions limits its scope, which motivates the development of our second, comprehensive model.

Long-Term MOE (LTMOE)

The LTMOE model introduces a novel framework that moves beyond the fixed capacity assumptions of STMOE by constructing a new dynamic cost curve for gas generation. In place of the regression approach above, we use Capture Prices to directly estimate MOE Total Value, and from this can derive the Marginal MOE. This approach considers the cost of constructing new gas capacity at the average price, rather than the marginal price assumed in the regression method, more realistically reflecting how the market would respond over time. We then incorporate an endogenous gas price model, assessing how shifts in natural gas demand, such as those required to replace wind generation, affect natural gas prices.

By removing the limiting assumption of the STMOE, this LTMOE model enables us to assess the broader impact of wind development (or its absence) on the UK energy system over the last 15 years.

Flowchart Description of Models

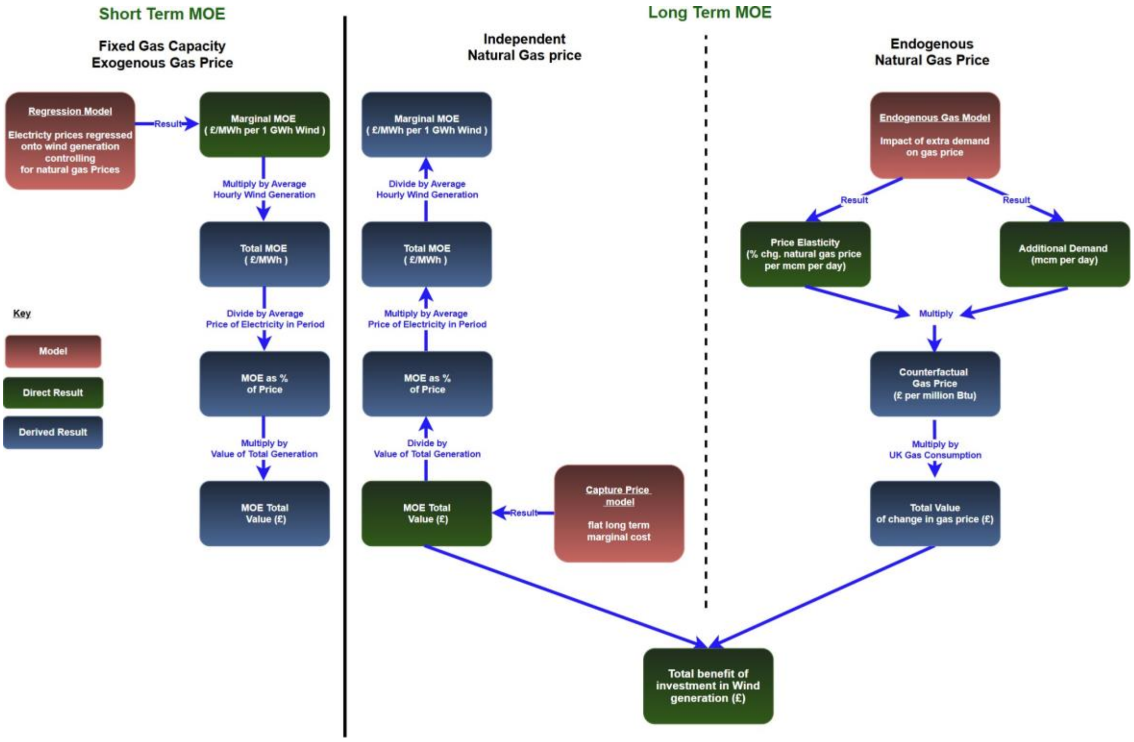

Fig. 6 Models used to assess financial impact of wind generation

Key Terms

Marginal MOE - £/GW - the impact on electricity prices from a 1GW change in the supply of electricity from wind. In many papers, this is referred to as Specific MOE or simply MOE.

Total MOE - £/MWh - the total impact at overall market level of wind generation on the electricity price.

MOE Total Value - £ - the financial value to the consumer of the change in electricity price resulting from the MOE.

Short-Term MOE (STMOE) - the impact on energy prices of wind generation with ceteris paribus conditions of constant generating capacity and independent gas prices.

Long-Term MOE (LTMOE) - the impact on energy prices of wind generation relaxing the ceteris paribus conditions of constant generating capacity and independent gas prices.

Capture Price - the weighted average price obtained by each type of electricity generator in the wholesale market.

Short-Term MOE Model Specification & Assumptions

To estimate the Marginal MOE, we follow the approach commonly used in the literature, by applying a multivariate OLS regression model controlling for natural gas prices, specified as follows:

$$E.Price_t = \beta_0 + \beta_1 Wind_t + \beta_2 NG.Price_t + \varepsilon_t$$

$E.Price_t$ denotes hourly UK wholesale electricity prices (£ / MWh), Windt is hourly UK wind generation in GWh with NG.Pricet, daily UK natural gas prices in p/therm, as control variable.

B_2 is the regression constant, Bi are the regression coefficients and ϵt is the idiosyncratic error term. B1 specifically represents the Marginal MOE in £/MWh per 1 GW change in wind generation.

Wind generation is assumed to be weather-driven and unaffected by price signals. The model also assumes a one-way causal relationship—wind affects electricity prices, but not gas prices. This limitation of the STMOE model is addressed in the LTMOE model discussed below.

Natural gas prices are a crucial determinant of UK electricity prices (Halttunen et al., 2020). Including natural gas as a control yielded an R2 of 0.7, comparable to other more complex studies, so we opted for a simpler specification with fewer controls, rather than optimise the R2 at the expense of model clarity.

In addition to the full period regression, we ran annual sub-period regressions to track how MOE evolves over time – a method well supported by (Cludius et al., 2013; Halttunen et al., 2020; Shao et al., 2022). Whilst other papers such as (Gelabert et al., 2011) and (Cludius et al., 2013) use time dummy variables (e.g., daily, monthly, and annual dummies) to control for temporal effects, they reveal little on how coefficients change with time, which is why they are not used in this paper.

Following the steps from the flowchart in Figure 6, we perform the following calculations:

$$\textbf{Total MOE} = \textbf{Marginal MOE} \times \textbf{Average hourly wind generation}$$

$$\textbf{MOE as \% of price} = \frac{\textbf{Total MOE}}{\textbf{Price of electricity}}$$

MOE Total Value* = *MOE as % of price* × *value of total generation

Data Series Testing

Prior to regression, the following tests were performed.

Stationarity is essential for OLS regression to avoid spurious results. We tested all variables -electricity prices, wind generation, and natural gas prices-for unit roots using Augmented Dickey-Fuller (ADF) tests the null hypothesis of non-stationarity was rejected at the 5% level for all series, indicating stationarity in levels and that we did not need to apply logarithms or first differences. Wind generation and natural gas prices show low Pearson correlation, suggesting they are not linearly related and can be considered independent in the regression. To correct for potential heteroskedasticity and autocorrelation in residuals, we applied Newey-West (1987) robust standard errors.

Long-Term MOE Model Specification

a) Flexible generation capacity

To estimate Total MOE in the Long-Term MOE Model, we first relax the assumption that installed capacity is fixed. Instead, we assume in the absence of wind investment, equivalent gas generation would have been built. Gas generators are assumed to operate in competitive markets, earning a normal level of profit at prevailing market prices they obtain for electricity generation. We also assume a flat long-term marginal cost curve for gas generation, with all inputs variable, meaning that in this model, new gas generation capacity can be constructed at the same average cost as existing plants, not at their marginal cost as assumed in the STMOE model. Without wind's price dampening effect, electricity prices would always align with the marginal cost of gas generation, meaning all non-dispatchable generators will receive the same price as gas generation. Therefore, we calculate the gas Capture Price to assess the Total MOE, as follows.

Capture Price is the average price received by each type of generator for a given time period, thought of generally as:

$$\textit{Capture Price}_t^g = \frac{\textit{Total Wholesale Revenue}_t^g}{\textit{Total Energy Generated}_t^g}$$

and calculated as follows

$$\textit{Capture Price}_t^g = \frac{\sum_{i=0}^{n} (\text{Gen}_i^g \times E'\text{Price}_i)}{\sum_{i=0}^{n} \text{Gen}_i^g}$$

C.Price$_t^g$ denotes Capture price for a given year *t* and generation type *g* in £/MWh, and Gen$_i^g$ hourly generation in period *i* for generation type *g* in MWh and *E.Price$_i$:* hourly wholesale price of electricity in period *i* in £/MWh

MOE Total price = Non-fossil Generation Valued at Gas Capture Price - Value of Non-fossil Generation

$$\textit{MOE as \% of price} = \frac{\textit{MOE total value}}{\textit{Value of total generation}}$$

$$\textit{Total MOE} = \textit{MOE as \% of price} \times \textit{price of electricity}$$

$$\textit{Marginal MOE} = \frac{\textit{Total MOE}}{\textit{Average hourly wind generation}}$$

Note that this method works in the reverse direction to the Marginal MOE method where we begin with the Marginal MOE and from there calculate the Total MOE.

b) Endogenous Natural Gas price

The second component of the LTMOE model examines how building new gas capacity to replace wind generation would affect the natural gas market and drive changes in gas prices. Assuming that natural gas prices are independent of such demand shifts would be to ignore one of the most important factors influencing both gas and electricity prices in the UK. Figure 7 starkly illustrates how sensitive gas prices are to shifts in supply and demand with the example of the 2022 energy crisis, triggered by the Russia-Ukraine conflict.

Gas & Electricity Prices

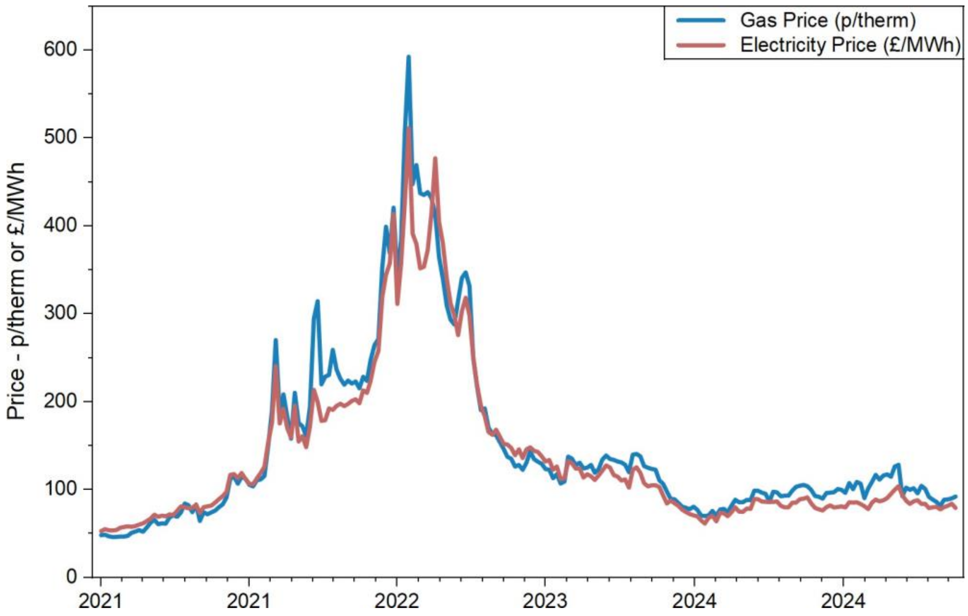

Fig. 7 Gas & Electricity Prices between Feb 2021 – May 2025

Source: OFGEM

We estimated the additional natural gas demand required to replace the output of the wind sector in Europe using an empirical conversion rate of 2300 GWh of generation per mcm per day of gas. This was estimated from the ratio of natural gas usage in the power sector to electricity generation by gas generators 2016-2023 (BNEF, 2025). As shown in Figure 8, by 2023 this would require additional gas demand of 273 mcm/day, exceeding the 223 mcm/day drop in Russian pipeline gas that caused the 2022 energy crisis (Energy Institute, 2025). This highlights that assuming wind generation has no effect on gas prices is highly unrealistic for this scale of changes.

European Wind Generation (Gas equivalent)

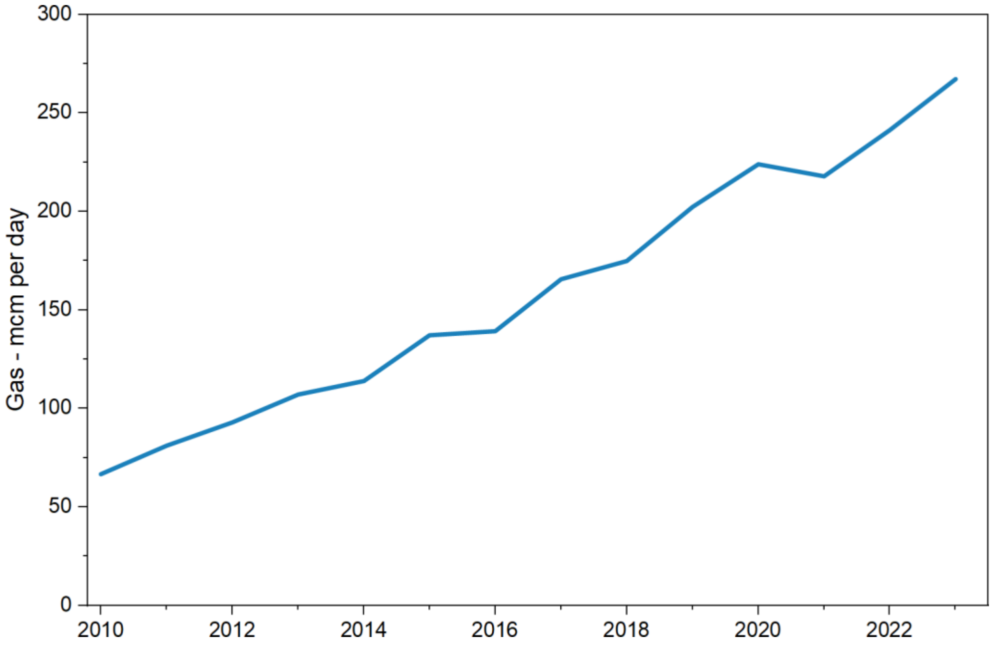

Fig. 8 Gas demand required to replace European Wind Generation

Source: Author calculations, BNEF

To estimate the price elasticity, we examined the relationship between gas demand and prices in the European natural gas market (ex-Ukraine and Turkey). Using an OLS regression for 2010-2021, we found each additional mcm/day of extra gas demand in Europe increased prices by 0.4%. We applied this price elasticity to the annual changes in gas demand required to replace European wind generation above shown in Figure 8, starting from the 2008 Climate Change Act. Acknowledging the dangers of applying long-term elasticities to the energy crisis of 2022, we conservatively capped the price impact of extra demand to £10/MWh, the price premium observed in 2021 before the crisis.

Model testing

We tested the price elasticity model against two recent periods, where the drivers of the changes in the gas price were well understood. According to (ACER, 2022), in 2021 European gas prices roses due to a combined drop of 111 mcm per day in Russian pipeline and LNG imports. For 2022, we used 223 mcm per day reduction in Russian pipeline gas (Energy Institute, 2025), compared both scenarios to average gas prices to avoid the distorting effects of the highest price spikes.

Table 3

Performance of Price Elasticity model

	(1) Gas Supply change mcm per day	(2) Price elasticity % of model	(3)=(1)*(2) Model % changes	(4) Actual % change
May 2021 - Oct 2021	111	0.4%	44%	170%
Oct 2021 - Sep 2022	223	0.4%	89%	113%

Source: ACER, Energy Institute, Author calculations

The results in Table 3 show how the model produces reasonable results but, in both cases, underestimates the change in market prices observed. This means that the model is conservative and likely underrepresents the price changes in response to changes in demand and supply dynamics.

Scope of the Model and Unaddressed factors

Whilst the model provides valuable insights, no one model can capture every aspect of a complex system. Importantly we have chosen to not include broader system costs, the broader impact of RE beyond wind generation in the UK, and the carbon emission impact in the financial impact of investment in wind generation.

Costs in addition to subsidies

This paper focuses on quantifying the wholesale electricity market as a proxy for generation costs. A common criticism of this approach is that in a similar way to the use of Levelized Cost of Energy (LCOE) (Lazard, 2025) it does not include all system costs (Moraski & Spokas, 2025). These include: Grid infrastructure costs as renewables are located further away from demand and intermittency costs including storage and peak load management (Dale et al., 2004). It is a very fair observation that this paper does not attempt a holistic system-wide evaluation of all associated costs of a type of generation, nor the additional benefits of wind energy such the positive economic impact on local communities (Glasson et al., 2022). It does not attempt to cover a number of related important issues of the economics of wind energy which are covered in other literature (Climate Change Committee, 2023; European Wind Energy Association, 2009) and deals with the narrower area of wholesale energy markets.

However, the same issue exists for the additional system costs for fossil fuels, as the idea that fossil fuels do not also require government investment and support is a myth. As an importer of fossil fuels, large-scale LNG imports from the large producing countries of the US and Qatar would be needed for Europe to replace wind with gas generation. But LNG, like Renewables, requires massive upfront capital investment including ships, gassing, and degassing plants. The IEA estimates that the total investment requirement globally for LNG is currently $280bn per year just to maintain the current path (IEA, 2023). This figure would be far higher if we slowed down or even attempted to reverse the energy transition with higher demand for fossil fuels requiring even more investment. It is also not credible to expect that a huge expansion of LNG infrastructure could be privately financed without public support as the return on this infrastructure investment is hugely dependent on the future price of gas. The IEA estimate that just a 20% change in price of LNG equates to $300bn in profitability (IEA, 2023). Like Renewables, LNG infrastructure requires large upfront capital expenditure which private markets are not able to do with highly uncertain future revenues (Nikhalat-Jahromi et al., 2017).

Further fossil fuel costs which are not incorporated into this model include reduced volatility of energy prices which has a clear and large economic benefit (Ghorbani Pashakolaie et al., 2024) as well as the value of energy security as fossil fuels are imported, with huge foreign policy and national security implications (IEA, 2024).

A study of the broader comparative costs and benefits of investment and government support for renewable energy and fossil fuels is beyond the scope of this paper and is worthy of further study. However, the frequent implicit assumption that it is only renewable energy system costs that are missing from a system-wide analysis is clearly flawed.

Expand beyond the UK

It is beyond the scope of this paper, but a similar analysis could be performed for the broader role of renewable energy and the impact of the global energy transition. A chart of the scenarios for the global demand for natural gas in Figure 9 illustrates the impact of the speed of the energy transition on global natural gas demand and therefore price. Maintaining our current path, we are in the IEEJ Reference scenario, a world of even higher gas demand and high fossil fuel prices. If we are successful in achieving the global policy goals of Net Zero, then the consumption of natural gas must necessarily fall to much lower levels. This will lead to far lower fossil fuel prices which on a marginal basis will make fossil fuels look a cheap energy source.

This comparison shows the importance of not basing opinions on the financial merits of RE vs fossil fuels based on marginal pricing analysis. The irony is that a move to a cheaper RE system will lead to lower marginal costs for fossil fuels making this conceptual error ever more dangerous.

Global Natural Gas Demand – Scenarios Forecast

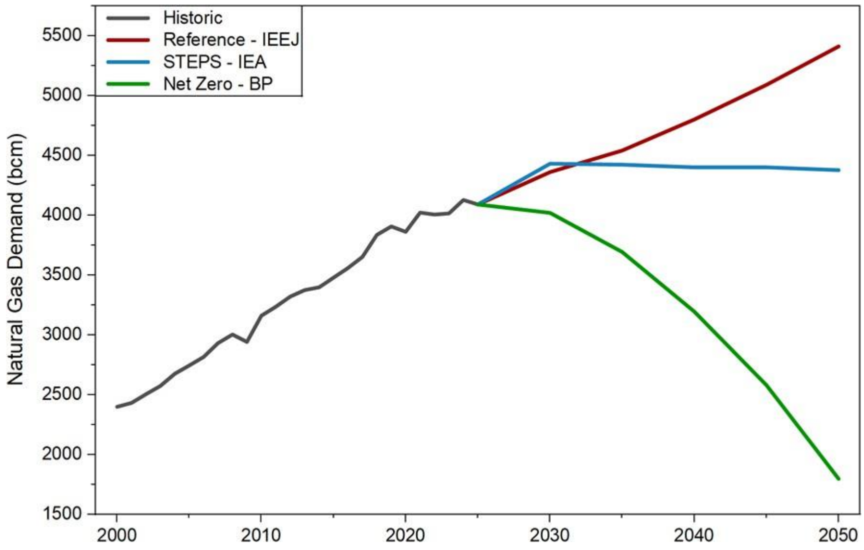

Fig. 9 Global Natural Gas Demand, historic& future, from various forecast scenarios
Source: Energy Institute, IEA, BP, IEEJ

Carbon emission costs

Another obvious omission from the model in this paper is any consideration of the costs of carbon and the impact of the energy transition on climate change. This is a deliberate choice as there already exists a comprehensive literature on this topic and any estimate of carbon cost can be easily added to this purely financial analysis. The other reason for this choice is to have this paper stand solely as a financial evaluation of the energy transition. (Stern & Stiglitz, 2023) note the problem of “getting the counterfactual wrong” in what they call the “standard argument” where climate change mitigation is incorrectly assumed to have economic costs greater than the benefits, partly because the financial and economic costs of inaction are incorrectly calculated. It is very common in public debate to see criticisms of the energy transition on financial grounds countered by support for energy transition on climate change grounds. These arguments do not have a common ground and so can create mutual misunderstanding. Supporters of the energy transition are quickly categorised as financially naïve and opponents as climate deniers. In fact, this paper makes the case that the energy transition is compelling on a purely financial basis even before any consideration of climate change.

Short-Term MOE Results

The Marginal MOE in Table 4 is seen to be consistently negative, showing that higher wind generation lowers the price of electricity on the margin.

Table 4

Short-Term MOE Model Results

	(1) Marginal MOE	(2) Total MOE	(3) MOE as % of Price	(4) Total Value of MOE	(5) Subsidy	(6)=(4)-(5) Net
Units	£/GW	£/MWh	%	£ bn	£ bn	£ bn
2010	-3.46	-1.82	4%	0.6	0.6	0.0
2011	-2.11	-2.86	6%	0.9	0.8	0.1
2012	-2.23	-3.95	8%	1.3	1.1	0.2
2013	-2.24	-5.47	10%	1.8	1.6	0.2
2014	-1.07	-3.09	7%	1.0	1.8	-0.9
2015	-1.10	-3.97	9%	1.2	2.4	-1.2
2016	-1.30	-4.48	10%	1.4	2.4	-1.0
2017	-0.78	-3.94	8%	1.2	3.3	-2.1
2018	-0.37	-2.14	4%	0.6	4.2	-3.6
2019	-0.83	-5.52	12%	1.6	4.9	-3.3
2020	-1.07	-8.32	22%	2.3	6.0	-3.7
2021	-3.41	-24.23	20%	6.9	4.2	2.6
2022	-6.41	-56.48	27%	16.4	3.9	12.4
2023	-2.84	-25.64	26%	7.0	5.9	1.2
2024	-2.37	-22.32	30%			
Total				44.1	43.1	0.9

Source: Author calculations, LCCC, OFGEM

From 2010 to 2023, the Marginal MOE ranged from -0.37 £/GW in 2018 to -6.41 £/GW in 2022. These results align well with those in the Literature Review (Figure 5) and closely match the results in (Shao et al., 2022) for the same UK market over the same period, as shown in Figure 10.

Marginal MOE Comparison

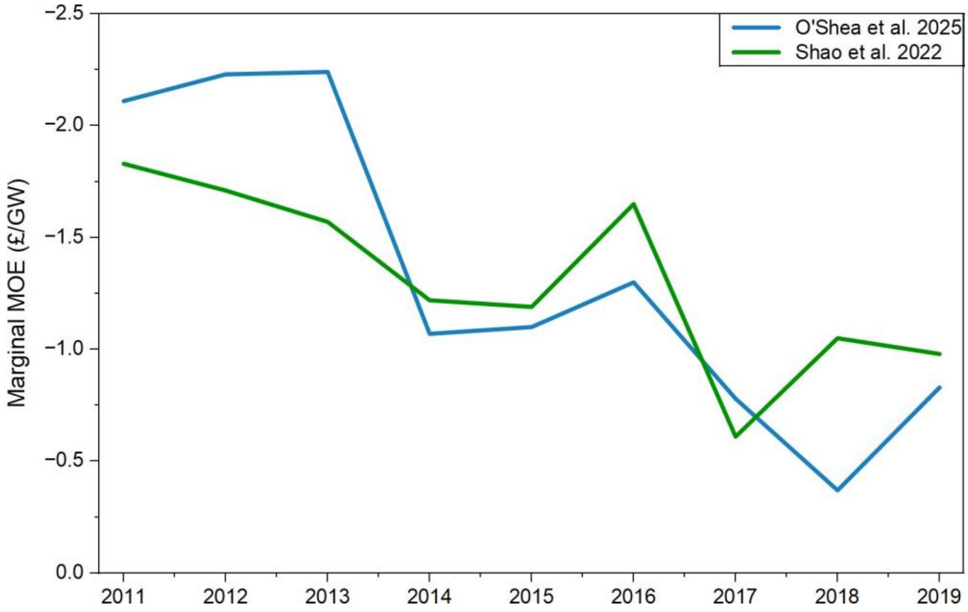

Fig. 10 Comparison of Marginal MOE results for the UK between 2011-2019. Y-axis has been reversed Source: NESO

The results are consistent with the broad consensus that wind energy was a significant financial cost (Shao et al., 2022), but that recently the reverse is the case with a cumulative net benefit from 2010-2023 a net positive £0.9bn.

Short-Term MOE Discussion

While the Short-Term MOE (STMOE) model provides valuable insights into the immediate effects of wind generation on electricity prices, we need to recognise the limitations of using marginal analysis for evaluating systemic change. It assumes the existing gas supply curve remains unchanged, which is reasonable for short-term impacts but highly restrictive for the long-term shift of replacing 30% of UK electricity generation. We cannot confidently assume we can extrapolate a modelled linear relationship designed to study short-term price dynamics to estimate out of sample relationships where its ceteris paribus assumptions do not hold.

In addition, the UK may be particularly badly suited to regression analysis as it has “both high VRE (Variable Renewable Energy) penetration and low explanatory power from VRE” (Halttunen et al., 2020) which is attributed to the observation that “electricity prices correlate with the price of natural gas” as seen in Figure 7. This means that multiple regressions using gas prices yield high R2 values that reflect the dominant influence of gas prices rather than wind generation, which is the variable we are attempting to study.

Furthermore, the underlying data may not be suitable for the use of linear regression. (Ajanaku & Collins, 2024) note that “spot electricity prices do not exhibit Gaussian distribution” and consider it “extremely unlikely that models OLS techniques will have Gaussian residuals”. Along with other authors (Do et al., 2019; Hagfors et al., 2016; Maciejowska, 2020; Sapio, 2019; Sirin & Yilmaz, 2020), they attempt to deal with this issue by using Quintile regressions whereby they can examine different parts of the data set separately. The Quintile approach may lead to a better, more granular estimation of the Marginal MOE but it also highlights that the underlying relationship between wind generation and electricity price is non-linear and so linear extrapolation from Marginal to Total MOE is not appropriate.

Perhaps the most important issue in using this marginal method for the analysis of a non-marginal change is that it produces results which do not appear reasonable. From Table 4 we see that the STMOE model gives the result that MOE as a percentage of price is over 20% from 2020 onwards. However, this would imply electricity prices consistently over 20% higher compared to their usual relationship to gas prices as seen in Figure 7, meaning gas generators would be making much higher-than-normal profits. The ceteris paribus assumption required for the marginal model means that there is assumed to be no supply response from new gas generators despite the large financial incentive to create more gas generating capacity.

Long-Term MOE Results

a) Flexible generation capacity

The results for LTMOE with flexible gas generation capacity, shown in Table 5, give Total Value of MOE of £14.2bn for 2010-2023.

Table 5

Long-Term MOE Model Results

	(1) Marginal MOE	(2) Total MOE	(3) MOE as % of Price	(4) Total Value of MOE
Units	£/GW	£/MWh	%	£ bn
2010	-0.14	-0.07	0%	0.0
2011	-0.25	-0.34	1%	0.1
2012	-0.56	-1.00	2%	0.3
2013	-0.70	-1.69	3%	0.5
2014	-0.33	-0.97	2%	0.3
2015	-0.39	-1.40	3%	0.4
2016	-0.56	-1.94	5%	0.6
2017	-0.33	-1.64	4%	0.5
2018	-0.17	-1.00	2%	0.3
2019	-0.30	-1.98	4%	0.6
2020	-0.42	-3.25	9%	0.9
2021	-1.01	-7.19	6%	2.0
2022	-2.06	-18.18	9%	5.3
2023	-0.93	-8.41	9%	2.3
Total				14.2

Source: Author calculations, LCCC, OFGEM

Figure 11 confirms that both STMOE and LTMOE show the impact of wind generation on the electricity price has grown with increasing wind capacity. This is due to two factors: the widening gap in Capture prices between wind and gas (as seen back in Figure 4), and the rising share of wind in the generation mix. The LTMOE is lower because it uses a flexible long-term capacity with a flat long-term marginal cost curve - rather than STMOE, which assumes fixed capacity and rising marginal costs. This Capture Price approach not only avoids the methodological issues of extrapolating marginal cost curves, it gives a more realistic set of results that preserve the profitability of the gas generators.

MOE & Wind Generation Share

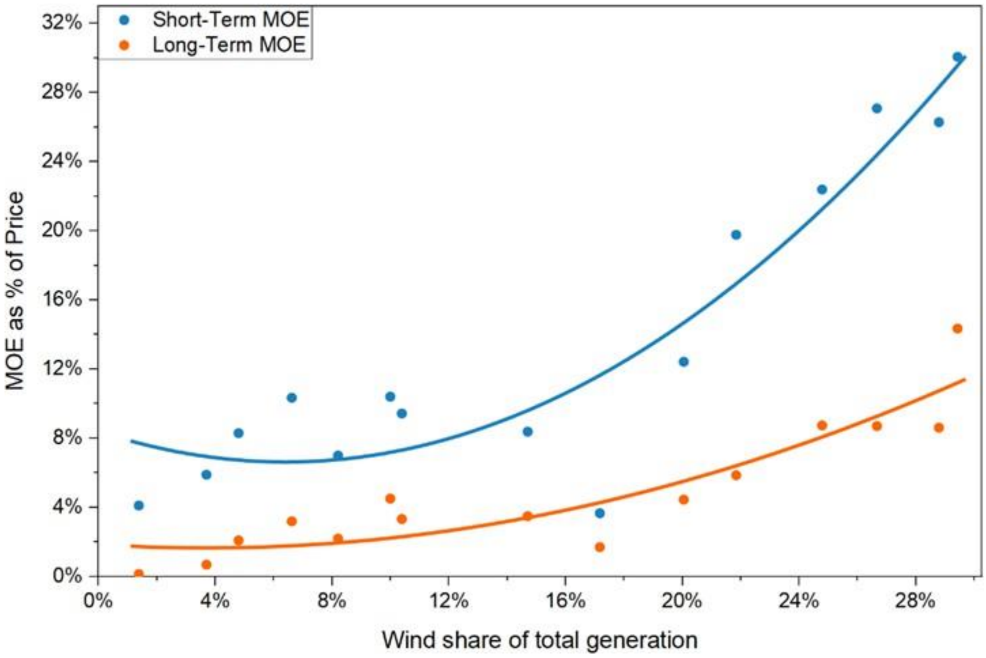

Fig. 11 Scatter plot comparing STMOE & LTMOE to Wind share of total generation

Source: NESO, Author calculations

b) Endogenous Natural Gas price

The move from short-term to long-term MOE is an important step, but it’s not complete for a systemic counterfactual analysis. It is not consistent to allow gas capacity to adjust over time without accounting for how that increased gas demand would impact gas prices. The endogenous gas price model incorporates this and shows increased demand for gas, leading to higher gas prices, as shown in Table 6. As described in Methods we conservatively include a price cap of £10/MMBtu to recognise the exceptional market conditions of 2022. Figure 12 shows that while the model predicts higher gas prices, the impact is much smaller than the £27/MMBtu range seen in natural gas markets over the past decade. This shows that the model results are well within the range of historical supply and demand effects.

Table 6

Gas Price Model Results

	Historic Gas Price	Model Gas Price	Difference	Model Gas Price	Difference
	Europe			cap at 10	cap at 10
	£ / MMBtu	£ / MMBtu	£ / MMBtu	£ / MMBtu	£ / MMBtu
2010	4.3	4.7	0.4	4.7	0.4
2011	5.7	6.6	0.8	6.6	0.8
2012	5.9	7.1	1.2	7.1	1.2
2013	6.7	8.5	1.8	8.5	1.8
2014	4.9	6.4	1.5	6.4	1.5
2015	4.2	6.0	1.8	6.0	1.8
2016	3.3	4.8	1.5	4.8	1.5
2017	4.4	7.0	2.6	7.0	2.6
2018	5.9	9.7	3.8	9.7	3.8
2019	3.5	6.4	2.9	6.4	2.9
2020	2.4	4.8	2.4	4.8	2.4
2021	11.4	22.1	10.7	21.4	10.0
2022	30.0	63.6	33.6	40.0	10.0
2023	10.3	24.2	13.9	20.3	10.0

Source: Energy Institute

Historic & Model Gas Price

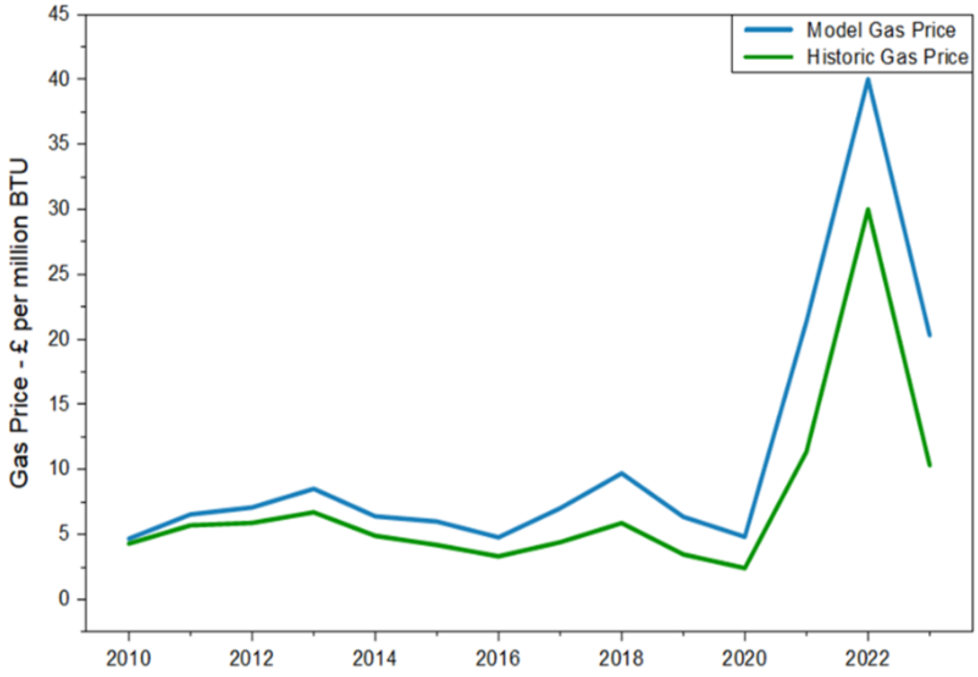

Fig. 12 Comparison between Historic and Model Gas Price

Source: Energy Institute, Author calculations

We can now quantify the value of installed wind capacity to the UK consumer through paying a lower price for their natural gas consumption. Specifically, we calculate the product of total gas UK demand and the price change from the gas model above. As seen in Table 7, the resulting UK savings from 2010 to 2023 amount to £133.3bn, benefiting not only electricity users but also households and industries that consume natural gas directly.

Table 7

Implied UK savings from gas consumption

	(1) Annual Natural Gas Consumption	(2) Endogenous Gas Model Price Impact	(3)=(1)*(2) Savings to UK Consumer
	UK		
	million Btu per year	£ / MMBtu	£ bn
2010	3,545,742,600	0.36	1.29
2011	2,949,067,213	0.84	2.5
2012	2,768,354,982	1.19	3.3
2013	2,747,727,360	1.81	5.0
2014	2,521,998,990	1.50	3.8
2015	2,593,635,682	1.79	4.7
2016	2,876,339,840	1.46	4.2
2017	2,816,236,253	2.61	7.3
2018	2,838,553,178	3.82	10.8
2019	2,803,455,360	2.89	8.1
2020	2,644,695,360	2.41	6.4
2021	2,770,357,496	10.00	27.7
2022	2,537,573,411	10.00	25.4
2023	2,290,307,724	10.00	22.9
Total			133.3

Source: Energy Institute, Author Calculations

Alternative gas price model – LNG-convergence

To test the robustness of our model, we compare this endogenous gas model with a reasonable scenario where UK gas prices simply track global LNG prices - the prevailing market price for incremental gas demand. In effect, the lack of wind generation would have removed the excess supply in the European gas market, removing the 15 years of cheap natural gas enjoyed by UK consumers. As shown in Table 8 and Figure 13, cumulative savings using the LNG-convergence model are significantly higher, reaching £91.3bn from 2010-2020, compared with £57.3bn for the endogenous gas model. This further demonstrates that the results of this paper are conservative and not overly dependent on the specific gas model used.

Table 8

UK Savings – Comparing Endogenous model to LNG - Convergence Model

	(1) Annual Natural Gas Consumption	(2) Endogenous Gas Model	(3)=(1)*(2) Savings to UK Consumer	(4) LNG - Convergence Model	(5)=(1)*(4) Savings to UK Consumer
	UK	Price impact		Price impact	
	million BTu per year	£ / MMBtu	£ bn	£ / MMBtu	£ bn
2010	3,545,742,600	0.36	1.3	2.49	8.8
2011	2,949,067,213	0.84	2.5	3.24	9.5
2012	2,768,354,982	1.19	3.3	4.29	11.9
2013	2,747,727,360	1.81	5.0	3.21	8.8
2014	2,521,998,990	1.50	3.8	4.63	11.7
2015	2,593,635,682	1.79	4.7	2.40	6.2
2016	2,876,339,840	1.46	4.2	1.65	4.8
2017	2,816,236,253	2.61	7.3	1.66	4.7
2018	2,838,553,178	3.82	10.8	1.39	4.0
2019	2,803,455,360	2.89	8.1	4.14	11.6
2020	2,644,695,360	2.41	6.4	3.51	9.3
Total			57.3		91.3

Source: Energy Institute, Author calculations

LNG-convergence & Endogenous Model Gas Price

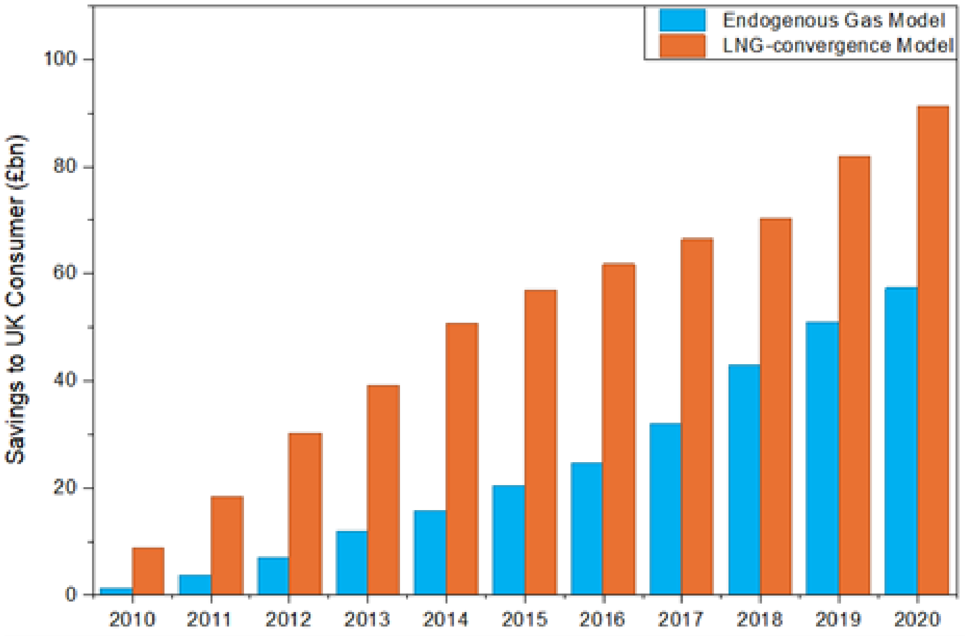

Fig. 13 Comparison between LNG-convergence & Endogenous Gas Price

Source: Energy Institute, Author calculations

Total Financial Impact on UK consumer

Table 9 brings together the full picture, combining the MOE Total Value, gas savings and subsidies. The result is a total net saving of £104bn for UK consumers between 2010 and 2023, reflecting a clear financial benefit for developing wind generation, once the impact on the price of natural gas is included in the model. By contrast, if we were to only consider the Short-Term MOE, as in the majority of the academic literature, the net benefit would appear to be just £0.9bn. This finding not only challenges the widespread belief that wind generation has historically imposed a significant financial burden on the UK, it instead demonstrates that it has consistently delivered substantial financial benefits over time.” To put this into context, this net benefit of £104bn is larger than the £90bn the UK has spent on gas since 2021 as a result of rising prices related to the Russian invasion of Ukraine (ECIU, 2025).

These findings strongly support Ed Miliband’s position that “the answers to security, and affordability, as well as sustainability, all now point in the direction of investing in clean energy”, but disagree with his statement that he “could not have said that in 2008” (Miliband, 2024).

Table 9

Long Term MOE – Endogenous Gas Model Results

	(1) Total value of MOE	(2) Savings to UK Consumer	(3) Total Subsidy	(4)=(1)+(2)-(3) Net
	£ bn	£ bn	£ bn	£ bn
2010	0.0	1.3	0.6	0.7
2011	0.1	2.5	0.8	1.8
2012	0.3	3.3	1.1	2.5
2013	0.5	5.0	1.6	3.9
2014	0.3	3.8	1.8	2.2
2015	0.4	4.7	2.4	2.7
2016	0.6	4.2	2.4	2.4
2017	0.5	7.3	3.3	4.5
2018	0.3	10.8	4.2	6.9
2019	0.6	8.1	4.9	3.8
2020	0.9	6.4	6.0	1.3
2021	2.0	27.7	4.3	25.5
2022	5.3	25.4	3.9	26.7
2023	2.3	22.9	5.9	19.4
Total	14.5	133.3	43.2	104.3

Source: Author Calculations

While wind generation delivers huge savings to UK consumers , the benefits are not uniformly distributed. As shown in Table 10, consumers of electricity pay 100% of subsidies, but receive only 18% of the net financial benefit. Meanwhile, natural gas users, who pay nothing toward wind investment, have enjoyed 82% of the benefit since 2010.

Table 10

Distributed benefits of gas model savings

	(1)	(2)	(3)=(1)*(2)	(4)	(5)	(6)=(3)+(4)-(5)	(7)=(1)-(3)	(8)	(9)=(7)-(8)
			Electricity users				Other gas users		
	Gas model savings	Share of gas used for electricity generation	From gas price impact	MOE - total value	Subsidy paid through bills	Net benefit to electricity users	From gas price impact	Subsidy paid through bills	Net benefit to electricity users
	£bn	%	£bn	£bn	£bn	£bn	£bn	£bn	£bn
2010	1.3	47%	0.6	0.0	0.6	0.0	0.7	-	0.7
2011	2.5	39%	1.0	0.1	0.8	0.3	1.5	-	1.5
2012	3.3	26%	0.8	0.3	1.1	0.1	2.4	-	2.4
2013	5.0	25%	1.2	0.5	1.6	0.2	3.7	-	3.7
2014	3.8	28%	1.1	0.3	1.8	-0.5	2.7	-	2.7
2015	4.7	28%	1.3	0.4	2.4	-0.7	3.4	-	3.4
2016	4.2	42%	1.8	0.6	2.4	-0.1	2.4	-	2.4
2017	7.3	40%	2.9	0.5	3.3	0.1	4.4	-	4.4
2018	10.8	39%	4.2	0.3	4.2	0.3	6.7	-	6.7
2019	8.1	39%	3.2	0.6	4.9	-1.1	4.9	-	4.9
2020	6.4	35%	2.2	0.9	6.0	-2.9	4.2	-	4.2
2021	27.7	38%	10.4	2.0	4.3	8.2	17.3	-	17.3
2022	25.4	38%	9.7	5.3	3.9	11.1	15.6	-	15.6
2023	22.9	32%	7.2	2.3	5.9	3.7	15.7	-	15.7
Total	138.3		41.8	14.2	43.2	12.8	96.4	0	96.4
				% of Net Benefit to Electricity Users		12%	% of Net Benefit to Gas Users		88%

Source: Author calculations, NESO

The results are striking, wind investment delivers enormous positive externalities. The biggest winners are not the investors, wind generation firms or even electricity consumers who foot the bill for subsidies – it is natural gas consumers, who benefit from reduced household and industrial energy bills.

As wind capacity grows, it can be seen as successfully reducing electricity prices, but this does not guarantee profits for the wind generators, as the same effect cannibalises its own market. Lower prices are a benefit for consumers and represent a positive externality where there is no market mechanism to transfer the consumer benefit of lower electricity prices back to the wind generators. This is why the simplistic assessment that the wind industry is a failure or a drag on the UK economy due to its need for government support is so deeply mistaken. It is perfectly possible for the wind industry to be consistently unprofitable without government support yet still deliver a net financial and economic benefit to the country.

Policy implications

The results shown in Table 10 and Figure 14 show the disparity between the beneficiaries of the financial support for wind generation and who pays for it. This has important justice implications for the energy transition as the impact of wind generation support is in effect a huge subsidy to consumers of fossil fuels, being paid for by users of renewable energy. From a fairness perspective it would make more sense to more equally share the costs as well as the benefits by splitting the subsidy costs between electricity and gas bills.

This imbalance, where electricity consumers fund subsidies that primarily benefit gas users, raises critical policy concerns about fairness and alignment with stated goals of transitioning away from the reliance on fossil fuels and towards the electrification of the UK economy.

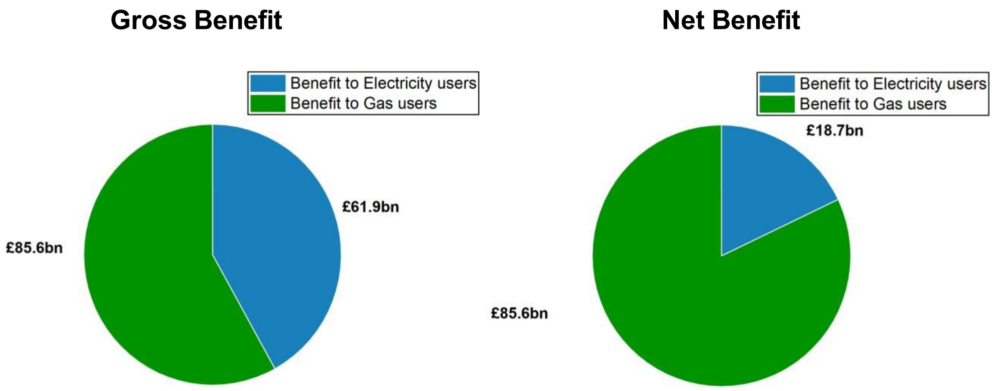

Fig. 14 Gross and Net Benefit to UK Electricity and Gas users

Source: Author calculations

Limits to natural gas price changes

Given the importance of the impact of natural gas prices we should examine if there are any factors which would limit the modelled rise in prices. This step of evaluating a model's applicability to reality is critical but often ignored (Thompson, 2022). We described earlier the issues of using a marginal MOE model to estimate larger changes as the key ceteris paribus assumptions were not realistic. For electricity generation the decision not to invest in wind would have led to a change in behaviour, building gas generators, which materially changes the price of gas. For the gas model the rise in prices could potentially lead to behaviours which would mitigate that rise. The key ones to examine are the potential for new natural gas production, sourcing gas from global markets, substitution to other fossil fuels and demand destruction.

a. New production

We can compare the size of the extra demand to the recent political controversy over new exploration licences in N Sea which was the focus of the Just Stop Oil campaign (JustStopOil, 2025). These licenses had the "potential" to add 600 million boe by 2060 (OEUK, 2024) which even if fully realised would amount to just 4% of current UK production (NSTA, 2025) whereas the extra gas supply required to replace wind generation would be more than double the entire gas production of the UK (Energy Institute, 2025). There is no domestic increase in natural gas production that could come close to meeting the additional gas that would be needed to replace wind generation.

b. Global gas markets

As the EU is an importer of natural gas the additional demand would need to be met from international markets in the form of LNG. The change in the demand-supply dynamic from the additional gas demand would be to move European gas prices closer to international prices as we can see in Figure 15. We saw in Table 8 that this alternative model for gas prices gives a larger impact than the endogenous gas model with a benefit of £91bn as compared to £57bn from 2010-2020.

Gas Prices – Model & Historic & Japan

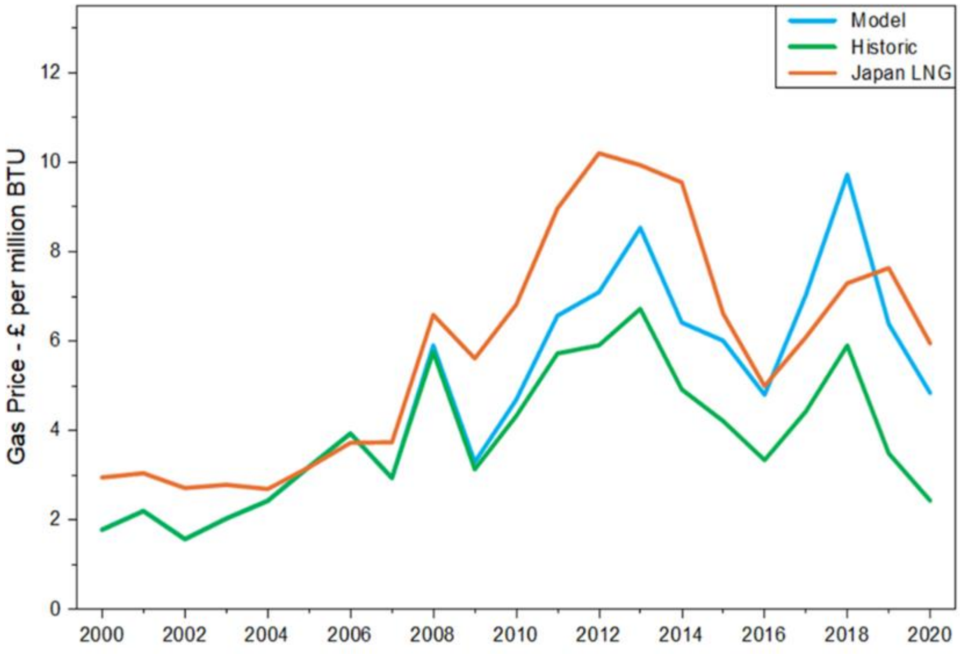

Fig. 15 Model & Historic gas prices from 2000-2020

Source: Energy Institute

We should also recognise the limitations of international gas market arbitrage for a supply shift of the order of 200 mcm per day. In Table 8 we showed that the endogenous gas model was conservative against an alternative model that Europe could source unlimited gas from global LNG markets. However, we can see from 2021 and 2022 that when Europe had a shortage of gas and increased its LNG imports that it could not seamlessly source an unlimited amount of LNG from global markets at a fixed price. Instead, we saw a huge shift in the relative prices in global markets (Asa & Nautwima, 2025; Sim, 2024). We can see in Figure 164 a large rise in Asian LNG prices which doubled in 2022 and in addition European gas prices rose above Asian LNG prices in

2021 and to more than double those LNG prices in 2022. This strongly suggests that the gas model in this paper is highly conservative as a projection of the impact on gas prices in Europe from a demand change of an even larger size than the energy crisis of 2022.

Gas Price – European market & International LNG

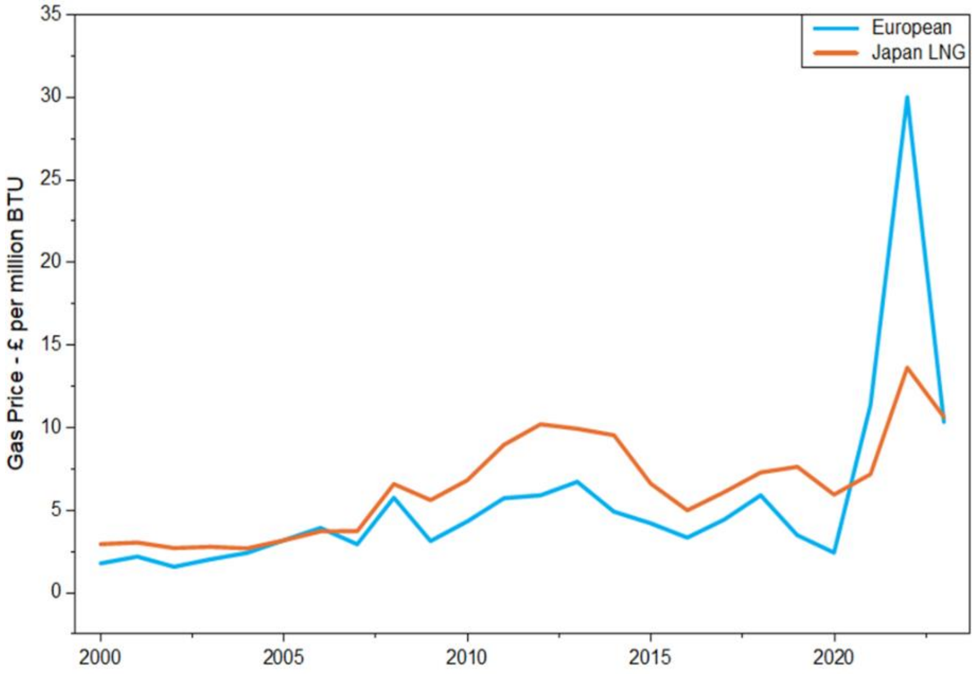

Fig. 16 European Gas Price and International LNG

Source: Energy Institute

c. Other fossil fuel markets

A potential source of limit on price rises is for substitution to other fossil fuels if the relative price of gas makes it expensive. To examine the relationship between gas and oil markets (Hartley et al., 2008) we can begin with the conversion factors for energy content, obtained from the EIA website which is 5.8 MMBtu per barrel for WTI. Looking at the ratio of market in Figure 17, the ratio of oil to gas prices has been consistently far above the energy equivalence line, averaging 11 from 2010-20 compared to an energy equivalence ratio of 5.8. This shows that gas has been consistently cheap relative to oil. For the modelled gas price, with an unchanged oil price, the ratio would average 6.9, still well above the energy equivalence ratio meaning gas prices would need to rise even further for a substitution from gas to oil to be even theoretically attractive. This does not even factor in the extra cost of infrastructure as gas and oil are not fungible in their usage or that any substitution into oil would lead to a higher oil price.

Oil to Gas Ratio

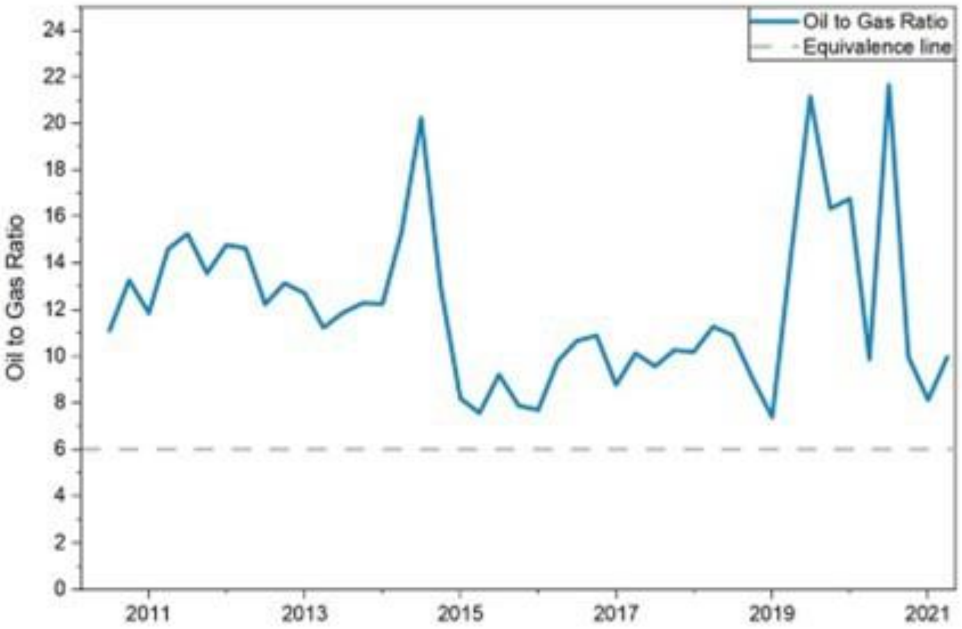

Fig. 17. Oil (Brent – USD per barrel) to Gas (TTF- USD per million btu) ratio with energy equivalence line
Source: Bloomberg

If we look at coal, we also see problems substituting for gas. As shown in Figure 18a, in 2021 and 2022 coal prices rose alongside natural gas prices, with coal prices more than quadrupling in an 18-month period, so we cannot assume an unlimited ability to switch to coal at a constant coal price. Looking at this question empirically, we also note from Figure 18b that coal imports continued their trend decline. There has not been any substitution in Europe recently back into coal despite a ten-fold spike in gas prices from 2021-22 and then sustained high prices since.

European Coal & Gas

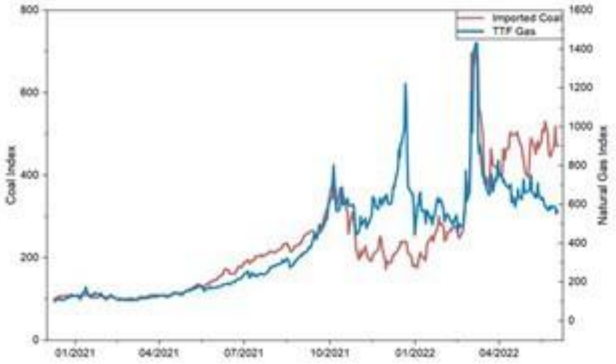

Fig. 18a European imported coal and traded gas
Source: Bloomberg

European Coal Imports

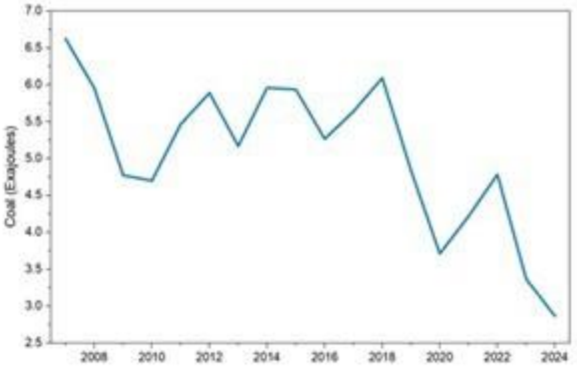

Fig. 18b European Net Coal Imports
Source: Bloomberg

d. Demand destruction

We have clear empirical evidence that when gas prices rise sharply, demand destruction takes place which in turn limits the rise in prices. The rise in gas prices in the energy crisis from £11/MMBtu in 2021 to £30/MMBtu in 2022, led to a fall in gas consumption of 207 mcm per day, which was the primary means of limiting further price rises.

Recognising this factor, we added a cap to the gas price model of a £10/MMBtu, the level of the premium in 2021 before the crisis. It is clear from the above that the modelled rise in gas prices is well below any arbitrage limits from increased production, international gas markets or substitution to other fossil fuels. The potential for demand destruction as a price limitation has been reflected in the £10/MMBtu cap in the gas price model. However, it is important to recognise that while demand destruction may limit prices, it comes with enormous additional economic and social costs as both industry and households are forced to cut back on their energy usage.

Conclusion

This study employs a novel approach to understanding the financial effects of wind generation on the energy market. By looking beyond short-term effects on the energy system of wind energy and the standard Merit Order Effect analysis, the study considers what would happen if wind power had been systemically replaced by gas. Moving from a short-term to long-term model allows the assumption of unchanged capacity to be challenged. A flat long-term marginal cost curve for gas generation can be applied, reducing the Merit Order Effect impact on electricity prices. With the new assumption of new gas capacity, we also needed to relax the assumption of independent natural gas prices, instead taking into account the impact of additional annual demand for natural gas to replace wind generation. The counterfactual scenario of gas rather than wind generation in Europe implies an annual and ongoing increase of demand larger than the reduction in Russian pipeline gas that caused the energy crisis of 2022. We found that the direct financial benefit from 2010-2023 of lower electricity prices was £14.2bn, with an even greater benefit from its impact on lowering natural gas prices of £133.3bn. This combined benefit is far larger than the scale of subsidies in the period of £43.2bn meaning that the net benefit to the UK consumer has been £104.3bn.

This study found that wind generation lowers electricity prices for consumers but especially for wind generators, as they cannibalise their own market. The nature of the wind industry is that their growth damages their own profitability while in turn creating large value for others. This is the opposite of the industrial externalities often assumed, such as the negative externalities from tobacco and sugar, where the industry does not pay for the increased associated healthcare costs. This means that the profitability of wind generators is a flawed measure of the financial value of the sector to the UK. The payments via RO and CfD do not create an industry with excess profits, or prop up an economic and financial drain, they facilitate cheaper energy for UK consumers.

Wind generation is better understood as a public good like roads and schools, where private markets do not build at the nationally optimal level, and so government support is the way to achieve a better outcome for the country overall. There is a large financial benefit to the UK consumer, and we should reframe UK government support as a high-return national investment rather than a subsidy.

References

ACER. (2022). *Acer's final assessment of the eu wholesale electricity market design* (Report). ACER. https://www.acer.europa.eu/sites/default/files/documents/Publications/Final_Assessment_EU_Wholesale_Electricity_Market_Design.pdf

Ajanaku, B. A., & Collins, A. R. (2024). "comparing merit order effects of wind penetration across wholesale electricity markets". *Renewable Energy*, *226*, 120372. https://doi.org/https://doi.org/10.1016/j.renene.2024.120372

Antweiler, W., & Muesgens, F. (2021). On the long-term merit order effect of renewable energies. *Energy Economics*, *99*, 105275. https://doi.org/https://doi.org/10.1016/j.eneco.2021.105275

Asa, A., & Nautwima, J. (2025). Factors influencing natural gas and lng market prices in the global energy economy: A comprehensive review. *11*, 21–33. https://doi.org/10.18775/ijied.1849-7551-7020.2015.111.2003

BNEF. (2025). *Bloombergnef generation database* (Report).

Bode, S., & Groscurth, H.-M. (2006). *Zur wirkung des eeg auf den" strompreis"* (Report). HWWA Discussion Paper.

Cevik, S., & Ninomiya, K. (2023). Chasing the sun and catching the wind: Energy transition and electricity prices in europe. *Journal of Economics and Finance*, *47*. https://doi.org/10.1007/s12197-023-09626-x

Climate Change Committee. (2023). *Delivering a reliable decarbonised power system* (Report). Climate Change Committee. https://www.theccc.org.uk/wp-content/uploads/2023/03/Delivering-a-reliable-decarbonised-power-system.pdf

Clò, S., Cataldi, A., & Zoppoli, P. (2015). The merit-order effect in the italian power market: The impact of solar and wind generation on national wholesale electricity prices. *Energy Policy*, *77*, 79–88. https://doi.org/https://doi.org/10.1016/j.enpol.2014.11.038

Cludius, J., Hermann, H., & Matthes, F. (2013). The merit order effect of wind and photovoltaic electricity generation in germany 2008-2012. *Center for Energy and Environmental Markets. Working Paper. Sydney*.

Dale, L., Milborrow, D., Slark, R., & Strbac, G. (2004). Total cost estimates for large-scale wind scenarios in uk. *Energy Policy*, *32*(17), 1949–1956. https://doi.org/https://doi.org/10.1016/j.enpol.2004.03.012

Denny, E., O'Mahoney, A., & Lannoye, E. (2017). Modelling the impact of wind generation on electricity market prices in ireland: An econometric versus unit commitment approach. *Renewable Energy*, *104*, 109–119. https://doi.org/https://doi.org/10.1016/j.renene.2016.11.003

Do, L. P. C., Lyócsa, Š., & Molnár, P. (2019). Impact of wind and solar production on electricity prices: Quantile regression approach [doi:

10.1080/01605682.2019.1634783]. *Journal of the Operational Research Society*, *70*(10), 1752–1768. https://doi.org/10.1080/01605682.2019.1634783

ECIU. (2025). Russian invasion anniversary: £140 bn gas bill for uk since crisis began. https://eciu.net/media/press-releases/2025/russian-invasion-anniversary-140bn-gas-bill-for-uk-since-crisis-began

Ellersiek, C., & Gnerre, N. (2023). Understanding european natural gas market dynamics: An arch analysis of the relationship between natural gas prices and imports.

Energy Institute. (2025). *Statistical review of world energy* (Report). Energy Institute.

European Wind Energy Association. (2009). *The economics of wind energy*. EWEA.

Filimonova, I. V., Komarova, A. V., Sharma, R., & Novikov, A. Y. (2022). Transformation of international liquefied natural gas markets: New trade routes. *Energy Reports*, *8*, 675–682. https://doi.org/https://doi.org/10.1016/j.egyr.2022.07.069

Gasparella, D., A. Koolen, & Zucker, A. (2023). *The merit order and price-setting dynamics in european electricity markets* (Report No. JRC134300). https://publications.jrc.ec.europa.eu/repository/handle/JRC134300

Gelabert, L., Labandeira, X., & Linares, P. (2011). An ex-post analysis of the effect of renewable and cogeneration on spanish electricity prices. *Energy Economics*, *33*, S59–S65. https://doi.org/10.1016/j.eneco.2011.07.027

Ghorbani Pashakolaie, V., Cotton, M., & Jansen, M. (2024). The co-benefits of offshore wind under the uk renewable obligation scheme: Integrating sustainability in energy policy evaluation. *Energy Policy*, *192*, 114259. https://doi.org/https://doi.org/10.1016/j.enpol.2024.114259

Gil, H. A., Gomez-Quiles, C., & Riquelme, J. (2012). Large-scale wind power integration and wholesale electricity trading benefits: Estimation via an ex post approach. *Energy Policy*, *41*, 849–859. https://doi.org/https://doi.org/10.1016/j.enpol.2011.11.067

Glasson, J., Durning, B., Welch, K., & Olorundami, T. (2022). The local socio-economic impacts of offshore wind farms. *Environmental Impact Assessment Review*, *95*, 106783. https://doi.org/https://doi.org/10.1016/j.eiar.2022.106783

Grimwood, G. G., & Ares, E. (2016). Energy: The renewables obligation. *House of Commons Library*.

Gürtler, M., & Paulsen, T. (2018). The effect of wind and solar power forecasts on day-ahead and intraday electricity prices in germany. *Energy Economics*, *75*, 150–162.

Hagfors, L. I., Paraschiv, F., Molnar, P., & Westgaard, S. (2016). Using quantile regression to analyze the effect of renewables on eex price formation. *Renew. Energy Environ. Sustain.*, *1*, 32. https://doi.org/10.1051/rees/2016036

Halttunen, K., Staffell, I., Slade, R., Green, R., Saint-Drenan, Y.-M., & Jansen, M. (2020). Global assessment of the merit-order effect and revenue cannibalisation for variable renewable energy. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3741232

Hartley, P. R., Medlock, K. B., & Rosthal, J. E. (2008). The relationship of natural gas to oil prices. *The Energy Journal*, *29*(3), 47–65. http://www.jstor.org/stable/41323169

Hauser, P., Schmidt, M., & Möst, D. (2016). Gas markets in flux: Analysis of components and influences for natural gas pricing in europe. *2016 13th International Conference on the European Energy Market (EEM)*, 1–8. https://doi.org/10.1109/EEM.2016.7521359

IEA. (2023). *Outlooks for gas markets and investment* (Report). IEA. https://www.iea.org/reports/outlooks-for-gas-markets-and-investment

IEA. (2024). *Global gas security review 2024* (Report). IEA. https://www.iea.org/reports/global-gas-security-review-2024

Jónsson, T., Pinson, P., & Madsen, H. (2010). On the market impact of wind energy forecasts. *Energy Economics*, *32*(2), 313–320. https://doi.org/https://doi.org/10.1016/j.eneco.2009.10.018

JustStopOil. (2025). Just stop oil faqs. https://juststopoil.org/faqs/

Ketterer, J. C. (2014). The impact of wind power generation on the electricity price in germany. *Energy Economics*, *44*, 270–280. https://doi.org/https://doi.org/10.1016/j.eneco.2014.04.003

Kyritsis, E., Andersson, J., & Serletis, A. (2017). Electricity prices, large-scale renewable integration, and policy implications. *Energy Policy*, *101*, 550–560. https://doi.org/https://doi.org/10.1016/j.enpol.2016.11.014

Lazard. (2025). *Lazard's 2025 lcoe+ report* (Report). Lazard.

Maciejowska, K. (2020). Assessing the impact of renewable energy sources on the electricity price level and variability – a quantile regression approach. *Energy Economics*, *85*, 104532. https://doi.org/https://doi.org/10.1016/j.eneco.2019.104532

Miliband, E. (2024). Keynote speech by ed miliband. *Energy UK conference*. https://www.gov.uk/government/speeches/energy-uk-conference-2024-keynote-speech-by-by-ed-miliband

Mills, A., Wiser, R., Millstein, D., Carvallo, J. P., Gorman, W., Seel, J., & Jeong, S. (2021). The impact of wind, solar, and other factors on the decline in wholesale power prices in the united states. *Applied Energy*, *283*, 116266. https://doi.org/https://doi.org/10.1016/j.apenergy.2020.116266

Moraski, M., J. Qvist, & Spokas, K. (2025). *Beyond lcoe: A systems-oriented perspective for evaluating electricity decarbonization pathways* (Report). Clean Air Task Force. https://www.catf.us/resource/beyond-lcoe/

Neubarth, J., Woll, O., Weber, C., & Gerecht, M. (2006). Beeinflussung der spotmarktpreise durch windstromerzeugung. *Energiewirtschaftliche Tagesfragen*, *56*(7), 42.

Nieuwenhout, F., & Brand, A. (2011). The impact of wind power on day-ahead electricity prices in the netherlands. *2011 8th International Conference on the European Energy Market, EEM 11*. https://doi.org/10.1109/EEM.2011.5953013

Nikhalat-Jahromi, H., Fontes, D. B., & Cochrane, R. A. (2017). Future liquefied natural gas business structure: A review and comparison of oil and liquefied natural gas sectors. *WIREs Energy and Environment*, *6*(4), e240. https://doi.org/https://doi.org/10.1002/wene.240

NordPool. (2022). *2022 annual report* (Report). Nord Pool.

NSTA. (2025). Production and expenditure projections. https://www.nstauthority.co.uk/data-and-insights/insights-and-analysis/production-and-expenditure-projections/

Oestergaard, P., Morthorst, P., Moesgaard, R., & Enevoldsen, S. (2006). Wind energy's significance to the price of power in denmark; vindkraftens betydning for elprisen i danmark.

OEUK. (2024). New oil and gas licences strengthen every sector of the uk. https://oeuk.org.uk/new-oil-and-gas-licences-strengthen-every-sector-of-the-uk/#:~:text=A%20total%20of%2082%20offers%20to%2050,to%202060%2C%20or%20545%20mmboe%20by%202050

O'Mahoney, A., & Denny, E. (2011). The merit order effect of wind generation on the irish electricity market.

Quint, D., & Dahlke, S. (2019). The impact of wind generation on wholesale electricity market prices in the midcontinent independent system operator energy market: An empirical investigation. *Energy*, *169*, 456–466. https://doi.org/https://doi.org/10.1016/j.energy.2018.12.028

Sáenz de Miera, G., del Río González, P., & Vizcaíno, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in spain. *Energy Policy*, *36*(9), 3345–3359. https://doi.org/https://doi.org/10.1016/j.enpol.2008.04.022

Sapio, A. (2019). Greener, more integrated, and less volatile? a quantile regression analysis of italian wholesale electricity prices. *Energy Policy*, *126*, 452–469. https://doi.org/https://doi.org/10.1016/j.enpol.2018.10.017

Sensfuß, F. (2011). Analysen zum merit-order effekt erneuerbarer energien. *Update für das Jahr 2010*.

Sensfuß, F., Ragwitz, M., & Genoese, M. (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in germany. *Energy Policy*, *36*(8), 3086–3094. https://doi.org/https://doi.org/10.1016/j.enpol.2008.03.035

Shao, J., Chen, H., Li, J., & Liu, G. (2022). An evaluation of the consumer-funded renewable obligation scheme in the uk for wind power generation. *Renewable and Sustainable Energy Reviews*, *153*, 111788. https://doi.org/https://doi.org/10.1016/j.rser.2021.111788

Shao, J., Li, J., & Liu, G. (2023). The impacts of consumer-funded renewable support schemes in the uk: From the perspective of consumers or the electricity sector? *Renewable and Sustainable Energy Reviews*, *183*, 113498. https://doi.org/https://doi.org/10.1016/j.rser.2023.113498

Sim, L.-C. (2024). The arab gulf states in the asian energy market: Is the russia-ukraine war a game changer? [doi: 10.1080/01442872.2023.2279986]. *Policy Studies*, *45*(3-4), 633–652. https://doi.org/10.1080/01442872.2023.2279986

Sirin, S. M., & Yilmaz, B. N. (2020). Variable renewable energy technologies in the turkish electricity market: Quantile regression analysis of the merit-order effect. *Energy Policy*, *144*, 111660. https://doi.org/https://doi.org/10.1016/j.enpol.2020.111660

Stern, N., & Stiglitz, J. E. (2023). Climate change and growth. *Industrial and Corporate Change*, *32*(2), 277–303.

Thompson, E. (2022). *Escape from model land: How mathematical models can lead us astray and what we can do about it*. John Murray Press. https://books.google.co.uk/books?id=OJtuEAAAQBAJ

Traber, T., & Kemfert, C. (2011). Gone with the wind?—electricity market prices and incentives to invest in thermal power plants under increasing wind energy supply. *Energy Economics*, *33*(2), 249–256.

UNFCCC. (1998). Kyoto protocol to the united nations framework convention on climate change.

Watson, N., & Bolton, P. (2024). Contracts for difference. *House of Commons Library*. https://researchbriefings.files.parliament.uk/documents/CBP-9871/CBP-9871.pdf

Weber, C., & Woll, O. (2007). *Merit-order-effekte von erneuerbaren energien-zu schön um wahr zu sein?* (Report). EWL Working Paper.

Weigt, H. (2009). Germany’s wind energy: The potential for fossil capacity replacement and cost saving. *Applied Energy*, *86*(10), 1857–1863.

Welisch, M., Ortner, A., & Resch, G. (2016). Assessment of res technology market values and the merit-order effect – an econometric multi-country analysis. *Energy Environment*, *27*(1), 105–121. https://doi.org/10.1177/0958305x16638574

World Energy Council. (2020). World energy trilemma index 2020. *World Energy Council: London, UK*.

Würzburg, K., Labandeira, X., & Linares, P. (2013). Renewable generation and electricity prices: Taking stock and new evidence for germany and austria. *Energy Economics*, *40*, S159–S171. https://doi.org/https://doi.org/10.1016/j.eneco.2013.09.011

Zakeri, B., Staffell, I., Dodds, P. E., Grubb, M., Ekins, P., Jääskeläinen, J., Cross, S., Helin, K., & Castagneto Gissey, G. (2023). The role of natural gas in setting electricity prices in europe. *Energy Reports*, *10*, 2778–2792. https://doi.org/https://doi.org/10.1016/j.egyr.2023.09.069

Zipp, A. (2017). The marketability of variable renewable energy in liberalized electricity markets–an empirical analysis. *Renewable Energy*, *113*, 1111–1121.