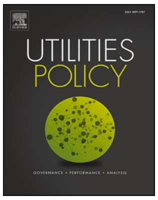
Utilities Policy 97 (2025) 102044

Contents lists available at ScienceDirect

Utilities Policy

journal homepage: www.elsevier.com/locate/jup



Full-length article

The intertemporal unfairness of the feed-in tariff scheme in the United Kingdom: Catching up across regions

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

ARTICLE INFO

Handling Editor: Janice A. Beecher

JEL classification:
H31
Fiscal Policies and Behaviour of Economic Agents: Household
Q28
Renewable Resources and Conservation: Government Policy
Q48
Energy: Government Policy
Q55
Environmental Economics: Technological Innovation

Keywords:
Solar photovoltaic
Feed-in tariff
Intertemporal fairness

ABSTRACT

The Feed-in Tariff (FIT) scheme in the UK was designed to promote residential solar photovoltaic (PV) projects by offering fixed payments for electricity generated, thereby positioning solar PV as an investment opportunity for households. This study investigates the role of income in shaping the uptake of solar PV under the FIT scheme and assesses the intertemporal fairness of the financial returns it provides. Using data from 323 local authority districts, the analysis focuses on two major installation peaks in 2011 and 2015, which correspond to significant changes in tariff rates. The findings reveal a positive relationship between income and solar PV adoption during the first peak, but a negative relationship in the second. This shift suggests that as installation costs declined, lower-income regions began to catch up in adopting solar PV. However, by estimating the expected (ex ante) rates of return across these periods, the study identifies a substantial decline in returns, both between the two peaks and following sharp reductions in tariff rates. These results indicate that early adopters in higher-income regions achieved significantly higher financial returns than those who adopted later. The study reveals a form of intertemporal unfairness embedded in the FIT scheme, confirming the need for more frequent and responsive tariff adjustments to ensure consistent investment incentives over time.

1. Introduction

Prior to 2010, the adoption of solar photovoltaic (PV) projects expanded in countries such as Germany and Spain, supported by favourable policy frameworks. In response, the UK government introduced the Feed-in Tariff (FIT) scheme in April 2010 to encourage the uptake of small-scale renewable electricity projects by providing higher returns on investment and shorter payback periods.[1][2] Under the scheme, electricity generators receive a fixed payment for each unit of electricity produced, and distribution network operators are obligated to accept this output into the grid. By March 2020, the installed capacity of small-scale technologies had reached 6.23 GW (GW), with solar PV accounting for 5.04 GW.[3]

Several survey-based studies suggest that the FIT scheme did not adequately address the high upfront installation costs, which remained a primary barrier to household adoption of solar PV systems (Keirstead, 2007; Gooding et al., 2013; Balcombe et al., 2014). As a result, higher-income households were more likely to invest in solar PV, while those with limited financial resources were unable to benefit. However, this expected positive relationship between income and uptake has not been supported by empirical studies, which have reported either insignificant or inverse correlations in analyses using cumulative installed capacity up to a specific year (Balta-Ozkan et al., 2015, 2021; Collier et al., 2023).

---

* Corresponding author.
E-mail address: jinke.li@swansea.ac.uk (J. Li).

[1] The Renewables Obligation scheme, a quota-based system, was introduced in April 2002 to promote investment in large scale renewable electricity projects. For recent studies, see Li et al. (2020), Shao et al. (2021), and Shao et al. (2022).

[2] The FIT scheme operated in Great Britain (England, Wales, and Scotland), which accounted for 97.2 percent of the United Kingdom's total population in 2021. For simplicity, the term "UK" is used throughout this study.

[3] For comparison, installed capacity under the Renewables Obligation scheme reached 35.42 GW as of March 2020 (Wang et al., 2024b).

https://doi.org/10.1016/j.jup.2025.102044
Received 16 June 2025; Received in revised form 30 August 2025; Accepted 30 August 2025

Motivated by the inconsistency between survey findings and empirical evidence, this paper investigates the correlation between disposable income and the uptake of solar PV using data from 323 local authority districts in the UK. The analysis is based on the annual installed capacity in kilowatts (kW) per thousand residents, which accounts for differences in regional population size. While the full sample from 2010 to 2018 indicates a positive relationship between income and uptake, the analysis focuses specifically on the years 2011 and 2015, which experienced two distinct peaks in installation activity prior to reductions in tariff rates. The results reveal that disposable income had a positive correlation in the first peak but a negative correlation in the second, suggesting a catch-up process across regions during the period, which is supported by the FIT scheme. Robustness checks using two alternative measures — the annual installed capacity of projects below 10 kW and the annual number of installations — confirm the consistency of these findings.

While it is common for new technologies to attract both early and late adopters, a critical issue known as intertemporal fairness arises when adoption involves investment and is supported by a government subsidy scheme. Whether the FIT scheme achieves intertemporal fairness depends on whether early and late adopters receive comparable rates of return. To explore this, we examine the decision-making processes of households in December 2011 and December 2015.

Two major policy reviews were conducted in 2011 and 2015, resulting in substantial reductions in tariff rates in March 2012 and February 2016, respectively (DECC, 2012a, 2015b).[4] The observed peaks in installations prior to these reductions suggest that the FIT scheme provided effective financial incentives, which encouraged the uptake of solar PV projects. However, the expected rate of return for installations in December 2011 was 10.84 %, compared to 6.58 % in December 2015. This difference indicates that early adopters, who were more likely to have the financial means to afford higher installation costs, benefited more during the early stage of the scheme. Therefore, the scheme can be considered intertemporally unfair. This conclusion is further reinforced by the significant decline in returns observed immediately after the two major reductions in tariff rates.

This study makes a significant contribution to the literature in three primary ways. First, it reveals the relationship between income and the installation of solar PV projects in the UK, addressing the previously reported negative or insignificant correlations, which lacked further explanation. Second, by focusing on the two installation peaks in 2011 and 2015, the analysis suggests a catch-up process across regions, in which lower-income areas gradually increased uptake as installation costs declined. Third, the study calculates the ex ante rate of return for installations at different points in time, revealing a substantial decline in returns between 2011 and 2015, as well as before and after the tariff reductions in both years. These differences in returns indicate that the FIT scheme was intertemporally unfair, as early adopters, who were more likely to be located in higher-income regions, gained significantly higher returns than late adopters from lower-income areas.

In addition to the income-based explanation explored in this study, there are at least two other plausible hypotheses that could explain the observed adoption patterns. First, it is possible that solar installers initially focused their efforts on higher-income areas due to limited industry capacity in the early phase of the FIT scheme. Second, targeted or influential media campaigns in lower-income areas may have contributed to the surge in installations in 2015. These alternative explanations offer valuable insights into household decision-making and market dynamics. However, due to data limitations, particularly the absence of consistent and measurable indicators of installer behaviour and local media influence at the district level, this study focuses on the income-based catch-up effect, which can be empirically tested with the available data.

The structure of the paper is as follows. Section 2 reviews the relevant literature, while Section 3 outlines the background of the study. Section 4 describes the data sources and model specifications. Section 5 presents the results of the regression analysis. Section 6 examines the decision-making processes of households, and Section 7 provides the conclusion.

2. Literature review

According to the theory of Crossing the Chasm (Moore, 2014), the adoption of new technologies typically begins with early adopters, followed by late adopters, reflecting differing attitudes towards innovation. Beyond these attitudinal factors, financial circumstances may also influence adoption decisions. The learning curve theory suggests that the costs of new technologies decline over time, making them increasingly affordable for a broader range of consumers (Nemet, 2006; Defeuilley, 2019; Parveen et al., 2025; Qadir et al., 2025). If income becomes a determining factor, regions with greater financial capacity are better positioned to afford expensive technologies initially, with uptake gradually expanding to lower-income regions. Since the return on investment in solar panel projects generates financial returns over time, the variation in return rates between early and late adopters becomes a relevant concern. This issue is particularly relevant to intertemporal fairness.

Prior to the FIT scheme, it was recognised that high installation costs were one of the major barriers to solar PV uptake (Faiers and Neame, 2006; Allen et al., 2008), and the resulting long payback periods reduced consumers' willingness to invest (Watson et al., 2008; Bergman et al., 2009; Scarpa and Willis, 2010; Claudy et al., 2011). After introducing the FIT scheme, NHBC Foundation (2011) estimates that the payback time was mainly reduced. DECC (2011b) indicates that approximately 40 % of consumers who had installed microgeneration reported that the scheme was crucial in their decision to proceed with the installation. Balcombe et al. (2013) suggest that the reduced payback time substantially encouraged the uptake of solar PV in the UK.

The tariff rates in the FIT scheme were reduced in 2012, sparking a debate about its effectiveness. Cherrington et al. (2013) suggest that, considering the reduced installation costs of solar PV, decreased FIT rates can still lead to a healthy return on investment and marginally prolonged payback periods. However, Muhammad-Sukki et al. (2013) predict that the installation of solar PV would decrease with the reduced FIT rates. Pearce and Slade (2018) suggest that current tariffs are too low to significantly affect uptake, while falling costs are the primary driver of installation. Castaneda et al. (2020) argue that the reduced FIT rate would lead to fewer solar PV installations but indicate that the UK could still maintain its growth potential.

While the FIT scheme has helped increase rates of return on investment over the lifetime of projects, another crucial aspect is affordability at the point of decision-making. Balcombe et al. (2013) indicate that, although the scheme has provided subsidies to encourage uptake by reducing payback periods, it did not sufficiently address installation costs. Therefore, household income should be relevant to decisions regarding the uptake of solar PV as it determines affordability. Among survey studies related to the UK, Keirstead (2007) suggests that households with solar PV installation had a higher average income than the national average. Gooding et al. (2013) suggest that although the FIT scheme may support the return for consumers who install a solar PV system, households that cannot afford installation costs receive no benefit. Indeed, Balcombe et al. (2014) suggest that low income is one of the main financial barriers and negatively affects the diffusion of solar PV in the UK, as shown in their survey on the acceptance of

---

[4] DECC (Department of Energy and Climate Change), BEIS (Department for Business, Energy and Industrial Strategy), and DESNZ (Department for Energy Security and Net Zero) are successive UK government departments responsible for energy policy, with DECC operating until 2016, BEIS from 2016 to 2023, and DESNZ established in 2023 to focus specifically on energy security and net zero objectives.

microgeneration.

The correlation between income and the uptake of solar PV has been examined using econometric methods in studies focusing on the UK, but has found insignificant or negative results. Richter (2013) finds that income does not affect the installation of solar PV based on the monthly added numbers of installations at 2239 zip code regions from April 2010 to March 2013. Balta-Ozkan et al. (2015) also find that income does not affect the diffusion of solar PV based on the cumulative number of installations as of June 2013 at the 134 NUTS3 regions.[5] In a subsequent study, Balta-Ozkan et al. (2021) found a negative correlation between income and solar PV uptake, based on the cumulative number of installations as of December 2014, across the 378 local authority districts (LADs). Collier et al. (2023) confirm the negative correlation between income and cumulative installed capacity as of April 2019 at the 34,753 LSOA (Lower Layer Super Output Area) areas.

The relationship between income and solar PV installations remains inconclusive across international studies. Positive associations have been identified in research conducted in Germany (Dharshing, 2017; Jacksohn et al., 2019), Belgium (De Groote et al., 2016), the Netherlands (Vasseur and Kemp, 2015), Ireland (Claudy et al., 2010), Australia (Bondio et al., 2018), and the United States (Lukanov and Krieger, 2019; Mildenberger et al., 2019). However, other studies have reported a negative relationship in Germany (Müller and Rode, 2013), Italy (Copiello and Grillenzoni, 2021), Sweden (Palm, 2020), the Netherlands (van der Kam et al., 2018), Australia (Best et al., 2019, 2024; Best and Chareunsy, 2022), Canada (Islam and Meade, 2013), and the United States (Kurdgelashvili et al., 2019; White, 2019).

3. Background

The UK government introduced the FIT scheme in April 2010 to support small-scale renewable electricity generation projects with capacities of up to 5 MW (MW). Under the scheme, registered installations were eligible to receive tariff rates set at the time of application approval, with payments indexed to the Retail Prices Index (RPI) to ensure stable returns on investment. For solar photovoltaic (PV) systems, the support period was 25 years for projects installed before August 1, 2012, and 20 years for those installed on or after that date (Ofgem, 2011, 2013).

3.1. *Deployment trends under the FIT scheme*

The FIT scheme covered a range of technologies, including solar photovoltaic (PV), wind, anaerobic digestion, hydro, and micro combined heat and power (CHP).[6] By April 2020, a total of 867,232 installation projects had been registered, with a combined installed capacity of 6226 MW. Among the eligible technologies, solar PV accounted for the largest share, contributing 5037 MW or 80.90 percent of the total capacity. Next was wind at 713 MW (11.45 percent), anaerobic digestion at 278 MW (4.47 percent), hydro at 198 MW (3.18 percent), and micro-CHP at 575 kW (0.01 percent). The cumulative installed capacity by technology, from the 2010–11 obligation year through to 2019–20, is presented in Table 1.

The distribution of installations under the FIT scheme varied significantly across regions. As shown in Table 2, the cumulative installed capacity from 2010–11 through to 2019–20 differed widely by location. The South West and Scotland recorded the highest levels of installed capacity, at 1151 MW and 762 MW, respectively. In contrast, London and the North East had the lowest installed capacities, at 127 MW and 208 MW, respectively. Given these substantial regional disparities, this study aims to identify and explain the factors that influence these regional differences, using data at the local authority district level.

3.2. *Tariff structure and policy amendments*

Under the FIT scheme, tariff rates comprised two components. First, generators received a generation tariff for each kilowatt-hour (kWh) of electricity produced. The rate varied according to factors such as the type of technology and the scale of the installation.[7] Second, generators received an export tariff for surplus electricity sold back to the grid, up to half of the total electricity generated. The scheme operated under a deemed export arrangement, whereby 50 percent of the generated electricity was assumed to be exported, regardless of the actual quantity fed into the grid. The scheme closed to new applicants in April 2019 and was subsequently replaced by the Smart Export Guarantee (SEG), which took effect in January 2020.[8]

This analysis focuses on solar PV technology, which was divided into several capacity size categories: 0–4 kW, 4–10 kW, 10–50 kW, 50–100 kW, and 100–500 kW. According to the installation data, the majority of awarded solar PV projects, accounting for 92.95 %, were in the smallest category, which is less than 4 kW in size. This category was further subdivided into new build and retrofit installations, with the latter referring to systems added to existing buildings.

Fig. 1 presents the tariff rates adjusted by the Retail Prices Index (RPI), expressed in 2023/24 prices, for solar PV projects installed between 2010–11 and 2019–20 (Ofgem, 2023). The solid line represents the generation tariff for retrofit installations with capacity below 4 kW.[9] The generation tariff for systems installed in April 2010 was 68.30 pence per kWh, but fell to 25.37 pence after March 2012 and to 5.46 pence after February 2016. In comparison, the export tariff was 4.82 pence per kWh for installations completed before July 31, 2012, increasing to 6.79 pence for those installed on or after August 1, 2012.

The two significant reductions in tariff rates were the result of major amendments to the FIT scheme, implemented in response to falling installation costs and increasing overall support costs. The first amendment occurred in March 2012, introducing a reduction in tariff rates alongside a pre-planned degression mechanism, which established a schedule for regular tariff decreases every three months (DECC, 2012b). The second amendment took place in February 2016 and introduced deployment caps to limit the number of installations permitted for each eligible technology within each three-month period (DECC, 2015b). Once a cap was reached, no additional installations could be registered during that period, and all remaining applications were placed in a queue for the following period. Moreover, if deployment caps were exceeded, a further 10 percent contingent reduction in tariff rates was applied in the next period.

---

[5] An example of statistical geography is as follows: East Midlands (NUTS1), Derbyshire and Nottinghamshire (NUTS2), North Nottinghamshire (NUTS3), and Mansfield (Local Authority District).

[6] For combined heat and power (CHP), the maximum eligible capacity was 2 MW, with a support duration of 10 years.

[7] Under the Renewables Obligation scheme for large scale renewable projects, support was differentiated through a banding system based on the number of certificates awarded per megawatt-hour of electricity generated (Wang et al., 2024a). For instance, the banding level for offshore wind increased from one to 1.5 in April 2009, while that for onshore wind decreased from one to 0.9 in April 2013.

[8] Unlike the consumer-funded FIT scheme, the Smart Export Guarantee (SEG) is a government-backed initiative financed through taxation. Under the SEG, electricity suppliers are required to pay small scale generators for low carbon electricity exported to the National Grid, but not for electricity generated. In contrast to the FIT scheme, where tariffs were set by Ofgem, SEG suppliers determine the export rate, contract length, and other terms.

[9] Fig. 1 also shows the tariff rates for installations of 0–4 kW (new build) and 4–10 kW (standard). Initially, the tariff rate for new build properties was 59.57 pence per kWh, lower than that for occupied homes. These two rates were merged in March 2012. Similarly, the tariff for standard installations matched that of new builds but became slightly lower after March 2012, before both rates were merged again in February 2016.

Table 1
Cumulative installed capacity (in MW) under the FIT scheme by technology.

Obligation year (April–March)	Solar PV	Wind	Anaerobic digestion	Hydro	Micro CHP	Total
2010–11	77.70	18.90	1.80	9.90	–	108.32
2011–12	987.71	53.68	10.74	21.47	–	1073.60
2012–13	1568.08	142.55	35.64	35.64	–	1781.91
2013–14	1871.37	331.64	118.44	47.38	–	2368.83
2014–15	2446.80	562.10	198.39	99.19	–	3306.49
2015–16	3609.30	513.73	176.52	104.49	0.52	4404.55
2016–17	4539.39	684.13	249.79	175.77	0.54	5649.62
2017–18	4793.94	716.80	286.50	217.77	0.54	6015.54
2018–19	4917.40	702.18	277.13	196.96	0.55	6212.41
2019–20	5036.51	712.52	277.66	198.48	0.58	6225.74

Sources: FIT annual reports.

Table 2
Cumulative installed capacity (in MW) under the FIT scheme by region.

Obligation year (April–March)	South West	Scotland	South East	East of England	East Midlands	Yorkshire & the Humber
2010–11	18.83	21.79	15.64	10.66	7.60	12.28
2013–14	490.94	240.26	318.78	256.43	243.50	202.37
2016–17	1061.46	685.75	647.54	615.35	605.50	473.58
2019–20	1150.53	762.45	718.29	672.94	646.96	519.07
	West Midlands	**Wales**	**North West**	**North East**	**London**	**Total**
2010–11	6.02	4.67	5.72	1.85	3.26	108.32
2013–14	168.66	150.46	166.94	79.04	51.45	2368.83
2016–17	426.76	419.39	417.47	190.71	106.10	5649.62
2019–20	480.39	476.82	462.11	208.32	127.86	6225.74

Sources: FIT annual reports.

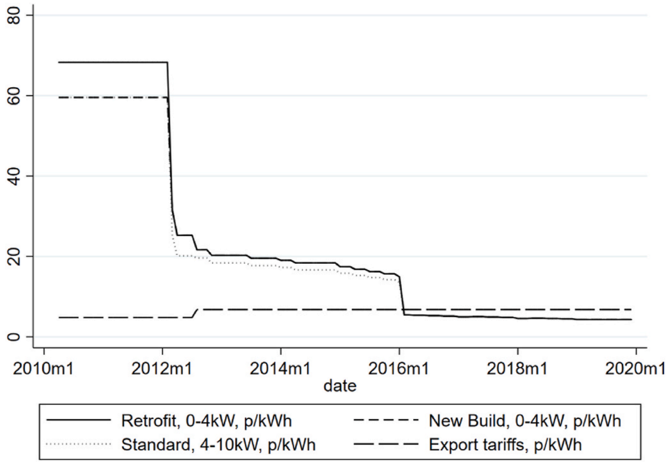


Fig. 1. RPI-adjusted FIT tariff rates by installation year, in pence per kWh (2023–24 prices).
Source: Ofgem.

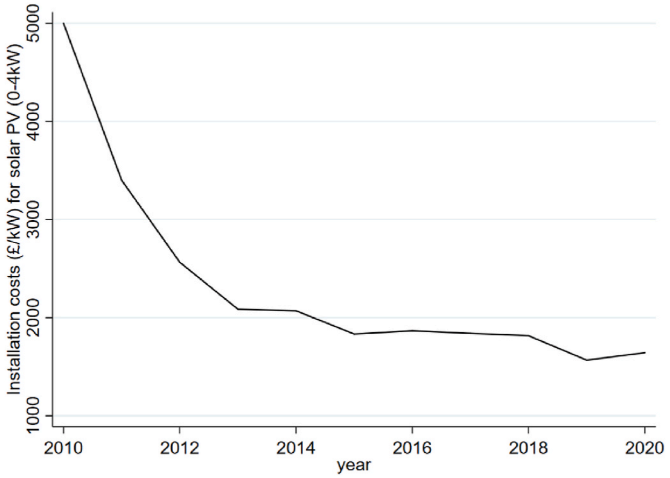


Fig. 2. Average installation costs (in £/kW) of solar PV systems (0–4 kW).
Source: BEIS and DECC.

3.3. *Trends in solar PV installation costs*

Installation costs also play a crucial role in household decision-making. Fig. 2 illustrates the consistent decline in installation costs of solar PV systems with capacities ranging from 0 to 4 kW. For the period prior to 2013, data were obtained from early reports published by the Department of Energy and Climate Change (DECC, 2012b, 2012c), which show that installation costs per kW fell sharply from approximately £5000 in 2010–2011 to £2564 in 2012–2013. This downward trend continued in subsequent years, with costs decreasing from £2086 per kW in 2013–2014 to £1642 per kW in 2020–2021, based on data from the Department for Energy Security and Net Zero (DESNZ, 2025c). This significant reduction in costs is primarily attributed to technological advancements and declining manufacturing costs (IRENA, 2020).

4. Data and model specification

4.1. Data

Data on installations supported by the FIT scheme from April 2010 to April 2020 were obtained from Ofgem (2021). In total, 867,232 projects were recorded, representing a combined installed capacity of 6.23 GW. The majority of these installations served domestic purposes, with 829,985 projects accounting for 2.95 GW. In terms of technology, solar photovoltaic (PV) systems were the dominant type, comprising 860,369 projects and 5.13 GW of capacity. This study focuses specifically on domestic solar PV installations, which totalled 820,960 projects with a combined capacity of 2.87 GW. Each installation is linked to a local authority district, allowing for the aggregation of installed capacity by district and by year.

Given that most solar PV systems were installed on residential rooftops, installation activity is expected to be correlated with population size. Therefore, we calculated the annual installed capacity per thousand residents for each local authority district, using population estimates from the Office for National Statistics (ONS, 2021). Fig. 3 illustrates the annual added installed capacity, measured in kW per thousand residents, at the national level. The figure presents two lines: one (dashed line) includes London, and the other (solid line) excludes it.[10] Two clear peaks are visible in 2011 and 2015, occurring just before major tariff reductions and policy amendments in March 2012 and February 2016, respectively. These patterns motivate focusing on these two years to explore whether the factors influencing solar PV installation differed across the two peak periods.

The prosperity of each local authority district is measured using regional gross disposable household income (GDHI) per capita for the period from 2010 to 2018, based on data from the Office for National Statistics (ONS, 2021). Since decisions to invest in solar PV systems are made by individual households, GDHI per capita is a more suitable measure than aggregate income for the entire district population.

In addition to income, several location-specific variables are included in the analysis. First, solar radiation data were obtained from the Photovoltaic Geographical Information System (European Commission, 2022). Using the latitude and longitude of each local authority district, we extracted corresponding values for Global Horizontal Irradiance (GHI), which represents the average monthly solar radiation energy that hits one square meter of a horizontal plane, measured in kWh/m^2. This variable is particularly relevant for assessing the potential performance of photovoltaic systems.

Other contextual variables were sourced from the Census 2011 and include population density, housing type, and the proportion of households using gas for heating (ONS, 2011).[11] Additionally, data on annual average household electricity consumption in kWh at the local authority level were obtained from the Department for Business, Energy and Industrial Strategy (DESNZ, 2025b).

Table 3 presents the descriptive statistics for the variables used in the analysis. After merging all data sources, the final dataset comprises 323 local authority districts, which form the basis for the subsequent empirical analysis.

The annual installed capacity per thousand residents has a mean of 6.07 kW in the full sample, which comprises 2907 observations. The values vary considerably, ranging from a minimum of 0.02 kW to a maximum of 56.76 kW. During the two peak years of installation, the average values were 12.11 kW in 2011 and 10.81 kW in 2015. Two alternative indicators, the annual installed capacity of projects under 10 kW per thousand residents and the annual number of installed projects per thousand residents, exhibit similar patterns across these years.

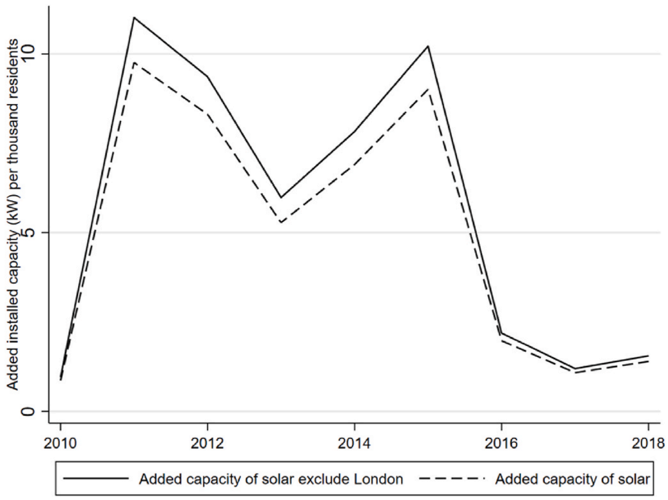


Fig. 3. Annual installed capacity (kW) of domestic solar PV per thousand residents.
Source: Author's calculations based on data from BEIS and ONS.

Disposable income per capita has a mean value of £18,131 across the full sample, with averages of £16,451 in 2011 and £18,964 in 2015. Hourly solar radiation averages 86.04 kWh per square metre and remains relatively stable between 2011 and 2015. Population density, which is often used to assess the spatial feasibility of solar PV adoption, has a mean of 9.94 residents per hectare. In terms of housing type, the average is 68 percent detached or semi-detached dwellings. The percentage of households using gas as the primary heating source averages 77 percent, indicating that gas remains the dominant heating method in the UK. Since these three variables — population density, housing type, and gas heating — are derived from the Census 2011, their values remain constant for both 2011 and 2015. Finally, average household electricity consumption is 4011 kWh and shows a modest decline between 2011 and 2015, which may reflect improvements in energy efficiency.

4.2. Model specification

In our specification, the dependent variable, $IC_{i,t}$, represents the annual installed capacity of solar PV per thousand residents in local authority district i in year t. The specification is expressed as follows:

$$\log(IC_{i,t}) = \beta_0 + \beta_1 \cdot \log(GDHI_{i,t}) + \beta_2 \cdot \log(SR_{i,t}) + \beta_3 \cdot \log(Den_i) + \beta_4 \cdot Type_i + \beta_5 \cdot Gas_i + \beta_6 \cdot \log(EC_{i,t}) + \beta_7 \cdot \log(Tar_t) + \beta_8 \cdot \log(Cost_t) + \varepsilon_{i,t} \tag{1}$$

where $GDHI_{i,t}$ denotes the disposable income per capita, $SR_{i,t}$ is the hourly solar radiation, Den_i represents the population density, $Type_i$ measures the share of detached and semidetached houses, Gas_i captures the share of households using gas for heating, $EC_{i,t}$ is the average household electricity consumption, Tar_t denotes tariff rates, and $Cost_t$ indicates installation costs. Tariff rates and installation costs are region-invariant within a given year and are therefore excluded from the analysis of the two peak years, as they do not vary across local authority districts within those specific years.

In addition, we incorporate an interaction term between disposable income per capita and FIT tariff rates into the model. The extended specification is given as follows:

---

[10] London is a notable outlier, with the highest level of disposable income but the lowest number of solar PV installations, largely due to its high population density. Consequently, London, consisting of 33 local authority districts, is excluded from the study.

[11] Although Census 2021 data are available, this study uses Census 2011 data, which are more closely aligned with the years covered in the analysis.

Table 3
Descriptive statistics of variables used in the analysis.

Variables	2010–18			2011	2015	Data Sources
	N = 2907			N = 323	N = 323	
	Mean	Min	Max	Mean	Mean	
Installed capacity (kW) per thousand residents	6.07	0.02	56.76	12.11	10.81	Ofgem & ONS
Installed capacity (kW) per thousand residents (less than 10 kW)	5.39	0.02	51.93	11.31	9.40	
Installed projects per thousand	1.72	0.01	18.77	3.77	2.87	
Disposable income per capita (£)	18131	10852	33913	16451	18964	ONS
Solar radiation (kWh/m^2)	86.04	65.72	105.82	86.19	87.48	PGIS
Population density (per hectare)	9.94	0.10	50.70	9.94	9.94	Census 2011
Share of detached and semi-detached houses	0.59	0.17	0.85	0.59	0.59	
Share of gas heating	0.77	0.00	0.91	0.77	0.77	
Electricity consumption (kWh)	4011	2792	6081	4185	3992	BEIS

$$\begin{aligned}\log(IC_{i,t}) = {} & \beta_0 + \beta_1 \cdot \log(GDHI_{i,t}) + \beta_2 \cdot \log(SR_{i,t}) + \beta_3 \cdot \log(Den_i) + \beta_4 \cdot Type_i + \beta_5 \cdot Gas_i \\ & + \beta_6 \cdot \log(EC_{i,t}) + \beta_7 \cdot \log(Tar_t) + \beta_8 \cdot \log(Cost_t) + \beta_9 \cdot \log(GDHI_{i,t}) \cdot \log(Tar_t) + \varepsilon_{i,t}\end{aligned} \tag{2}$$

The coefficient on the interaction term, β_9, allows us to assess whether the correlation between income and solar PV adoption depends on the level of the FIT tariff.

For the robustness checks, we replace the dependent variable with two alternative measures, both expressed per thousand residents. The first is the annual installed capacity of solar PV systems with capacities below 10 kW, denoted as $IC_{i,t}^{10}$. The second is the annual number of installations, denoted as $NI_{i,t}$.

We employ ordinary least squares (OLS) estimation for the empirical analysis and conduct a series of diagnostic tests to assess model validity. First, the Breusch-Pagan test indicates the presence of heteroskedasticity. To address this issue, we apply the heteroskedasticity-consistent Huber–White estimator to obtain robust standard errors. Second, the results of Ramsey's RESET test indicate potential misspecification in the functional form. To address this, we apply a logarithmic transformation to the variables, resulting in a better-specified functional form.[12]

5. Empirical results

5.1. Main regression results

Table 4 Column 1 presents the results from estimating Equation (1) using the full sample covering the period from 2010 to 2018, with 2907 observations. The coefficient on disposable income per capita is positive and statistically significant, indicating that higher income levels are associated with a greater uptake of solar PV projects. This finding contrasts with previous studies that relied on cumulative installation data up to a given year and reported insignificant or negative relationships.

Among the other explanatory variables, solar radiation has a positive and significant correlation, as higher solar radiation increases potential electricity generation, thereby enhancing revenues from both generation and export payments. Turning to socio-demographic characteristics, population density has a negative correlation, suggesting that more densely populated areas may have limited physical space for solar PV installations. This finding is consistent with the positive relationship of the share of detached and semi-detached houses, which are typically more suitable for rooftop installations. In contrast, the share of households with gas heating systems has a negative correlation. This finding may indicate that households without access to gas heating are more likely to adopt solar PV as an alternative energy source, possibly to improve efficiency or support electric heating solutions.

Electricity consumption also has a negative correlation with uptake,

Table 4
Estimated results.

Independent variables	Main results			
	2010–18	2010–18	2011	2015
	Dependent variable			
	Annual installed capacity of solar projects per thousand residents (all domestic projects)			
Disposable income per capita	0.391*** (0.130)	0.0118 (0.215)	0.735** (0.333)	−0.652*** (0.229)
Solar radiation	2.553*** (0.222)	2.568*** (0.223)	3.315*** (0.420)	2.578*** (0.565)
Density of population	−0.242*** (0.0199)	−0.241*** (0.0199)	−0.317*** (0.0367)	−0.245*** (0.0434)
Share of detached and semi-detached houses	1.787*** (0.135)	1.788*** (0.135)	1.286*** (0.295)	1.501*** (0.248)
Share of houses with central heating	−1.128*** (0.283)	−1.134*** (0.283)	−1.033* (0.567)	−0.564 (0.605)
Electricity consumption	−2.386*** (0.264)	−2.398*** (0.264)	−2.150*** (0.660)	−1.919*** (0.524)
Tariff	1.998*** (0.0303)	1.585*** (0.209)		
Installation costs	−4.296*** (0.0724)	−4.258*** (0.0695)		
Interaction term between income and tariff		0.140* (0.0717)		
Constant	36.21*** (2.229)	37.09*** (2.298)	3.914 (5.549)	8.435* (4.824)
Observations	2907	2907	323	323
R-squared	0.717	0.717	0.655	0.514
F statistics	975.79***	875.41***	87.59***	49.84***

Heteroscedasticity-robust standard errors in parentheses; ***p $<$ 0.01, **p $<$ 0.05, *p $<$ 0.1.
All variables are expressed in logarithmic form, except for those measured as shares.

---

[12] Nevertheless, Villadsen and Wulff (2020) caution that many studies use log-transformed dependent variables to test hypotheses that are linear in nature, even though such transformations imply non-linear (exponential) relationships, and argue that researchers should justify the motivation behind such transformations.

possibly because households with higher usage are less motivated by environmental concerns or do not perceive solar PV as an effective means of reducing energy costs. Regarding the region-invariant variables, the results confirm expectations: higher tariff rates are positively associated with greater adoption of solar PV, while higher installation costs exhibit a negative correlation. These findings reinforce the role of financial incentives and affordability in shaping household investment decisions in solar technology.

To further investigate the correlation between disposable income and uptake at different tariff levels, we estimate Equation (2), which includes an interaction term between income and tariff rates. As shown in Column 2 of Table 4, the coefficient on the interaction term is positive and statistically significant at the 10 percent level, with a p-value of 0.052. This finding provides moderate evidence that the influence of income on solar PV adoption is more pronounced when tariff rates are higher. The results suggest that the correlation may vary throughout the FIT scheme, particularly as tariffs decline over time.

As substantial reductions in tariff rates were implemented in March 2012 and February 2016, the analysis focuses on the years 2011 and 2015, during which two notable peaks in solar PV installations were observed. This approach aims to capture potential changes in the correlation between disposable income per capita and solar PV uptake that may otherwise be obscured in the full sample. Column 3 of Table 4 presents the results for 2011, the year of the first peak. Disposable income per capita has a positive and statistically significant correlation with the adoption of solar PV. Specifically, a one percent increase in income per capita is associated with a 0.735 percent increase in installed capacity per thousand residents. This finding indicates that higher-income regions experienced greater uptake than lower-income regions during this period.

In contrast, Column 4 shows that in 2015, the year of the second peak, disposable income per capita had a statistically significant negative relationship to adoption. A 1 % decrease in income per capita was associated with a 0.652 % increase in installed capacity per thousand residents. In other words, lower-income regions exhibited higher uptake in 2015. This reversal in the correlation between the two periods is examined in greater detail in Section 5.3.

Table 5
Robustness checks using alternative adoption measures.

Robustness checks				
Independent variables	2011	2015	2011	2015
Dependent variable				
	Annual installed capacity of solar projects per thousand residents (domestic projects less than 10 kW)		Annual number of installations (all domestic projects)	
Disposable income per capita	0.843**	−0.769***	0.826**	−0.614**
	(0.332)	(0.230)	(0.329)	(0.253)
Solar radiation	3.170***	2.383***	3.265***	2.424***
	(0.401)	(0.542)	(0.403)	(0.553)
Density of population	−0.314***	−0.225***	−0.284***	−0.194***
	(0.0356)	(0.0420)	(0.0372)	(0.0421)
Share of detached and semi-detached houses	1.342***	1.666***	1.112***	1.652***
	(0.292)	(0.254)	(0.293)	(0.268)
Share of houses with central heating	−1.056*	−0.531	−1.069**	−0.798
	(0.545)	(0.567)	(0.527)	(0.552)
Electricity consumption	−2.429***	−2.134***	−2.359***	−2.325***
	(0.654)	(0.534)	(0.638)	(0.597)
Constant	6.502	11.13**	4.565	11.05**
	(5.419)	(4.740)	(5.241)	(5.185)
Observations	323	323	323	323
R-squared	0.648	0.487	0.597	0.422
F statistics	84.56***	47.25***	67.29***	36.72***

Heteroscedasticity-robust standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
All variables are expressed in logarithmic form, except for those measured as shares.

5.2. *Temporal variation in the income coefficients*

The contrasting significant coefficients of disposable income per capita in 2011 and 2015 highlight the limitations of the full-sample analysis, where a single positive relationship may obscure important temporal variation. The opposite signs observed at the two peaks indicate a catch-up process across regions during the implementation of the FIT scheme.

In 2011, when installation costs were relatively high, adoption was more feasible for households in higher-income regions, as they had the financial capacity to afford the upfront investment. As a result, these regions emerged as early adopters. By 2015, installation costs had declined considerably, making solar PV systems more accessible to households in lower-income regions. This increase in affordability enabled greater participation from these areas, which became more active in the later stages of the scheme as late adopters.

5.3. *Robustness checks*

We conduct robustness checks under two scenarios. In the first scenario, we focus on the annual installed capacity of solar PV projects with a capacity of less than 10 kW, excluding all installations with a capacity exceeding this threshold. In the second scenario, we examine the annual number of installations. In both cases, the variables are rescaled to reflect values per thousand residents. The results, presented in Table 5, confirm the positive correlation of income with solar PV uptake in 2011 and the inverse relationship in 2015. These findings suggest that the core results are robust to alternative measures of adoption.

6. Discussion: Intertemporal fairness and household decision-making

Although both early and late adopters benefited from the FIT scheme, tariff rates and installation costs underwent substantial changes over time. This section examines how these changes impacted adopters at various points in time to evaluate the intertemporal fairness of the FIT scheme. Specifically, it investigates the decision-making processes of households in December 2011 and December 2015. While ex-post current data on inflation and electricity prices are available, this analysis assumes that households based their expectations on ex-ante historical values, as these are more relevant to the decisions made at the time of installation.

6.1. *Assumptions for a representative solar PV installation*

As presented in Table 6, the analysis considers a representative solar photovoltaic (PV) project with a capacity of 2.6 kW and a load factor of 10.4 % (BEIS, 2020), resulting in an annual generation of 2368.70 kWh. Under the deemed export arrangement, 50 % of the electricity generated is assumed to be exported to the grid, amounting to 1184.35 kWh. The remaining 1184.35 kWh is consumed on-site.[13]

Table 6
Assumptions for a representative 2.6 kW solar PV installation.

Capacity (kW)	2.6
Load factor	0.104
Annual generation (kWh)	2368.70
Annual export (kWh)	1184.35
Annual on-site consumption (kWh)	1184.35

---

[13] For context, the average annual electricity consumption of a typical medium sized household in the UK is approximately 2700 kWh (Ofgem, 2025).

6.2. Estimating the expected real rate of return

This analysis focuses on expected rather than ex-post values, as the former more accurately reflects the conditions under which households decide whether to install a solar PV system. To estimate expectations for inflation and electricity prices, it is assumed that households use the average values from the preceding 2 years as a basis for forecasting future trends. While ex-post data are available, they do not represent the information available to decision-makers at the time of installation. For instance, the spike in electricity prices and inflation observed in 2022 could not have been anticipated by households that installed systems earlier.

The revenue from a solar PV installation consists of three components: generation payments, export payments, and savings on electricity costs. Let n be the total number of years considered. First, the expected real generation payment (RGP) is calculated as

$$E_t(RGP) = \sum_{i=1}^{n} \frac{G\cdot T^{G}\cdot[1+E_t(\pi^{RPI})]^{i-1}}{[1+E_t(\pi^{CPI})]^{i-1}} \tag{3}$$

where G represents the volume of electricity generated, and T^G denotes the generation tariff, which is indexed by the Retail Prices Index (RPI). The expected nominal values are then adjusted for inflation using the Consumer Price Index (CPI). Here, $E_t(\pi^{RPI})$ and $E_t(\pi^{CPI})$ refer to the expected inflation rates as measured by the RPI and CPI indices, respectively.[14]

Second, the expected real export payment (REP) is calculated as

$$E_t(REP) = \sum_{i=1}^{n} \frac{EX\cdot T^{EX}\cdot[1+E_t(\pi^{RPI})]^{i-1}}{[1+E_t(\pi^{CPI})]^{i-1}} \tag{4}$$

where EX is the volume of electricity exported and T^{EX} is the export tariff, also indexed by RPI and adjusted using CPI.

Third, the expected real saving (RS) from reduced electricity bills is calculated as

$$E_t(RS) = \sum_{i=1}^{n} \frac{C\cdot P^{e}\cdot[1+E_t(\pi^{CPI})]^{i-1}}{[1+E_t(\pi^{CPI})]^{i-1}} \tag{5}$$

where C is the volume of electricity consumed on-site and P^e is the retail electricity price, which is indexed by the CPI.

The expected total real revenue (TRR) over the lifetime of the solar PV system is the sum of the three components

$$E_t(TRR) = E_t(RGP) + E_t(REP) + E_t(RS) \tag{6}$$

The expected total real rate of return ($TRoR$) is then calculated as

$$E_t(TRoR) = \left[\frac{E_t(TRR) - IVN}{IVN}\right]\% \tag{7}$$

where INV is the initial installation cost. Finally, the expected average real rate of return ($ARoR$) over n years is

$$E_t(ARoR) = \frac{E_t(TRoR)}{n} \tag{8}$$

According to DECC, the FIT scheme was initially designed to deliver a return on investment of approximately 5 % for well-sited solar PV installations (DECC, 2011a).

Table 7
Expected investment returns for household solar PV installations in December 2011.

	Dec 2011	From March 3, 2012
Part A: Information		
Generation tariff (p/kWh)	43.30	21.00
Export tariff (p/kWh)	3.20	3.20
Expected inflation rate by RPI (%)	4.81	4.92
Expected inflation rate by CPI (%)	3.84	3.91
Expected retail electricity price (p/kWh)	12.11	12.32
Expected Bank Rate (%)	0.50	0.50
Part B: Calculation (25 years)		
Expected real generation payments (£)	28,732	14,000
Expected real exports payments (£)	1062	1067
Expected real electricity costs saved (£)	3586	3648
Expected total real revenue (£)	33,380	18,715
Initial costs (£)	9000	9000
Expected total real rate of return (%)	270.89 %	107.94 %
Expected average real rate of return (%)	10.84 %	4.32 %
Suggested rate of return in the 2011 review	4.50 %	

6.3. Case study: Household decisions in 2011

As installation costs began to decline, the UK government launched a review of the FIT scheme in 2011 (DECC, 2011a, 2012b) and subsequently decided to implement a substantial reduction in tariff rates from March 3, 2012. This section examines the decision-making process of households considering installation in December 2011.

Table 7A presents the relevant information for a typical domestic solar photovoltaic system (4 kW or less) installed on a building already occupied. In December 2011, the generation tariff stood at 43.3 pence/kWh; however, it was scheduled to drop to 21.0 pence/kWh from March 3, 2012 (DECC, 2012b). The export tariff remained unchanged at 3.2 pence/kWh.

In terms of inflation and electricity price expectations, it is assumed that, in December 2011, households formed expectations based on the average values from the preceding two years (December 2009 to November 2011). The expected inflation rates were 4.81 % using the RPI and 3.84 % using the CPI, and the expected retail electricity price was 12.11 pence/kWh (DESNZ, 2025a; ONS, 2025). Additionally, the expected Bank Rate was 0.5 %, derived from the same two-year average. For installations considered in March 2012, the expected values were updated using the average from March 2010 to February 2012.

Based on the information available to households in December 2011, Table 7B presents the expected total real revenue, the expected total real rate of return, and the expected average real rate of return. A 25-year time horizon is used in the calculation, reflecting the typical lifespan of most solar panels. Moreover, under the FIT scheme, solar PV projects installed before April 2012 were eligible for support over a 25-year period.

According to Table 7B, the expected total real revenue for a system installed in December 2011 was £33,380. Given installation costs of £9000 (DECC, 2011a), this corresponds to an expected total real rate of return of 270.89 % and an expected average real rate of return of 10.84 %.[15] This figure is substantially higher than the suggested return of approximately 5 % envisioned at the time the FIT scheme was introduced (DECC, 2011c), especially considering that the expected risk-free Bank Rate set by the Bank of England was only 0.5 %.

By comparison, for installations after March 2012, the expected total real revenue fell to £18,715. In both scenarios, households are assumed to have expected installation costs of £9,000, as the tariff reduction was intended to reflect cost reductions that had already occurred, rather than

---

[14] The Retail Prices Index (RPI) and the Consumer Prices Index (CPI), both published by the Office for National Statistics (ONS), are commonly used measures of inflation in the UK. RPI generally produces higher inflation estimates than CPI, mainly because it includes housing costs, which are excluded from CPI. This discrepancy has led to criticism that support schemes such as the Renewables Obligation and the Feed-in Tariff are overly generous, as they are indexed to RPI (Economic Affairs Committee, 2019).

[15] For simplicity, this analysis excludes maintenance and removal costs. If included, these costs would result in a slightly lower expected real rate of return.

anticipating further future declines. Under these assumptions, installations after March 2012 yielded an expected total real rate of return of 107.94 % and an expected average rate of return of 4.32 %. This figure is broadly consistent with the suggested return of 4.5 % for solar projects up to 4 kW outlined in the 2011 review (DECC, 2012a).

Thus, a solar PV installation in December 2011 represented an attractive investment opportunity, with an expected average real return of 10.84 % over a 25-year period. However, this return was more than halved following the tariff reduction implemented in March 2012. The surge in installations in 2011 suggests that households responded strongly to the financial incentives offered by the FIT scheme. Nevertheless, the installation cost of £9000 indicates that access to upfront funding remained a barrier for many households.

6.4. *Case study: Household decisions in 2015*

As installation costs continued to decline, the government launched a second review on the FIT scheme in 2015 (DECC, 2015a, 2015b), leading to another substantial reduction in tariff rates from February 8, 2016. This section examines the decision-making process of households in December 2015. Although the support period for new installations was reduced to 20 years, a 25-year horizon is still applied in the analysis, as households are expected to continue saving on electricity costs beyond the tariff duration.[16]

Table 8A presents the relevant information for a typical solar PV system (4 kW or less) installed on an existing building. In December 2015, the generation tariff was 11.22 pence/kWh, which fell to 3.95 pence/kWh from February 8, 2016 (Ofgem, 2017). The export tariff remained relatively stable, at 4.85 pence/kWh in December 2015 and 4.91 pence/kWh after the reduction.

For inflation and electricity price expectations, it is assumed that households used the average values from the preceding two years (December 2013 to November 2015). Based on this, the expected inflation rates were 1.75 % (RPI) and 0.83 % (CPI), while the expected retail electricity price was 15.22 pence/kWh (DESNZ, 2025a; ONS, 2025). Additionally, the expected Bank Rate was 0.5 percent, derived from the same two-year average. For installations considered in February 2016, the expected values were updated using the average from February 2014 to January 2016.

Table 8
Expected investment returns for household solar PV installations in December 2015.

	Dec 2015	From Feb 8, 2016
Part A: Information		
Generation tariff (p/kWh)	11.22	3.95
Export tariff (p/kWh)	4.85	4.91
Expected inflation rate by RPI (%)	1.75	1.62
Expected inflation rate by CPI (%)	0.83	0.68
Expected retail electricity price (p/kWh)	15.08	15.07
Expected Bank Rate (%)	0.50	0.50
Part B: Calculation (25 years)		
Expected real generation payments (£)	5802	2047
Expected real exports payments (£)	1254	1272
Expected real electricity costs saved (£)	4465	4462
Expected total real revenue (£)	11,521	7781
Initial costs (£)	4357	4357
Expected total real rate of return (%)	164.43 %	78.59 %
Expected average real rate of return (%)	6.58 %	3.14 %
Suggested rate of return in the 2015 review	4.80 %	

Table 8B shows that, for the December 2015 installation, the expected total real revenue was £11,521. Given an installation cost of £4357 (DESNZ, 2025c), this results in an expected total real rate of return of 164.43 % and an expected average real rate of return of 6.58 %. In contrast, for an installation in February 2016, the expected total real revenue was £7,781, yielding a total real rate of return of 78.59 % and an average rate of return of 3.14 %. Compared with the suggested rate of return of 4.8 % outlined in the 2015 review, the results indicate that the pre-planned tariff degression introduced in 2012 did not adequately reflect the pace of declining installation costs.

Therefore, installing solar PV in December 2015 represented a reasonable investment opportunity, with an expected real return of 6.58 % over a 25-year period. However, this return fell by more than half to 3.14 % following the substantial reduction in tariff rates from February 2016. The surge in installations observed in 2015 suggests that households once again responded actively to the financial incentives provided by the FIT scheme, as the investment became significantly less attractive after the reduction.

The lower installation cost of £4357 in December 2015 enabled households with more limited financial resources to benefit from the investment opportunity. However, the rate of return was lower compared to installations made in December 2011. When combined with the estimation results, this suggests that higher-income regions, which were more active in installing solar projects during the first peak, secured greater returns than lower-income regions that were more engaged during the second peak. This outcome highlights the issue of intertemporal unfairness within the FIT scheme, as returns on investment in solar PV systems varied significantly according to the timing of installation, particularly between 2011 and 2015 and between periods before and after the two major reductions in tariff rates.

7. Conclusion

While survey studies have suggested that household income should have a positive influence on the uptake of solar PV, empirical studies in the UK have reported either insignificant or inverse relationships based on cumulative capacity. Motivated by this inconsistency, we analysed the annual added installed capacity of solar PV across 323 local authority districts and found that disposable income had a positive relationship over the entire sample period from 2010 to 2018.

To capture potential changes over time, we focused on two specific years, 2011 and 2015, when notable peaks in installation activity were observed. The analysis of these two peak years provided an opportunity to assess whether the determinants of solar PV uptake shifted during different phases of the FIT scheme. Based on the estimated results for the two specific years, we found that the correlation between disposable income and solar PV uptake was positive in 2011 but became negative in 2015. Robustness checks using two alternative measures — the annual installed capacity of projects below 10 kW and the annual number of installations — confirmed the consistency of these findings. The positive relationship observed in 2011 indicates that higher-income regions were more likely to afford the relatively high installation costs during the early stage of the scheme. In contrast, the negative relationship in 2015 suggests that lower-income regions began to catch up as installation costs declined. Therefore, throughout the FIT scheme, higher-income regions adopted solar PV earlier, while lower-income regions gradually increased their participation in the later stages.

We then examined the decision-making process of households during the two periods of peak solar PV installations. In the first peak in 2011, prior to the significant reduction in tariffs in March 2012, our analysis indicates that a solar PV project installed in December 2011 would yield an expected real rate of return of 10.84 percent. This return decreased to 4.32 percent for projects installed after March 2012. During the second peak in 2015, before another major tariff reduction in February 2016, the expected real rate of return for a solar PV installation was 6.58 percent, falling to 3.14 percent for installations after February 2016.

---

[16] In the analysis based on a 20-year horizon, the expected average real rates of return are 7.20 % for installations in December 2015 and 2.91 % for those in February 2016.

In both instances, the surge in installation activity occurred before the substantial decline in expected returns, suggesting that households responded strongly to the financial incentives provided by the FIT scheme. This response confirms the scheme's effectiveness in promoting the adoption of solar PV systems. However, the expected rates of return were generally higher than the 4.5 to 5 percent target set out in the scheme's design, particularly the 10.84 percent in 2011. This finding suggests that there were insufficient tariff adjustments to offset the decline in installation costs.

Two major lessons can be drawn from this analysis with important implications for policymaking. Although the FIT scheme was closed in 2019, the UK's experience offers valuable insights for other countries that are still promoting solar energy and other renewable technologies, such as heat pumps. First, this study reveals the intertemporal unfairness of the FIT scheme, as projects installed at different points in time yielded substantially different rates of return. The first source of disparity arises from the variation in returns between the two installation peaks in 2011 and 2015, while the second stems from the sharp differences in returns observed before and after the major tariff reductions. Since household income plays a significant role in determining the ability to invest in solar PV, this intertemporal unfairness disproportionately benefited higher-income regions. These households were better positioned to access the most favourable investment opportunities, as they had sufficient financial resources to cover the high installation costs during the early phase of the scheme.

Second, the regulator relied on two major policy reviews, conducted in 2011 and 2015, to implement significant changes to tariff rates. Although a degression mechanism was introduced after 2012 to provide pre-planned and periodic reductions in tariffs, this approach may not have fully captured the pace of declining technology costs. The need for a second policy review in 2015 confirms this limitation. We suggest developing a dynamic forecasting model to ensure more consistent returns for both early and late adopters. In such a model, a targeted rate of return could be combined with forecast values of key variables, such as inflation and electricity prices, to estimate tariff levels more frequently and promptly. For instance, using a rolling average of the previous two years, tariff rates could be adjusted monthly to reflect revised expectations. Although the model would rely on expected rather than actual outcomes, it could enable more responsive policymaking, helping to avoid abrupt tariff reductions and the associated sharp declines in expected returns.

This study has several limitations, and future research could explore several promising directions for further investigation. First, although the analysis identifies higher-income regions as early adopters, it does not thoroughly examine the underlying reasons for this pattern. For instance, given the limited capacity of the solar installation industry in the early years, it is possible that installers initially concentrated their marketing and service efforts in higher-income areas. Additionally, peer effects may have played a role, with households more likely to install solar panels after observing installations in nearby areas or exposure through media coverage. Further investigation into these behavioral and industry-level factors would enhance the understanding of consumer behavior and the broader drivers of solar PV adoption, complementing the catch-up effect documented in this study. Second, this study does not fully address the role of perceived risk in household decision-making. When the FIT scheme was introduced in 2010, solar PV systems were still considered novel technologies by many households. As such, households may have perceived installations as relatively risky investments and therefore required a higher expected rate of return to compensate for this uncertainty. Further research into households' risk perceptions and the impacts on the required rate of return would provide valuable insights from a financial perspective. Third, while the analysis focuses on the intertemporal fairness of the FIT scheme, the issue of intratemporal fairness — meaning fairness across households at a given point in time — also deserves attention. Investigating this would require the collection of household-level data to assess how income influences access to solar PV, along with a careful review of the funding structure of the FIT scheme and consideration of alternative funding models that may improve equity. Fourth, while this study focuses on factors such as income and solar radiation influencing the adoption of solar PV, future research could explore the broader economic impacts of solar energy deployment.[17]

CRediT authorship contribution statement

Bill Lee: Writing – original draft, Software, Formal analysis, Data curation. **Jinke Li:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Jing Shao:** Writing – review & editing, Validation, Software, Methodology.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

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

Data availability

Data will be made available on request.

References

Aldersey-Williams, J., Broadbent, I.D., Strachan, P.A., 2020. Analysis of United Kingdom offshore wind farm performance using public data: Improving the evidence base for policymaking. Util. Policy 62. https://doi.org/10.1016/j.jup.2019.100985.

Allen, S.R., Hammond, G.P., McManus, M.C., 2008. Prospects for and barriers to domestic micro-generation: A United Kingdom perspective. Appl. Energy 85 (6), 528–544. https://doi.org/10.1016/j.apenergy.2007.09.006.

Balcombe, P., Rigby, D., Azapagic, A., 2013. Motivations and barriers associated with adopting microgeneration energy technologies in the UK. Renew. Sustain. Energy Rev. 22, 655–666. https://doi.org/10.1016/j.rser.2013.02.012.

Balcombe, P., Rigby, D., Azapagic, A., 2014. Investigating the importance of motivations and barriers related to microgeneration uptake in the UK. Appl. Energy 130, 403–418. https://doi.org/10.1016/j.apenergy.2014.05.047.

Balta-Ozkan, N., Yildirim, J., Connor, P.M., 2015. Regional distribution of photovoltaic deployment in the UK and its determinants: A spatial econometric approach. Energy Econ. 51, 417–429. https://doi.org/10.1016/j.eneco.2015.08.003.

Balta-Ozkan, N., Yildirim, J., Connor, P.M., Truckell, I., Hart, P., 2021. Energy transition at local level: Analyzing the role of peer effects and socio-economic factors on UK solar photovoltaic deployment. Energy Policy 148, 112004. https://doi.org/10.1016/j.enpol.2020.112004.

BEIS, 2020. Feed-in Tariff load factor analysis. Retrieved from. https://assets.publishing.service.gov.uk/media/61c3164c8fa8f54c0e4571b5/Feed-in_Tariff_load_factor_analysis_2020-21.pdf.

Bergman, N., Hawkes, A., Brett, D.J.L., Baker, P., Barton, J., Blanchard, R., Woodman, B., 2009. UK microgeneration. Part I: policy and behavioural aspects. Proceedings of the Institution of Civil Engineers - Energy 162 (1), 23–36. https://doi.org/10.1680/ener.2009.162.1.23.

Best, R., Burke, P.J., Nishitateno, S., 2019. Evaluating the effectiveness of Australia's small-scale renewable energy scheme for rooftop solar. Energy Econ. 84, 104475. https://doi.org/10.1016/j.eneco.2019.104475.

---

[17] For example, prior studies have examined the impacts of wind generation on both consumers and the wider economy in the UK (Aldersey-Williams et al., 2020; Shao et al., 2023).

Best, R., Chareunsy, A., 2022. The impact of income on household solar panel uptake: Exploring diverse results using Australian data. Energy Econ. 112. https://doi.org/10.1016/j.eneco.2022.106124.

Best, R., Marrone, M., Linnenluecke, M., 2024. Do income and capital influence household solar panel investment? A meta-regression. Energy J. 45 (4), 159–177. https://doi.org/10.1177/01956574241284501.

Bondio, S., Shahnazari, M., McHugh, A., 2018. The technology of the middle class: understanding the fulfilment of adoption intentions in Queensland's rapid uptake residential solar photovoltaics market. Renew. Sustain. Energy Rev. 93, 642–651. https://doi.org/10.1016/j.rser.2018.05.035.

Castaneda, M., Zapata, S., Cherni, J., Aristizabal, A.J., Dyner, I., 2020. The long-term effects of cautious feed-in tariff reductions on photovoltaic generation in the UK residential sector. Renew. Energy 155, 1432–1443.

Cherrington, R., Goodship, V., Longfield, A., Kirwan, K., 2013. The feed-in tariff in the UK: A case study focus on domestic photovoltaic systems. Renew. Energy 50, 421–426.

Claudy, M.C., Michelsen, C., O'Driscoll, A., 2011. The diffusion of microgeneration technologies–assessing the influence of perceived product characteristics on home owners' willingness to pay. Energy Policy 39 (3), 1459–1469. https://doi.org/10.1016/j.enpol.2010.12.018.

Claudy, M.C., Michelsen, C., O'Driscoll, A., Mullen, M.R., 2010. Consumer awareness in the adoption of microgeneration technologies. Renew. Sustain. Energy Rev. 14 (7), 2154–2160. https://doi.org/10.1016/j.rser.2010.03.028.

Collier, S.H.C., House, J.I., Connor, P.M., Harris, R., 2023. Distributed local energy: Assessing the determinants of domestic-scale solar photovoltaic uptake at the local level across England and Wales. Renew. Sustain. Energy Rev. 171. https://doi.org/10.1016/j.rser.2022.113036.

Copiello, S., Grillenzoni, C., 2021. Robust space–time modeling of solar photovoltaic deployment. Energy Rep. 7, 657–676. https://doi.org/10.1016/j.egyr.2021.07.087.

De Groote, O., Pepermans, G., Verboven, F., 2016. Heterogeneity in the adoption of photovoltaic systems in Flanders. Energy Econ. 59, 45–57. https://doi.org/10.1016/j.eneco.2016.07.008.

DECC, 2011a. Feed-in tariffs scheme: consultation on Comprehensive Review Phase 1 – tariffs for solar PV. Retrieved from. https://www.gov.uk/government/consultations/feed-in-tariffs-first-phase-of-a-comprehensive-review.

DECC, 2011b. Microgeneration Strategy. Retrieved from. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48114/2015-microgeneration-strategy.pdf.

DECC, 2011c. Updates to the feed-in tariffs model documentation of changes for solar PV consultation. Retrieved from. https://assets.publishing.service.gov.uk/media/5a790b48e5274a2acd18bc60/3365-updates-to-fits-model-doc.pdf.

DECC, 2012a. Feed-in tariffs scheme: Consultation on comprehensive review phase 2A: Solar PV cost control. Retrieved from. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/43079/4309-feedin-tariffs-scheme-phase-2a-consultation-paper.pdf.

DECC, 2012b. Feed-in tariffs scheme: Government response to consultation on comprehensive review phase 1 – tariffs for solar PV. Retrieved from. https://www.gov.uk/government/consultations/feed-in-tariffs-first-phase-of-a-comprehensive-review.

DECC, 2012c. Solar PV cost update. Retrieved from. https://www.gov.uk/government/consultations/solar-pv-cost-controls-comprehensive-review-phase-2a.

DECC, 2015a. Consultation on a review of the feed-in tariffs scheme. Retrieved from. https://www.gov.uk/government/consultations/consultation-on-a-review-of-the-feed-in-tariff-scheme.

DECC, 2015b. Review of the feed-in tariffs scheme: Government response. Retrieved from. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/487300/FITs_Review_Govt__response_Final.pdf.

Defeuilley, C., 2019. Energy transition and the future(s) of the electricity sector. Util. Policy 57, 97–105. https://doi.org/10.1016/j.jup.2019.03.002.

DESNZ, 2025a. International energy price comparison statistics. Retrieved from. https://www.gov.uk/government/collections/international-energy-price-comparisons.

DESNZ, 2025b. Regional and local authority electricity consumption statistics. Retrieved from. https://www.gov.uk/government/statistics/regional-and-local-authority-electricity-consumption-statistics#full-publication-update-history.

DESNZ, 2025c. Solar photovoltaic (PV) cost data. Retrieved from. https://www.gov.uk/government/statistics/solar-pv-cost-data.

Dharshing, S., 2017. Household dynamics of technology adoption: A spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany. Energy Res. Social Sci. 23, 113–124. https://doi.org/10.1016/j.erss.2016.10.012.

Economic Affairs Committee, 2019. Measuring inflation. Retrieved from. https://publications.parliament.uk/pa/ld201719/ldselect/ldeconaf/246/246.pdf.

European Commission, 2022. Photovoltaic geographical information system. Retrieved from. https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#api_5.1.

Faiers, A., Neame, C., 2006. Consumer attitudes towards domestic solar power systems. Energy Policy 34 (14), 1797–1806. https://doi.org/10.1016/j.enpol.2005.01.001.

Gooding, J., Edwards, H., Giesekam, J., Crook, R., 2013. Solar City Indicator: A methodology to predict city level PV installed capacity by combining physical capacity and socio-economic factors. Sol. Energy 95, 325–335. https://doi.org/10.1016/j.solener.2013.06.027.

IRENA, 2020. Renewable power generation costs in 2020. International Renewable Energy Agency. Retrieved from. https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.

Islam, T., Meade, N., 2013. The impact of attribute preferences on adoption timing: The case of photo-voltaic (PV) solar cells for household electricity generation. Energy Policy 55, 521–530. https://doi.org/10.1016/j.enpol.2012.12.041.

Jacksohn, A., Grösche, P., Rehdanz, K., Schröder, C., 2019. Drivers of renewable technology adoption in the household sector. Energy Econ. 81, 216–226. https://doi.org/10.1016/j.eneco.2019.04.001.

Keirstead, J., 2007. Behavioural responses to photovoltaic systems in the UK domestic sector. Energy Policy 35 (8), 4128–4141. https://doi.org/10.1016/j.enpol.2007.02.019.

Kurdgelashvili, L., Shih, C.-H., Yang, F., Garg, M., 2019. An empirical analysis of county-level residential PV adoption in California. Technol. Forecast. Soc. Change 139, 321–333. https://doi.org/10.1016/j.techfore.2018.11.021.

Li, J., Liu, G., Shao, J., 2020. Understanding the ROC transfer payment in the renewable obligation with the recycling mechanism in the United Kingdom. Energy Econ. 87, 104701. https://doi.org/10.1016/j.eneco.2020.104701.

Lukanov, B.R., Krieger, E.M., 2019. Distributed solar and environmental justice: Exploring the demographic and socio-economic trends of residential PV adoption in California. Energy Policy 134. https://doi.org/10.1016/j.enpol.2019.110935.

Mildenberger, M., Howe, P.D., Miljanich, C., 2019. Households with solar installations are ideologically diverse and more politically active than their neighbours. Nat. Energy 4 (12), 1033–1039. https://doi.org/10.1038/s41560-019-0498-8.

Moore, G., 2014. Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers, third ed. HarperCollins Publishers.

Muhammad-Sukki, F., Ramirez-Iniguez, R., Munir, A.B., Mohd Yasin, S.H., Abu-Bakar, S.H., McMeekin, S.G., Stewart, B.G., 2013. Revised feed-in tariff for solar photovoltaic in the United Kingdom: A cloudy future ahead? Energy Policy 52, 832–838. https://doi.org/10.1016/j.enpol.2012.09.062.

Müller, S., Rode, J., 2013. The adoption of photovoltaic systems in Wiesbaden, Germany. Econ. Innovat. N. Technol. 22 (5), 519–535. https://doi.org/10.1080/10438599.2013.804333.

Nemet, G.F., 2006. Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy 34 (17), 3218–3232. https://doi.org/10.1016/j.enpol.2005.06.020.

NHBC Foundation, 2011. Introduction to Feed-In Tariffs. Milton Keynes. IHS BRE Press. Retrieved from. https://www.nhbcfoundation.org/wp-content/uploads/2016/05/NF23-Introduction-to-Feed-in-Tariffs.pdf.

Ofgem, 2011. Feed-in tariff annual report 2010-11. Retrieved from. https://www.ofgem.gov.uk/publications/feed-tariff-fit-annual-report-2010-2011.

Ofgem, 2013. Feed-in tariff annual report 2012-13. Retrieved from. https://www.ofgem.gov.uk/publications/feed-tariff-fit-annual-report-2012-2013.

Ofgem, 2017. Feed-in tariff (FIT): tariff tables. Retrieved from. https://www.ofgem.gov.uk/environmental-and-social-schemes/feed-tariffs-fit/tariffs-and-payments?sort=publication_date&page=2.

Ofgem, 2021. Feed-in tariff installation report 30 June 2021. Retrieved from. https://www.ofgem.gov.uk/publications/feed-tariff-installation-report-30-june-2021.

Ofgem, 2023. Feed-in tariff (FIT): tariff table 1 April 2023. Retrieved from. https://www.ofgem.gov.uk/publications/feed-tariff-fit-tariff-table-1-april-2023.

Ofgem, 2025. Average gas and electricity usage. Retrieved from. https://www.ofgem.gov.uk/average-gas-and-electricity-usage.

ONS, 2021. Regional gross disposable household income, UK: 1997 to 2019. Retrieved from. https://www.gov.uk/government/statistics/regional-gross-disposable-household-income-uk-1997-to-2019.

ONS, 2025. Inflation and price indices. Retrieved from. https://www.ons.gov.uk/economy/inflationandpriceindices.

ONS, 2011. Census 2011. Retrieved from. https://www.ons.gov.uk/census/2011census.

Palm, A., 2020. Early adopters and their motives: Differences between earlier and later adopters of residential solar photovoltaics. Renew. Sustain. Energy Rev. 133. https://doi.org/10.1016/j.rser.2020.110142.

Parveen, Z., Salman, V., Jamil, F., 2025. Examining the challenges and drivers of solar photovoltaic adoption in the twin cities of Pakistan. Util. Policy 96. https://doi.org/10.1016/j.jup.2025.102005.

Pearce, P., Slade, R., 2018. Feed-in tariffs for solar microgeneration: Policy evaluation and capacity projections using a realistic agent-based model. Energy Policy 116, 95–111. https://doi.org/10.1016/j.enpol.2018.01.060.

Qadir, S.A., Ali, A., Islam, M.T., Shahid, M., 2025. Scenario analysis of Saudi Arabia's residential solar energy incentives. Util. Policy 96. https://doi.org/10.1016/j.jup.2025.101970.

Richter, L.-L., 2013. Social effects in the diffusion of solar photovoltaic technology in the UK. Cambridge Working Paper in Economics 1357. https://doi.org/10.17863/CAM.5680.

Scarpa, R., Willis, K., 2010. Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies. Energy Econ. 32 (1), 129–136. https://doi.org/10.1016/j.eneco.2009.06.004.

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. Renew. Sustain. Energy Rev. 153, 111788. https://doi.org/10.1016/j.rser.2021.111788.

Shao, J., Li, J., Liu, G., 2021. Vertical integration, recycling mechanism, and disadvantaged independent suppliers in the renewable obligation in the UK. Energy Econ. 94, 105093. https://doi.org/10.1016/j.eneco.2020.105093.

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? Renew. Sustain. Energy Rev. 183, 113498. https://doi.org/10.1016/j.rser.2023.113498.

van der Kam, M.J., Meelen, A.A.H., van Sark, W.G.J.H.M., Alkemade, F., 2018. Diffusion of solar photovoltaic systems and electric vehicles among Dutch consumers: Implications for the energy transition. Energy Res. Social Sci. 46, 68–85. https://doi.org/10.1016/j.erss.2018.06.003.

Vasseur, V., Kemp, R., 2015. The adoption of PV in The Netherlands: A statistical analysis of adoption factors. Renew. Sustain. Energy Rev. 41, 483–494. https://doi.org/10.1016/j.rser.2014.08.020.

Villadsen, A.R., Wulff, J.N., 2020. Statistical myths about log-transformed dependent variables and how to better estimate exponential models. Br. J. Manag. 32 (3), 779–796. https://doi.org/10.1111/1467-8551.12431.

Wang, Y., Li, J., O'Leary, N., Shao, J., 2024a. Banding: A game changer in the Renewables Obligation scheme in the United Kingdom. Energy Econ. 130, 107331. https://doi.org/10.1016/j.eneco.2024.107331.

Wang, Y., Li, J., O'Leary, N., Shao, J., 2024b. Excess demand or excess supply? A comparison of renewable energy certificate markets in the United Kingdom and Australia. Util. Policy 86, 101705. https://doi.org/10.1016/j.jup.2023.101705.

Watson, J., Sauter, R., Bahaj, B., James, P., Myers, L., Wing, R., 2008. Domestic micro-generation: Economic, regulatory and policy issues for the UK. Energy Policy 36 (8), 3095–3106. https://doi.org/10.1016/j.enpol.2008.04.028.

White, L.V., 2019. Increasing residential solar installations in California: Have local permitting processes historically driven differences between cities? Energy Policy 124, 46–53. https://doi.org/10.1016/j.enpol.2018.09.034.