The merit order effect of solar power: Consumer and sectoral impacts under the Renewables Obligation and Feed-in Tariff schemes in the United Kingdom

Bill Lee[a], Jinke Li[a,*], Jing Shao[b]
[a] Department of Economics, School of Social Sciences, Swansea University, United Kingdom
[b] University of Wales Trinity Saint David, United Kingdom
** Corresponding author (jinke.li@swansea.ac.uk)*

Abstract

Solar power has become an increasingly important component of the United Kingdom's electricity system, yet its economic impacts remain less well understood than those of wind power. This study examines the merit order effect of solar generation on wholesale electricity prices and evaluates its implications for consumers and the wider electricity sector. Using daily hourly average data from April 2014 to March 2024, the analysis shows that solar generation significantly reduces wholesale electricity prices, although the magnitude of this effect varies across market conditions. In most years, the reduction in electricity expenditure was insufficient to offset the costs of the Renewables Obligation and Feed-in Tariff schemes, leading to net consumer losses. During the 2021–23 energy crisis, however, exceptionally high wholesale prices amplified the price-reducing effect of solar generation, generating substantial consumer gains. Beyond consumer impacts, the study quantifies sector-wide benefits from reduced fossil fuel imports and lower carbon emissions, which remain positive throughout the sample period. A comparison of the two schemes highlights trade-offs in policy design. The RO delivered solar capacity at lower costs and generated larger sector-wide gains, reflecting its emphasis on cost-effectiveness, while the FIT provided greater investment certainty and encouraged broad participation, albeit at higher costs.

Keywords: Solar generation, Merit order effect, Imports of fossil fuels, Carbon emissions, Renewables Obligation, Feed-in Tariff

Q21 - Renewable Resources and Conservation: Demand and Supply • Prices

Q41 - Energy: Demand and Supply • Prices

Q48 - Energy: Government Policy

Q51 - Environmental Economics: Valuation of Environmental Effects

1. Introduction

The transition to a low-carbon electricity system is central to the United Kingdom's commitment to achieving net zero greenhouse gas emissions by 2050.[1] Over recent decades, the rapid expansion of renewable energy has reshaped both the electricity generation mix and the operation of wholesale electricity markets. Wind power accounted for 29.23 per cent of total electricity generation by 2024, while solar generation increased from 0.01 per cent in 2010 to 5.04 per cent in 2024 [1]. Although solar remains smaller than wind, its role is expected to expand substantially, with the Sixth Carbon Budget projecting solar generation to rise from 12.9 TWh in 2020 to 60 TWh by 2035 [2]. Solar power is also closely linked to household and community participation, and only around 5.5 per cent of UK households have installed solar panels, suggesting substantial scope for further uptake [3].

Both solar and wind energy are weather-dependent, and rising generation from these sources can alter net demand patterns and increase the need for flexibility resources [4]. However, solar differs from wind in its temporal characteristics. Solar output follows a predictable daily pattern and exhibits strong seasonal variation, with generation concentrated during daylight hours and peaking in summer. This allows solar generation to reduce wholesale electricity prices during daytime periods by displacing higher-cost marginal generation. Whether these price reductions are sufficient to offset the costs of solar support schemes remains an empirical question.

A defining characteristic of renewable energy sources is the merit order effect, whereby low marginal-cost generation displaces more expensive conventional plant, reducing wholesale electricity prices. This mechanism has been widely documented in electricity markets with increasing renewable penetration and, in some circumstances, can result in negative prices when renewable output exceeds system demand or available flexibility [5, 6]. However, UK evidence has focused mainly on wind power, while empirical evidence on solar generation remains more limited, particularly over longer time horizons and during periods of extreme price volatility. Moreover, existing studies often estimate price effects in isolation, without linking them to consumer gains after accounting for support scheme costs, or to wider sectoral benefits from reduced fossil fuel imports and carbon emissions.

The UK provides a valuable setting for examining these issues because solar deployment was supported mainly through two policy instruments with different objectives: the Renewables Obligation (RO) and the Feed-in Tariff (FIT). The RO was a market-based certificate scheme that placed greater emphasis on cost-effectiveness and market integration, while the FIT provided fixed tariff payments to encourage small-scale and household participation. These differences imply that the two schemes should be assessed in relation to their respective policy objectives rather than through a uniform cost comparison.[2]

---

[1] In the UK, the main electricity market serves Great Britain (England, Wales, and Scotland), which accounted for 97.2 per cent of the UK population in 2021, while Northern Ireland shares an electricity market with Ireland.

[2] Following the closure of the RO and FIT schemes, solar deployment has continued to receive support through

This study examines the impact of solar generation on wholesale electricity prices in the UK using daily hourly average data from April 2014 to March 2024. It makes three contributions. First, it provides evidence on the merit order effect of solar generation in the UK electricity market. Second, it links estimated price effects to consumer gains by comparing reductions in electricity expenditure with solar-attributed RO and FIT costs. Third, it evaluates wider sectoral gains from reduced fossil fuel imports and carbon emissions, while comparing the economic implications of the RO and FIT schemes.

The remainder of the study is organised as follows. Section 2 reviews the literature. Section 3 presents the background. Section 4 describes the data and empirical specification. Section 5 reports the estimation results. Section 6 evaluates consumer and sector-wide benefits, and Section 7 concludes.

2. Literature review

A large body of literature examines the merit order effect of renewable electricity generation, whereby low marginal-cost renewables reduce wholesale electricity prices by displacing fossil fuel-based generation. Empirical evidence has been reported across several liberalised electricity markets, including the UK [7], Germany [8-11], Spain [12, 13], Italy [14, 15], Australia [16, 17], and the United States [18, 19]. These studies generally show that higher wind and solar generation is associated with reductions in wholesale electricity prices, although the magnitude of the effect varies across technologies, market conditions and system characteristics. For the UK, existing evidence has focused mainly on wind power. For example, [7] find that a one GWh increase in hourly wind generation reduces wholesale electricity prices by £1.28/MWh. By contrast, evidence on the price effect of solar generation in the UK remains more limited.

A second stream of literature compares wholesale price reductions from renewable generation with the costs of support schemes. The findings are mixed. Some studies find that the merit order effect can exceed subsidy and balancing costs, generating positive consumer gains [15, 20-22]. However, other studies show that support costs may outweigh price reductions, leading to consumer losses [7, 15, 23, 24]. These contrasting findings suggest that the net consumer impact of renewable support depends on market conditions, policy design and the characteristics of the supported technology.

A third stream of research considers wider economic benefits beyond wholesale price reductions. Renewable generation can reduce fossil fuel imports and lower carbon emissions, creating additional gains for the electricity sector. Evidence from Spain and wider European studies suggests

---

subsequent mechanisms, including Contracts for Difference and the Smart Export Guarantee. However, to date, the scale of capacity supported under these schemes and the associated costs remain limited. As a result, they are not included in the empirical analysis of this study, which focuses on the period during which the RO and FIT schemes played a dominant role in shaping solar deployment in the UK.

that avoided fuel imports and emissions can be substantial [25, 26]. For the UK, [27] argue that such monetary savings should be treated as net gains to the electricity sector rather than offset directly against support costs, because these payments are transferred to renewable generators within the sector. This perspective is particularly relevant, as consumer gains may be negative in some years even when wider sectoral gains remain positive.

Building on these studies, this paper examines the merit order effect of solar generation in the UK and links the estimated price effects to both consumer gains and wider sectoral gains. It also compares the RO and FIT schemes, which supported solar deployment through different policy designs and objectives.

3. Background: UK electricity generation and renewable support schemes

3.1 The evolution of the UK electricity generation mix

As shown in Figure 1, total electricity generation in the UK exhibited a downward trend between 2010 and 2024, declining from 382.07 TWh to 284.95 TWh. This reduction is largely attributable to improvements in energy efficiency, although overall generation is expected to increase in the future as electrification intensifies [28].[3] Over the same period, the most pronounced change was the sharp decline in coal-fired generation, which fell from 107.59 TWh to just 1.90 TWh, alongside a substantial expansion in wind generation from 10.29 TWh to 84.06 TWh, accounting for 29.23 per cent of total generation. Notwithstanding these shifts, natural gas continues to represent the largest source of electricity generation, although its share declined from 45.97 per cent to 30.41 per cent over the period.

With respect to solar power, electricity generation increased markedly from 0.04 TWh to 14.79 TWh, accounting for 5.04 per cent of total generation. At the household level, approximately 5.5 per cent of households currently have solar panels installed [3].[4] Given the recent regulatory changes introducing requirements for solar photovoltaic installation in new homes [29], solar is expected to account for a growing share of the electricity generation mix in the future.

---

[3] Other electricity sources, including oil, natural hydro, pumped storage, battery storage, and wave and tidal power, collectively contributed between 13 TWh and 17 TWh of generation over the period.

[4] Approximately 1.5 million houses have solar panels, out of 28.6 million households.

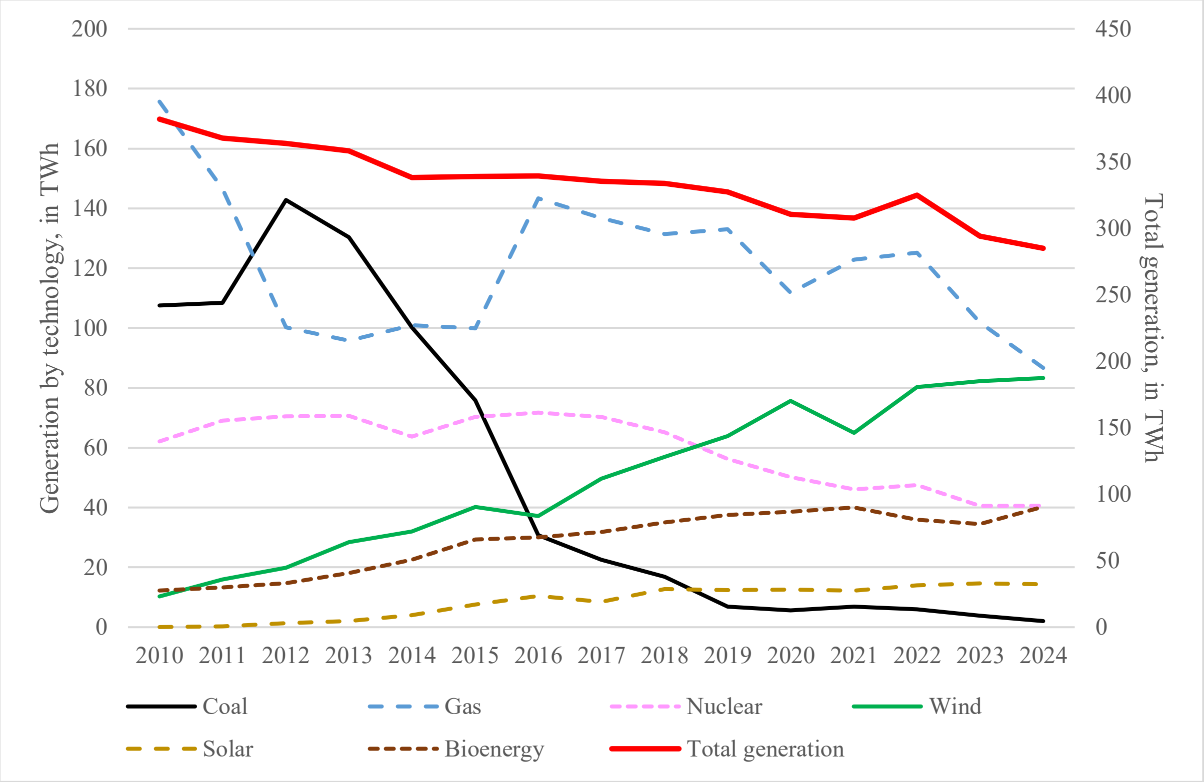

Figure 1. Electricity generation mix by technology in the UK, 2010-2024.

Source: Digest of UK Energy Statistics by DESNZ.

3.2 Temporal characteristics of solar generation

Solar photovoltaic generation exhibits a distinctive temporal profile. Unlike wind generation, which is volatile both within and across days, solar output follows a predictable daylight pattern, rising after sunrise, peaking around midday or early afternoon, and falling to zero after sunset. Its magnitude, however, varies substantially across seasons.

Figures 2 and 3 compare solar generation, wind generation and electricity demand in representative summer and winter periods. They show that solar generation aligns closely with daytime demand, particularly in summer, when solar output can account for around one-third of total demand during peak daylight periods. This pattern is consistent with [30], who note that solar PV reduces apparent demand during daylight hours.

However, solar generation does not coincide with the UK's seasonal demand peak, which typically occurs during winter evenings when heating demand is high and solar output is minimal or absent. This seasonal mismatch is evident in Figure 3, where December solar generation is much lower than in summer and contributes only modestly to total demand.

This temporal profile is important for the empirical analysis. Solar generation is expected to affect wholesale prices mainly during daylight hours, when it can displace higher-cost marginal generation. The analysis therefore distinguishes solar-related hours from non-solar hours when estimating the merit order effect of solar power.

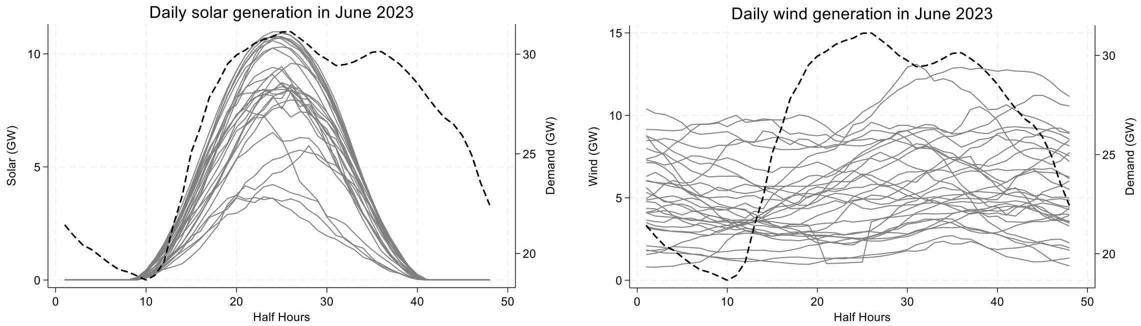

Figure 2. Intra-day electricity demand (dashed line) and renewable generation profiles in June 2023 (summer).

Source: National Energy System Operator.

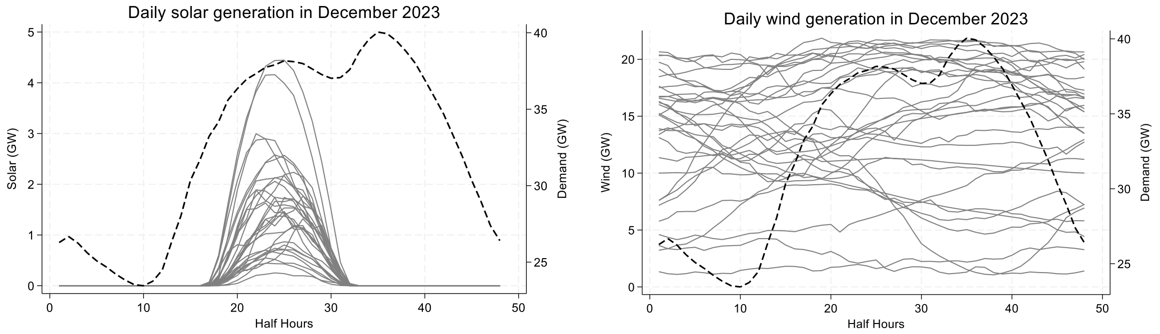

Figure 3. Intra-day electricity demand (dashed line) and renewable generation profiles in December 2023 (winter)

Source: National Energy System Operator.

3.3 The Renewables Obligation and Feed-in Tariff schemes

The expansion of solar capacity in the UK was supported mainly by two policy instruments: the RO and the FIT [31, 32]. As shown in Table 1, the two schemes differed in their target scale, support design and allocation of market risk.

The RO was a market-based certificate scheme that mainly supported larger renewable projects. Accredited generators received certificates for eligible renewable generation, which provided an additional revenue stream alongside the wholesale electricity price. As a result, RO-supported generators remained exposed to wholesale price movements and certificate market conditions. By contrast, the FIT scheme was designed to support small-scale and decentralised renewable generation, particularly domestic and commercial rooftop solar PV. It provided fixed generation and export tariff payments, offering investors greater revenue certainty and lower exposure to wholesale market volatility. This made the FIT particularly attractive to households and small-scale investors, although its more generous and predictable support structure also increased policy costs.

These differences are central to the interpretation of the empirical results. The RO placed greater emphasis on cost-effectiveness and market integration, while the FIT prioritised participation and revenue certainty. Therefore, the two schemes should not be evaluated solely through a uniform cost comparison. Instead, their performance should be assessed in relation to their respective policy objectives. Further details on the institutional design of the RO and FIT schemes are provided in Appendix 1.

Table 1. Key features of the Renewables Obligation (RO) and Feed-in Tariff (FIT) schemes

Feature	Renewables Obligation (RO)	Feed-in Tariff (FIT)
Policy objective	Promote large-scale renewable electricity deployment through a market-based certificate obligation	Encourage small-scale, decentralised renewable generation (≤ 5 MW) by providing revenue certainty
Target technologies	Solar PV, onshore and offshore wind, hydro, biomass, landfill gas, sewage gas, tidal stream and wave energy	Solar PV, small wind, hydro, anaerobic digestion, micro-CHP
Geographical coverage	England & Wales (RO), Scotland (ROS), Northern Ireland (NIRO)	Great Britain (England, Wales, Scotland)
Start date	April 2002 (England & Wales, Scotland); April 2005 (Northern Ireland)	April 2010
Closure to new entrants	March 2017 (with grace periods to March 2019, technology-specific)	March 2019
Support mechanism	Tradable certificates issued per MWh of eligible generation	Fixed generation tariff plus export tariff per kWh generated
Revenue sources for generators	Wholesale electricity price + sale of certificates	Guaranteed tariff payments independent of wholesale market prices
Cost recovery mechanism	Obligation on electricity suppliers; costs passed through to consumers	Levy on electricity suppliers; costs passed through to consumers
Exposure to market price risk	High (certificate prices and wholesale prices fluctuate)	Low (fixed, inflation-linked tariffs)
Policy successor	Contracts for Difference (CfD)	Smart Export Guarantee (SEG)

3.4 Solar capacity expansion and policy costs

Figure 4 summarises the evolution of solar capacity and the corresponding subsidy costs under the RO and FIT schemes. Solar capacity expanded substantially under both schemes, but with different cost profiles. By 2023–24, the RO supported 5,782 MW of accredited solar capacity, with approximately £595.10 million of scheme costs attributed to solar generation. In the same year, the FIT supported 5,149 MW of solar capacity, with estimated solar-attributed costs of £906.28 million.

This comparison suggests that the RO delivered solar capacity at lower attributed policy cost, reflecting its stronger emphasis on market-based support and cost-effectiveness. By contrast, the FIT provided more generous and predictable support, which encouraged household and small-scale participation but resulted in higher attributed costs. Further details on the cost-attribution method and supporting evidence on scheme transfers are provided in Appendix 2.

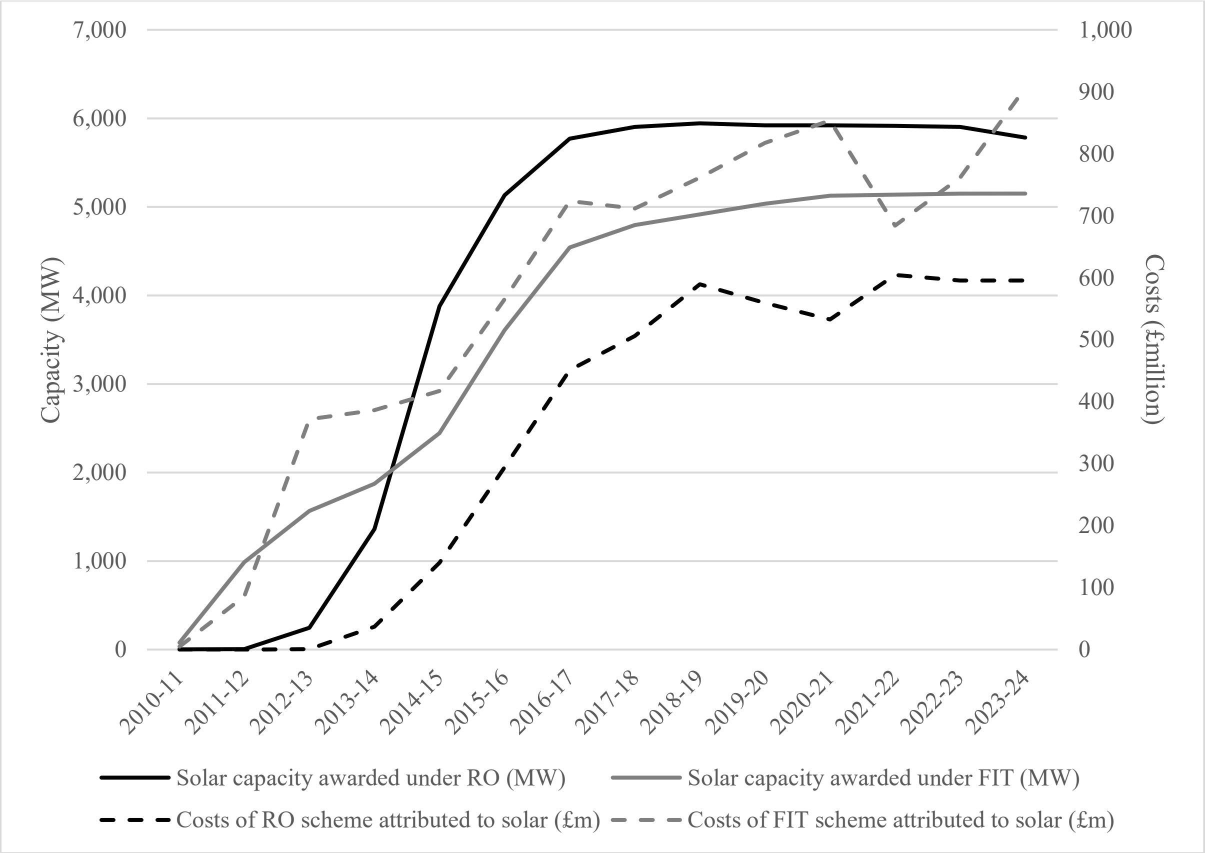

Figure 4. Solar capacity deployment and associated subsidy costs under the RO and FIT schemes

Source: RO annual reports and FIT annual reports.

4. Data and model specification

4.1 Data

This section describes the dataset covering the period from 1 April 2014 to 31 March 2024, comprising 3,653 days. The Market Index Price (MIP), obtained from Elexon, is used as the dependent variable to represent the wholesale electricity price in Great Britain [33]. Reported at half-hourly intervals, the MIP is calculated as the weighted average price of electricity traded on the intraday market, which enables continuous trading for same-day delivery.

Four system-related explanatory variables are included: electricity demand, wind generation, solar generation, and intraday trading volume, all sourced from the National Energy System Operator [34]. First, electricity demand is measured as the sum of national demand, which is recorded by meters connected to the transmission system, and estimated embedded wind and solar generation connected to the low voltage regional electricity networks. Second, wind generation is measured as the combined output of wind farms connected to the transmission network and estimated embedded wind generation. Third, solar generation is measured using estimated embedded output only. These embedded values are estimated by NESO using data on installed capacity and location, together with weather conditions such as wind speed and solar radiation. Fourth, intraday trading volume is included to control for market tightness.

Following the literature [15, 35], the half-hourly data are aggregated into daily hourly averages to reduce noise and highlight underlying trends. A previous study on the UK focusing on the impact of wind generation by [7] calculated daily hourly average solar generation over a 24-hour period. However, since solar generation does not occur at night, the daily hourly average solar generation is mechanically low and may understate the effective contribution of solar power during generating hours.

Therefore, to address this limitation, this study focuses on daytime hours when examining the impact of solar generation on electricity prices. Daylight hours are defined as periods with non-zero solar generation, which are classified as solar-related hours, while periods with zero solar generation are classified as non-solar-related hours. Because total daily solar generation is unchanged but is distributed over fewer hours, the resulting daily hourly average solar value is substantially higher than that calculated over a 24-hour period, whereas other variables such as electricity demand and wind generation remain broadly comparable.

This study also includes daily data on fossil fuel and carbon emission costs. Natural gas prices, measured in pence per therm, are obtained from the National Balancing Point, which serves as the principal gas trading hub in the UK. Coal prices, measured in US dollars per tonne, are sourced from the API2 index, the benchmark index for coal traded in the European market. Carbon prices, expressed in euros per tonne, are derived from the EU Emissions Trading System, under which power generators are required to surrender allowances for carbon emissions, increasing the marginal cost of fossil fuel-based electricity generation. In addition to carbon costs under the EU ETS, the Carbon Price Support was introduced in April 2013 as a supplementary tax on fossil fuel generators in the UK.[5] For consistency, all prices are converted into British pounds using daily exchange rates.[6]

Table 2. Descriptive statistics of key variables

	Solar hours				Non-solar hours	All hours	Summer	Winter
Variables	Mean	Std.Dev.	Min	Max	Mean	Mean	Mean	Mean
Market index price (£/MWh)	73.49	67.15	-19.06	834.45	68.29	70.62	70.89	80.99
Electricity demand (GWh)	35.38	5.36	23.44	50.60	28.78	32.08	30.90	40.60
Wind generation (GWh)	6.34	4.47	0.24	21.33	6.09	6.21	4.33	8.60
Solar generation (GWh)	2.22	1.25	0.07	5.73	0.00	1.22	2.82	1.30
Trading volume (GWh)	2.16	0.98	0.00	6.62	1.72	1.95	1.88	2.42
Gas price (pence/therm)	71.28	67.04	8.50	570.00	71.28	71.28	67.30	80.53

---

[5] Following the UK's withdrawal from the European Union, participation in the EU ETS ended on 31 December 2020, and the UK ETS was introduced from 1 January 2021. Given the close co-movement between monthly prices under the EU ETS and the UK ETS, daily EU ETS prices are used as a proxy for carbon costs in this study after January 2021 [36].

[6] Where price observations are unavailable for weekends, Saturday and Sunday values are assumed to be equal to those observed on the preceding Friday in order to maintain a continuous daily series.

Coal price (£/tonne)	78.42	61.82	30.11	341.10	78.42	78.42	82.12	71.55
Carbon price with CPS (£/tonne)	45.21	26.41	13.44	103.67	45.21	45.21	44.92	46.66

Table 2 provides a summary of the variables used in this analysis and reports their descriptive statistics.[7] These statistics offer an overview of the central tendency and variability of wholesale price, demand, generation, and costs variables, thereby illustrating the key characteristics of the dataset over the sample period. Table 2 includes statistics reported separately for solar hours, non-solar hours, and all hours in order to capture daily load variation, as well as for summer and winter to account for seasonal variations. In particular, based on solar hours only, the average daily hourly solar generation is 2.22 GWh, which is nearly double the corresponding average calculated over a 24-hour period.

To assess the time-series properties of the data, Augmented Dickey-Fuller tests were conducted for the main variables, with detailed results reported in Appendix 4. Most variables reject the null hypothesis of a unit root, while carbon prices show stronger time-dependent behaviour. The empirical specification therefore includes year, month and weekday fixed effects to absorb common temporal shocks and deterministic time patterns.

4.2 Model specification

The dependent variable in this study is the daily average hourly wholesale electricity price (*ep*). The first independent variable is electricity demand (*ed*), measured as the daily average hourly level of demand. Electricity consumption is assumed to be price inelastic and is therefore treated as an exogenous variable in the model. The other independent variables include wind generation (*wind*) and solar generation (*solar*), which are generally considered to be exogenous because they depend on weather conditions. In addition, intraday market trading volume (*vol*) is included to control for market conditions. To control for variations in fuel costs and carbon pricing, three additional explanatory variables are included: the gas price (*gasp*), the coal price (*coalp*), and the carbon price with Carbon Price Support (*carbonps*).

To capture seasonal and temporal variations, a set of time fixed effect variables is included in the model. These effects comprise year fixed effects D_t^y to account for longer-term market developments, month fixed effects D_t^m to reflect seasonal patterns in electricity consumption, and day-of-the-week fixed effects D_t^w, defined for each day from Monday to Sunday, to capture intra-week variation in demand.

The baseline model is defined as follows:

$$\begin{gathered} ep_t = \beta_0 + \beta_1 \cdot ed_t + \beta_2 \cdot wind_t + \beta_3 \cdot solar_t + \beta_4 \cdot vol_t \\ +\beta_5 \cdot gasp_t + \beta_6 \cdot coalp_t + \beta_7 \cdot carbonps_t + \gamma^y D_t^y + \gamma^m D_t^m + \gamma^w D_t^w + \varepsilon_t \qquad (1) \end{gathered}$$

where t represents daily intervals.

---

[7] Annual statistics are reported in Appendix 3.

Furthermore, to examine whether the impact of solar generation on electricity prices differs across seasons, this study considers an alternative specification that introduces interaction terms between solar generation and quarter dummies, specified as follows:

$$ep_t = \beta_0 + \beta_1 \cdot ed_t + \beta_2 \cdot wind_t + \beta_3 \cdot solar_t + \delta^q \cdot \left(solar_t \cdot D_t^q\right) + \beta_4 \cdot vol_t$$

$$+\beta_5 \cdot gasp_t + \beta_6 \cdot coalp_t + \beta_7 \cdot carbonps_t + \gamma^y D_t^y + \gamma^q D_t^q + \gamma^w D_t^w + \varepsilon_t \qquad (2)$$

The coefficient β_3 captures the marginal price effect of solar generation in the reference quarter, Summer, while the elements of δ^q measure deviations from this baseline across other quarters. In this specification, month fixed effects are excluded and replaced by quarter fixed effects D^q when analysing seasonal heterogeneity. This is required because quarter indicators are linear combinations of month indicators, and including both sets of fixed effects would induce perfect multicollinearity.

As renewable generation capacity has expanded over time, its impact on electricity prices may vary across different years. To examine this potential variation, Equation (1) is estimated separately for each year in the dataset, thereby allowing the identification of year-specific effects.

To ensure the reliability of the estimation results, statistical tests for heteroscedasticity and serial correlation are conducted. The Breusch-Pagan test is used to detect heteroscedasticity in the residuals, and the results indicate its presence, implying that a standard ordinary least squares approach may yield inefficient estimates. The Durbin-Watson test is then applied to assess serial correlation, confirming the presence of first-order autocorrelation and indicating that the OLS residuals are not independently distributed over time.

To address these issues, following [15], it is assumed that the residuals follow a first-order autoregressive process, AR(1), expressed as $\varepsilon_t = \rho\varepsilon_{t-1} + \omega_t$, where $|\rho| < 1$ and ω_t represents white noise. The model is subsequently estimated using the Prais-Winsten estimator with robust standard errors, which accounts for first-order serial correlation in the error term and yields inference that is robust to heteroscedasticity.

5. Estimation results

5.1 Baseline estimation results

The estimation results are reported in Table 3. The results in Column 1 are based on solar-related hours with non-zero solar generation. The coefficient for electricity demand is positive and statistically significant, indicating that a marginal increase of one GWh in demand leads to an increase of £1.51 per MWh in wholesale electricity prices. This finding is consistent with expectations, as higher demand typically requires the dispatch of more expensive generation units, thereby raising prices. Renewable energy sources demonstrate a pronounced merit order effect, whereby low-cost renewable generation displaces more expensive fossil fuel-based electricity. The coefficient for solar generation is negative and statistically significant, showing that a one GWh increase in solar output reduces wholesale electricity prices by £3.99 per MWh. This effect is larger than the corresponding impact of wind generation, which is estimated at £2.87 per MWh. The larger price effect of solar compared with wind can be attributed to solar generation's coincidence with peak demand periods on a daily basis, during which it displaces higher-cost marginal generators.

Results for non-solar hours are listed in Column 2. The impact of demand is stronger when there is no solar generation, with prices increasing by £2.42 per MWh for a one GWh increase in demand. This reflects the fact that the presence of solar generation during daylight hours helps to moderate the impact of demand on prices. This also implies that, in a system with a higher volume of solar capacity and reduced reliance on other fuel sources such as gas, the impact of rising demand on electricity prices may become larger during periods when solar is not operational. This raises concerns regarding energy security and provides evidence for the need for energy storage and other forms of flexibility.

For comparison, the results based on all hours are illustrated in Column 3. Although the estimated solar coefficients are similar across the solar hours and all hours specifications, the solar hours estimates are more appropriate for interpreting the marginal price effect of solar generation. Solar power is produced only during daylight hours, and restricting the sample to periods with non-zero solar output aligns the regression with the economic margin at which solar generation competes in the merit order. The similarity of the coefficients across specifications indicates that the results are robust to sample definition, while estimates from solar hours provide a more conceptually consistent basis for the subsequent calculations of gains to consumers.

Table 3. Prais-Winsten estimation results for wholesale electricity prices

	(1) Solar hours	(2) Non-solar hours	(3) All hours	(4) Solar hours with interaction terms
Electricity demand	1.514***	2.418***	1.870***	0.767***
	(0.267)	(0.291)	(0.272)	(0.242)
Wind generation	-2.873***	-3.101***	-3.016***	-2.941***
	(0.165)	(0.166)	(0.159)	(0.171)
Solar generation	-3.989***		-3.993***	-4.062***
	(0.564)		(0.808)	(0.746)
Trading volume	5.555***	4.972***	5.446***	5.045***
	(1.080)	(0.991)	(1.113)	(1.054)
Gas price	0.731***	0.606***	0.655***	0.736***
	(0.0345)	(0.0285)	(0.0294)	(0.0352)
Coal price	0.0877**	0.162***	0.143***	0.0862**
	(0.0392)	(0.0332)	(0.0351)	(0.0407)
Carbon price with CPS	0.289**	0.473***	0.362***	0.254**
	(0.119)	(0.105)	(0.105)	(0.119)
Solar generation* Spring dummy				0.0183
				(0.829)
Solar generation* Autumn dummy				0.371
				(1.109)

Solar generation* Winter dummy				0.432
				(1.029)
Constant	-59.90***	-86.19***	-70.35***	-20.18**
	(13.01)	(11.41)	(11.77)	(9.230)
Observations	3,653	3,653	3,653	3,653
R-squared	0.820	0.845	0.838	0.811
FE (year, month, weekday)	Yes	Yes	Yes	
FE (year, quarter, weekday)				Yes

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

To examine seasonal heterogeneity in the impact of solar generation, Column 4 reports the estimation results from Equation (2), which includes interaction terms between solar generation and quarter dummies. With summer used as the reference quarter, the coefficient on solar generation captures the summer-specific effect and indicates a statistically significant price-reducing impact of £4.062 per MWh. The coefficients on the interaction terms are positive, suggesting that the price-reducing effect of solar generation is weaker in spring, autumn, and winter relative to summer. However, none of these interaction terms is statistically significant, indicating that the differences across seasons are not statistically significant.

5.2 Time variation in the price effects of solar generation

The marginal impact of solar generation on wholesale electricity prices varies substantially across years, indicating that its value depends on prevailing market conditions [37]. To capture this variation, Equation (1) is estimated separately for each financial year, and Figure 5 presents the resulting coefficients for electricity demand, wind generation and solar generation.

The estimated price-reducing effect of solar generation ranges from approximately £1.80/MWh to £9.27/MWh, with all estimates statistically significant at the 5 per cent level.[8] The effect is larger in years with higher wholesale electricity prices and more expensive marginal generation. In these conditions, additional solar output displaces higher-cost fossil fuel generation, producing a stronger merit order effect. By contrast, when fuel costs and wholesale prices are lower, the displacement value of solar generation is more limited.

These year-specific estimates provide the basis for the consumer and sectoral gain calculations in Section 6. By allowing the solar price effect to vary over time, the analysis avoids imposing a single average effect across different market regimes.

---

[8] Full estimation results are reported in Appendix 5.

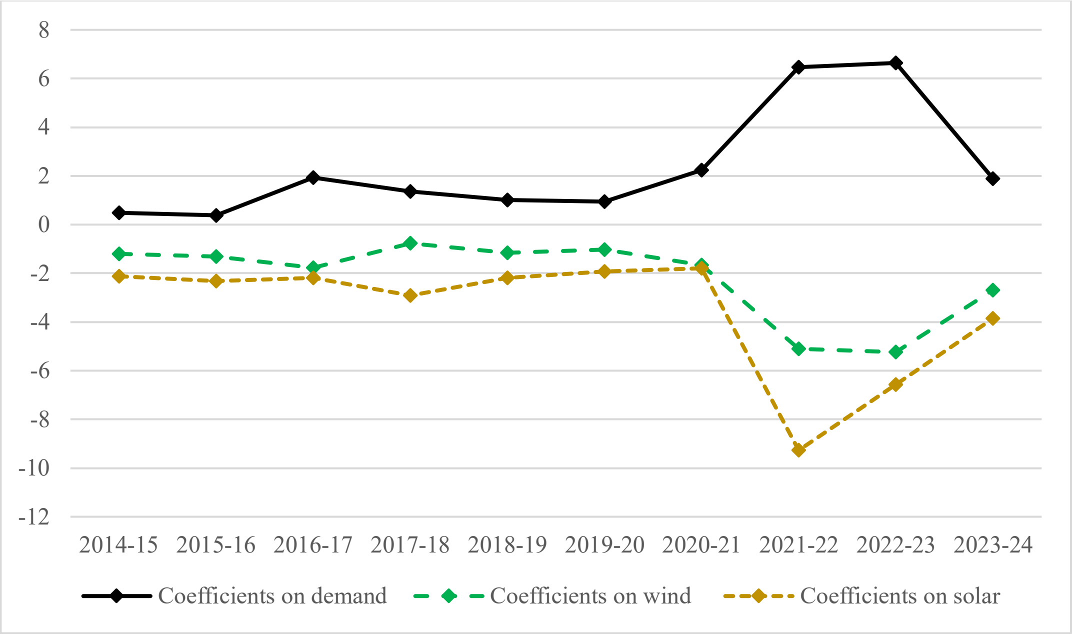

Figure 5. Year-specific marginal price effects of electricity demand, wind generation, and solar generation

5.3 Solar generation during the 2021-23 energy crisis

The large coefficients estimated for solar and wind generation in 2021–22 and 2022–23 coincide with severe disruption in European energy markets. Average wholesale electricity prices rose to £153.28/MWh in 2021–22 and £189.82/MWh in 2022–23, compared with £43.15/MWh in 2020–21. This increase was driven mainly by rising gas prices, reflecting post-pandemic demand recovery, constrained gas supply and geopolitical tensions following the Russia–Ukraine conflict.

Under these conditions, additional solar output displaced high-cost gas-fired generation and produced a much larger merit order effect than in normal market conditions. This explains why the estimated marginal price impact of solar generation exceeded £9/MWh in 2021–22, far above the long-run average.

These findings suggest that renewable generation can provide greater economic value during periods of extreme price stress by reducing reliance on marginal fossil fuel generation. This is important for the evaluation in Section 6, where the larger price effects during the energy crisis translate into substantial consumer gains that outweigh the costs of support schemes.

6. Discussion

6.1 Gains to consumers

Solar generation reduces wholesale electricity prices through the merit order effect, but the costs of support schemes are ultimately recovered from consumers through electricity bills. To assess the consumer impact, the estimated reduction in electricity expenditure is compared with the solar-attributed costs of the RO and FIT schemes. Solar generation under each scheme is estimated from installed capacity and annual solar load factors. Since solar output is concentrated during daylight periods, annual generation is converted into average hourly generation using approximately 13 solar-related hours per day. Further details are provided in Appendix 6.

Table 4 reports the estimated gains to consumers under the RO scheme. RO-supported solar generation increased from 2,507 GWh in 2014–15 to 5,539 GWh in 2023–24, while average hourly solar generation increased from 0.53 GWh to 1.17 GWh. Applying the estimated marginal price effects to electricity consumption during solar-related hours gives annual expenditure reductions ranging from £184.40 million to £1.13 billion.

Consumer gains are calculated by comparing these expenditure reductions with the solar-attributed costs of the RO scheme. Before the energy crisis, the results were mixed. Consumer gains were negative in 2019–20 and 2020–21, at -£210.83 million and -£238.79 million, respectively. However, gains became strongly positive during the energy crisis, reaching £896.86 million in 2021–22 and £528.27 million in 2022–23. This reflects the much stronger price-reducing effect of solar generation when wholesale electricity prices were exceptionally high, and consequently, solar generation led to substantial reductions in electricity expenditure that exceeded the associated subsidy costs.

Table 5 reports the corresponding estimates for the FIT scheme. FIT-supported solar generation increased from 2,067 GWh in 2014–15 to 4,881 GWh in 2023–24, while average hourly solar generation increased from 0.44 GWh to 1.03 GWh. The estimated reductions in electricity expenditure range from £152.05 million to £1.30 billion.

In most pre-crisis years, the FIT scheme generated larger consumer losses than the RO scheme because its subsidy costs were higher. Losses reached £525.08 million in 2019–20 and £600.07 million in 2020–21. However, as with the RO scheme, FIT-related consumer gains became positive during the energy crisis, reaching £617.10 million in 2021–22 and £216.37 million in 2022–23. Overall, the results show that solar support did not consistently generate positive consumer gains under normal market conditions, but it provided substantial consumer benefits when wholesale electricity prices were unusually high.

Table 4. Gains to consumers under the RO scheme

Financial year	(1) Solar generation under RO (GWh)	(2)=(1)/(365*13) Average hourly solar generation under RO (GWh)	(3) Estimated marginal impact of one GWh solar on the price (£/MWh)	(4)=(2)*(3) Total impact on price (£/MWh)	(5) Electricity consumption in solar-related hours (GWh)	(6)=(4)*(5) Total reduction in expenditure (£ million)	(7) Costs of RO attributed to solar (£ millions)	(8) Gain/loss to consumers via RO (£ millions)
2014-15	2,507	0.53	-2.13	-1.13	163,848	184.40	140.44	43.96
2015-16	4,488	0.95	-2.32	-2.20	162,532	357.24	294.04	63.21
2016-17	5,254	1.11	-2.18	-2.41	159,034	383.73	450.67	-66.94
2017-18	5,420	1.14	-2.92	-3.33	158,781	529.43	504.31	25.12
2018-19	5,811	1.22	-2.19	-2.68	156,418	418.92	586.98	-168.07
2019-20	5,582	1.18	-1.91	-2.25	154,655	348.22	559.05	-210.83
2020-21	5,468	1.15	-1.80	-2.07	142,935	295.82	534.60	-238.79
2021-22	5,149	1.09	-9.27	-10.06	149,253	1,501.31	604.45	896.86
2022-23	5,727	1.21	-6.58	-7.94	141,572	1,123.63	595.36	528.27
2023-24	5,539	1.17	-3.85	-4.50	140,098	629.81	595.10	34.72

Sources: Authors' calculations based on estimation results and data from RO annual reports, DESNZ, and NESO.

Table 5. Gains to consumers under the FIT scheme

Financial year	(1) Solar generation under FIT (GWh)	(2)=(1)/(365*13) Average hourly solar generation under FIT (GWh)	(3) Estimated marginal impact of one GWh solar on the price (£/MWh)	(4)=(2)*(3) Total impact on price (£/MWh)	(5) Electricity consumption in solar-related hours (GWh)	(6)=(4)*(5) Total reduction in expenditure (£ million)	(7) Costs of FIT attributed to solar (£ millions)	(8) Gain/loss to consumers via FIT (£ millions)
2014-15	2,067	0.44	-2.13	-0.93	163,848	152.05	417.19	-265.15
2015-16	3,016	0.64	-2.32	-1.48	162,532	240.09	564.96	-324.87
2016-17	3,926	0.83	-2.18	-1.80	159,034	286.72	723.86	-437.13
2017-18	4,333	0.91	-2.92	-2.67	158,781	423.27	711.61	-288.34
2018-19	4,764	1.00	-2.19	-2.20	156,418	343.46	761.54	-418.09
2019-20	4,682	0.99	-1.91	-1.89	154,655	292.11	817.19	-525.08
2020-21	4,692	0.99	-1.80	-1.78	142,935	253.84	853.92	-600.07
2021-22	4,464	0.94	-9.27	-8.72	149,253	1,301.56	684.46	617.10
2022-23	4,983	1.05	-6.58	-6.91	141,572	977.64	761.28	216.37
2023-24	4,881	1.03	-3.85	-3.96	140,098	554.96	906.28	-351.31

Sources: Authors' calculations based on estimation results and data from FIT annual reports, DESNZ, and NESO.

6.2 Net gain to the electricity sector

Evaluating solar generation solely from the consumer perspective provides only a partial assessment. Following [7], this study also considers the wider net gain to the electricity sector, where benefits arise from reduced fossil fuel imports and lower carbon emissions. Support costs are treated as transfers within the electricity sector, while avoided fuel and carbon costs represent sector-wide gains.

The calculation assumes that solar generation primarily displaces coal-fired generation, consistent with the pronounced decline in coal generation shown in Figure 1. Solar generation reduces the need for imported fossil fuels and lowers emissions from conventional generators. Avoided coal consumption is calculated using the [38] conversion factor of 0.513 tonnes of coal per MWh of coal-fired electricity. Avoided emissions are calculated using an emissions factor of 0.936 kg CO_2e per kWh for coal-fired generation [28, 39]. The resulting reductions are monetised using annual coal and carbon prices.

Tables 6 and 7 report the estimated sector-wide gains from solar generation under the RO and FIT schemes. Under the RO scheme, solar generation produced consistent positive net gains throughout the sample period. These gains ranged from £68.4 million in 2014–15 to £1.04 billion in 2022–23. The large gain in 2022–23 reflected both high coal prices and elevated carbon prices. In that year, RO-supported solar generation reached 5,727 GWh, implying avoided coal imports of 2.94 million tonnes and avoided emissions of 5.36 million tonnes of CO_2e.

The FIT scheme generated similar positive sector-wide benefits, although the gains were smaller because FIT-supported solar generation was lower than RO-supported generation. As shown in Table 7, sector-wide gains under the FIT ranged from £56.4 million in 2014–15 to approximately £0.90 billion in 2022–23. In 2022–23, FIT-supported solar generation reached 4,983 GWh, implying avoided coal consumption of 2.56 million tonnes and avoided emissions of 4.66 million tonnes of CO_2e.

Overall, the results show that solar generation created positive sector-wide gains under both schemes, even in years when consumers experienced losses after accounting for support costs. This suggests the importance of evaluating renewable support policies from a system-wide perspective, rather than focusing solely on consumer gains. The RO generated larger sector-wide gains than the FIT, mainly because it supported a larger volume of solar generation at lower attributed policy cost.

Table 6. Avoided costs from fuel imports and carbon emissions from solar generation under the RO scheme

	(1)	(2)=(1)*0.513	(3)	(4)=(2)*(3)	(5)=(1)*0.936	(6)	(7)=(5)*(6)
Financial year	Solar generation under RO (GWh)	Avoided usage of coal, 0.513 t/MWh (million tonnes)	Coal prices, annual average (£/tonne)	Avoided costs from fewer coal imports (£ million)	Avoided GHG emissions, 0.936 kg CO_2e /kWh (million tonnes)	Carbon prices, annual average (£/tonne)	Avoided costs from reduced emissions (£ million)
2014-15	2,507	1.29	43.87	56.42	2.35	5.11	12.00
2015-16	4,488	2.30	34.98	80.54	4.20	5.16	21.69
2016-17	5,254	2.70	53.03	142.95	4.92	4.25	20.89
2017-18	5,420	2.78	64.58	179.56	5.07	7.78	39.49
2018-19	5,811	2.98	68.05	202.85	5.44	18.63	101.31
2019-20	5,582	2.86	43.15	123.57	5.22	21.05	110.00
2020-21	5,468	2.80	41.71	116.98	5.12	26.26	134.41
2021-22	5,149	2.64	117.76	311.04	4.82	54.73	263.77
2022-23	5,727	2.94	223.86	657.68	5.36	70.89	380.02
2023-24	5,539	2.84	93.35	265.25	5.18	66.60	345.27

Sources: Authors’ calculations based on estimation results and data from RO annual reports, DESNZ, NESO, and Datastream.

Table 7. Avoided costs from fuel imports and carbon emissions from solar generation under the FIT scheme

	(1)	(2)=(1)*0.513	(3)	(4)=(2)*(3)	(5)=(1)*0.936	(6)	(7)=(5)*(6)
Financial year	Solar generation under FIT (GWh)	Avoided usage of coal, 0.513 t/MWh (million tonnes)	Coal prices, annual average (£/tonne)	Avoided costs from fewer coal imports (£ million)	Avoided GHG emissions, 0.936 kg CO_2e /kWh (million tonnes)	Carbon prices, annual average (£/tonne)	Avoided costs from reduced emissions (£ million)
2014-15	2,067	1.06	43.87	46.52	1.93	5.11	9.89
2015-16	3,016	1.55	34.98	54.12	2.82	5.16	14.58
2016-17	3,926	2.01	53.03	106.81	3.67	4.25	15.61
2017-18	4,333	2.22	64.58	143.56	4.06	7.78	31.57
2018-19	4,764	2.44	68.05	166.31	4.46	18.63	83.06
2019-20	4,682	2.40	43.15	103.66	4.38	21.05	92.28
2020-21	4,692	2.41	41.71	100.39	4.39	26.26	115.33
2021-22	4,464	2.29	117.76	269.66	4.18	54.73	228.68
2022-23	4,983	2.56	223.86	572.23	4.66	70.89	330.64
2023-24	4,881	2.50	93.35	233.73	4.57	66.60	304.24

Sources: Authors’ calculations based on estimation results and data from RO annual reports, DESNZ, NESO, and Datastream.

6.3 Comparison of the RO and FIT schemes

The analysis so far indicates that solar deployment under the RO scheme was achieved at lower subsidy costs and generated larger price-related benefits than deployment under the FIT scheme. As shown in Section 3.4, a simple comparison for 2023-24 illustrates this difference: the RO supported 5,782 MW of solar capacity at a cost of £595.10 million, while the FIT supported 5,149 MW at a higher cost of £906.28 million. Consistent with this, the results in Sections 6.1 and 6.2 show that solar generation supported under the RO generated larger and more persistent gains for consumers and the electricity sector, particularly during periods of high wholesale electricity prices. From a narrow efficiency perspective, defined in terms of delivering solar capacity, wholesale price reductions, and sector-wide benefits at lower cost, the RO therefore appears more cost-effective.

However, interpreting this result as evidence of the overall superiority of the RO scheme would be misleading. The RO and FIT schemes were designed with distinct objectives. The RO operated as a market-based mechanism that emphasised cost-effectiveness and integration into wholesale electricity markets through certificate trading. By contrast, the FIT scheme prioritised revenue certainty to accelerate early-stage deployment at a time when solar technology costs were higher and market uncertainty was substantial. The higher subsidy costs observed under the FIT scheme are therefore consistent with its intended role.

7. Conclusion

The transition towards a low-carbon electricity system has reshaped the UK's generation mix, with solar power playing an increasingly important role. This study examined the impact of solar generation on wholesale electricity prices and assessed whether the resulting price reductions offset the costs of support under the RO and FIT schemes.

Using daily hourly average data from April 2014 to March 2024, the empirical analysis confirms a robust merit order effect of solar generation. On average, a one GWh increase in solar output reduces wholesale electricity prices by around £4 per MWh. However, the magnitude of this effect is highly state dependent. During periods of normal market conditions, the price-reducing effect of solar generation is relatively modest, whereas during the energy crisis of 2021-22 and 2022-23, when wholesale prices were exceptionally high, the marginal impact exceeded £9 per MWh. These findings highlight the stabilising role of solar generation during periods of extreme price stress, when it displaces high-cost fossil fuel-based generation.

From the consumer perspective, the results show that in most years prior to the energy crisis, reductions in electricity expenditure resulting from lower wholesale prices were insufficient to offset the costs of renewable support schemes, leading to consumer losses. By contrast, during 2021-22 and 2022-23, elevated wholesale prices amplified the merit order effect of solar generation, generating substantial positive consumer gains. This pattern underscores that the distributional impacts of renewable support are not constant over time but depend critically on prevailing market conditions.

Extending the analysis beyond consumers, this study quantified sector-wide benefits arising from reduced fossil fuel imports and lower greenhouse gas emissions. Solar generation contributed to substantial reductions in coal-fired electricity generation, lowering reliance on imported fuels and reducing compliance costs associated with carbon pricing. When these effects are taken into account, solar generation generated consistent positive net gains for the electricity sector under both the RO and FIT schemes, even in years when consumer gains were negative. This finding highlights the importance of evaluating renewable energy policies from a system-wide perspective rather than focusing solely on consumer price effects.

A key contribution of the study lies in the comparison between the RO and FIT schemes. The results show that solar deployment under the RO scheme was more cost-effective in terms of delivering price reductions and sector-wide gains per unit of subsidy expenditure. However, this should not be interpreted as evidence of the overall superiority of the RO scheme. The two policies were designed with fundamentally different objectives. The RO emphasised market integration and exposure to wholesale price signals, whereas the FIT prioritised revenue certainty and broad participation by households and small-scale investors. The higher subsidy costs associated with the FIT scheme are therefore consistent with its distributional and developmental objectives.

Finally, the analysis highlights an emerging challenge associated with rising solar penetration. While solar generation reduces wholesale prices during daylight hours, prices become more sensitive to demand during non-solar hours, when solar output is unavailable and system margins are tighter. This finding points to the growing importance of flexibility solutions such as energy storage, demand-side response, and complementary low-carbon generation as solar capacity continues to expand.

Overall, the findings suggest that solar generation delivers substantial economic and environmental benefits, particularly during periods of high electricity prices, but that the effectiveness of support schemes depends critically on policy objectives and market context. Future research could extend this framework by incorporating dynamic investment responses, interactions with storage and network constraints, and comparisons with alternative support mechanisms such as Contracts for Difference, both within the UK and across other electricity markets.

Acknowledgements

The authors gratefully acknowledge the editor and two anonymous reviewers for their helpful and constructive comments and suggestions.

References

[1] DESNZ. (2025). *Energy Trends: UK electricity*. Retrieved from https://www.gov.uk/government/statistics/electricity-section-5-energy-trends

[2] Climate Change Committee. (2020). *The Sixth Carbon Budget - The UK's path to Net Zero*. Retrieved from https://www.theccc.org.uk/publication/sixth-carbon-budget/

[3] DESNZ. Homeowners could save hundreds on energy bills from solar drive. 2025.

[4] Staffell I, Pfenninger S. The increasing impact of weather on electricity supply and demand. Energy. 2018;145:65–78. doi:10.1016/j.energy.2017.12.051

[5] Grubb M, Newbery DM. UK Electricity Market Reform and the Energy Transition: Emerging Lessons. The Energy Journal. 2018;39(6). doi:10.5547/01956574.39.6.mgru

[6] Bunn DW, Yusupov T. The progressive inefficiency of replacing renewable obligation certificates with contracts-for-differences in the UK electricity market. Energy Policy. 2015;82:298–309. doi:10.1016/j.enpol.2015.01.002

[7] Shao J, Chen H, Li J, Liu G. An evaluation of the consumer-funded renewable obligation scheme in the UK for wind power generation. Renewable and Sustainable Energy Reviews. 2022;153:111788. doi:10.1016/j.rser.2021.111788

[8] Würzburg K, Labandeira X, Linares P. Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. Energy Economics. 2013;40:S159–S71. doi:10.1016/j.eneco.2013.09.011

[9] Zipp A. The marketability of variable renewable energy in liberalized electricity markets – An empirical analysis. Renewable Energy. 2017;113:1111–21. doi:10.1016/j.renene.2017.06.072

[10] Kolb S, Dillig M, Plankenbühler T, Karl J. The impact of renewables on electricity prices in Germany - An update for the years 2014–2018. Renewable and Sustainable Energy Reviews. 2020;134:110307. doi:10.1016/j.rser.2020.110307

[11] Keeley AR, Matsumoto Ki, Tanaka K, Sugiawan Y, Managi S. The Impact of Renewable Energy Generation on the Spot Market Price in Germany: Ex-Post Analysis using Boosting Method. The Energy Journal. 2021;42(1_suppl):1–22. doi:10.5547/01956574.42.S12.akee

[12] Gelabert L, Labandeira X, Linares P. An ex-post analysis of the effect of renewables and cogeneration on Spanish electricity prices. Energy Economics. 2011;33:S59–S65. doi:10.1016/j.eneco.2011.07.027

[13] Ciarreta A, Espinosa MP, Pizarro-Irizar C. Is green energy expensive? Empirical evidence from the Spanish electricity market. Energy Policy. 2014;69:205–15. doi:10.1016/j.enpol.2014.02.025

[14] De Siano R, Sapio A. Spatial merit order effects of renewables in the Italian power exchange. Energy Economics. 2022;108. doi:10.1016/j.eneco.2022.105827

[15] Clò S, Cataldi A, Zoppoli P. The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. Energy Policy. 2015;77:79–88. doi:10.1016/j.enpol.2014.11.038

[16] Bell WP, Wild P, Foster J, Hewson M. Revitalising the wind power induced merit order effect to reduce wholesale and retail electricity prices in Australia. Energy Economics. 2017;67:224–41. doi:10.1016/j.eneco.2017.08.003

[17] Marshman D, Brear M, Jeppesen M, Ring B. Performance of wholesale electricity markets with high wind penetration. Energy Economics. 2020;89:104803. doi:10.1016/j.eneco.2020.104803

[18] López Prol J, Steininger KW, Zilberman D. The cannibalization effect of wind and solar in the California wholesale electricity market. Energy Economics. 2020;85. doi:10.1016/j.eneco.2019.104552

[19] Ajanaku BA, Collins AR. "Comparing merit order effects of wind penetration across wholesale electricity markets". Renewable Energy. 2024;226. doi:10.1016/j.renene.2024.120372

[20] Di Cosmo V, Valeri L. Wind, storage, interconnection and the cost of electricity generation. Energy Economics. 2018;69:1–18. doi:10.1016/j.eneco.2017.11.003

[21] Sensfuß F, Ragwitz M, Genoese M. The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. Energy Policy. 2008;36(8):3086–94. doi:10.1016/j.enpol.2008.03.035

[22] Espinosa MP, Pizarro-Irizar C. Is renewable energy a cost-effective mitigation resource? An application to the Spanish electricity market. Renewable and Sustainable Energy Reviews. 2018;94:902–14. doi:10.1016/j.rser.2018.06.065

[23] Traber T, Kemfert C. Gone with the wind? - Electricity market prices and incentives to invest in thermal power plants under increasing wind energy supply. Energy Economics. 2011;33(2):249–56. doi:10.1016/j.eneco.2010.07.002

[24] Costa-Campi MT, Trujillo-Baute E. Retail price effects of feed-in tariff regulation. Energy Economics. 2015;51:157–65. doi:10.1016/j.eneco.2015.06.002

[25] Ortega M, Del Río P, Montero EA. Assessing the benefits and costs of renewable electricity. The Spanish case. Renewable and Sustainable Energy Reviews. 2013;27:294–304. doi:10.1016/j.rser.2013.06.012

[26] Ortega M, Río Pd, Ruiz P, Nijs W, Politis S. Analysing the influence of trade, technology learning and policy on the employment prospects of wind and solar energy deployment: The EU case. Renewable and Sustainable Energy Reviews. 2020;122. doi:10.1016/j.rser.2019.109657

[27] Shao J, Li J, Liu G. 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. 2023;183:113498. doi:10.1016/j.rser.2023.113498

[28] DESNZ. (2025). *Digest of UK Energy Statistics*. Retrieved from https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

[29] DESNZ. (2025). *Rooftop solar for new builds to save people money*. Retrieved from https://www.gov.uk/government/news/rooftop-solar-for-new-builds-to-save-people-money

[30] Boßmann T, Staffell I. The shape of future electricity demand: Exploring load curves in 2050s Germany and Britain. Energy. 2015;90:1317–33. doi:10.1016/j.energy.2015.06.082

[31] Lee B, Li J, Shao J. The intertemporal unfairness of the Feed-in Tariff scheme in the United Kingdom: Catching up across regions. Utilities Policy. 2025;97:102044. doi:10.1016/j.jup.2025.102044

[32] Shao J, Li J, Liu G. Vertical integration, recycling mechanism, and disadvantaged independent suppliers in the renewable obligation in the UK. Energy Economics. 2021;94:105093. doi:10.1016/j.eneco.2020.105093

[33] Elexon. (2019). *Market Index Definition Statement for Market Index Data Provider(s)*. Retrieved from https://bscdocs.elexon.co.uk/category-3-documents/market-index-definition-statement

[34] NESO. (2025). *The NESO Data Portal*. Retrieved from https://www.neso.energy/data-portal

[35] Raviv E, Bouwman KE, van Dijk D. Forecasting day-ahead electricity prices: Utilizing hourly prices. Energy Economics. 2015;50:227–39. doi:10.1016/j.eneco.2015.05.014

[36] National Audit Office. (2025). *UK Emissions Trading Scheme*. Retrieved from https://www.nao.org.uk/reports/uk-emissions-trading-scheme/

[37] Staffell I, Pfenninger S. Using bias-corrected reanalysis to simulate current and future wind power output. Energy. 2016;114:1224–39. doi:10.1016/j.energy.2016.08.068

[38] EIA. (2021). *How much coal, natural gas, or petroleum is used to generate a kilowatthour of electricity?* Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=667&t=6

[39] Jansen M, Staffell I, Green R. Daily Marginal CO2 Emissions Reductions from Wind and Solar Generation. 2018 15th International Conference on the European Energy Market (EEM). 2018. doi:10.1109/eem.2018.8469873