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Tenure, funding scheme and spatial diffusion of residential retrofit across Great Britain

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PEER-REVIEWED PAPER

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ABSTRACT

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Accelerating residential retrofit is central to net-zero targets, yet uptake remains uneven across places, tenures, and delivery funding scheme type. While a growing literature documents spatial diffusion of visible low-carbon technologies, little is known about how diffusion processes differ between owner-occupied, private, and social rental housing, or how these tenure channels interact across space.

This paper presents a large-scale spatial analysis of residential retrofit diffusion across local authorities (LAs) in England, Wales, and Scotland, distinguishing between market-led incentive schemes, namely the Feed-in Tariff (FiT), Renewable Heat Incentive (RHI), and Green Deal, and the supplier-obligation delivery scheme, Energy Company Obligation (ECO), as well as between owner/private and social housing tenure. Using longitudinal Energy Performance Certificate (EPC) records from 2012–2024, we infer retrofit events for solar photovoltaics (PV), wall insulation (WI), and heat pumps (HP), and attribute them to funding scheme type and housing tenure. Events are aggregated to LAs and analysed using global Moran's I statistics and dynamic two-way fixed-effects panel models to identify direct and indirect (spillover) effects.

Results show that diffusion mechanisms are scheme-tenure-technology specific. PV adoption under market incentive schemes exhibits strong spatial clustering and dynamic spillovers concentrated in owner-occupied and private-rented housing. WI shows weaker but still detectable within-tenure diffusion, particularly under supplier-obligation scheme, whereas HP adoption exhibits little evidence of positive spatial spillovers. Cross-tenure effects are asymmetric and technology-specific: for PV under market incentives, owner/private adoption stimulates neighbouring social-sector uptake, while social housing delivery is negatively associated with neighbouring owner/private uptake. These findings suggest that policy design shapes not only who adopts, but also how adoption spreads spatially across mixed-tenure areas.

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INTRODUCTION

Decarbonising the existing housing stock is one of the most pressing challenges for European climate policy. In Great Britain, residential buildings account for approximately 14% of greenhouse gas emissions (DESNZ, 2024), and the pace of retrofit including insulation upgrades, heat pump (HP) installations, and solar photovoltaics (PV) deployment, remains far below what is required to meet net-zero targets. Retrofit delivery policy mechanisms in the UK can be divided between centrally administered supplier-obligation scheme, such as the Energy Company Obligation (ECO), and market-facing incentive schemes such as the Feed-in Tariff (FiT), Renewable Heat Incentive (RHI), and Green Deal. We refer to these two categories collectively as 'funding scheme type' throughout this paper. These mechanisms target different market segments and operate through fundamentally different delivery logics.

A growing literature has documented that low-carbon technology adoption tends to cluster geographically. Spatial diffusion is the process by which adoption in one area stimulates adoption in neighbouring areas and has been observed for PV across multiple contexts (Bollinger and Gillingham, 2012; Müller and Rode, 2013; Rode and Weber, 2016). Peer effects, installer networks, and the visibility of rooftop installations have been proposed as underlying mechanisms. However, most existing work either focuses on a single technology or ignores the role of tenure and funding scheme type. The implicit assumption is that diffusion operates uniformly across the housing stock, which is unlikely given the different incentive structures, ownership arrangements, and decision-making processes that characterise owner-occupied, private rented, and social housing.

This paper addresses this gap by examining how spatial diffusion of residential retrofit varies across tenure types, scheme designs, and technologies in Great Britain. We make three contributions. First, we construct a large-scale panel dataset of retrofit events at the Local Authorities (LA) level using Energy Performance Certificate (EPC) records from 2012–2024, with events attributed to scheme type and tenure. Second, we apply global Moran's I statistics to document the spatial structure of adoption across years, revealing striking scheme-tenure-technology specific clustering patterns. Third, we estimate dynamic two-way fixed-effects panel models with spatial lags to quantify spillover effects within and across tenure channels across three retrofit technologies, PV, wall insulation (WI), and HP, providing a direct test of scheme-tenure-technology specific asymmetric diffusion in the residential retrofit context.

BACKGROUND

SPATIAL DIFFUSION OF LOW-CARBON TECHNOLOGIES

Evidence of spatial clustering in residential low-carbon technology adoption is well established for PV. Müller and Rode (2013) showed that PV adoption in Wiesbaden spread through neighbourhood peer effects, with proximity to existing installations a strong predictor of new adoptions. Bollinger and Gillingham (2012) found similar neighbourhood effects in California, attributing them to visibility and social learning. Rode and Weber (2016) extended this to county-level analysis in Germany, finding that spatial lags of past adoption significantly predict current uptake even after controlling for socioeconomic factors.

The mechanisms proposed in this literature include: the visibility of rooftop installations generating awareness and social norm signalling (Nolan et al., 2008); installer networks that concentrate marketing and installation capacity locally (Palm, 2018); and learning spillovers through which cost and performance information diffuses through social networks (Rogers, 2003). These mechanisms are plausibly technology-specific, for example PV panels are highly visible due to their rooftop placement, potentially enhancing neighbourhood awareness and imitation effects. By contrast, WI is only externally visible in some forms (e.g. external WI), while HP, although air-source units have externally visible components, are typically ground-mounted and may be partially obscured by walls, gardens, or other landscaping barriers. Moreover, HP adoption involves relatively high capital costs, installation complexity, and property-specific suitability constraints, factors that may suppress neighbourhood imitation effects regardless of visibility. Such mechanisms may also be attenuated or absent where households are not the primary retrofit decision-makers.

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TENURE AND FUNDING SCHEME TYPE AS MODERATORS OF DIFFUSION

The housing tenure context matters for diffusion because it shapes who makes adoption decisions, what incentives they face, and through what channels information flows. Owner-occupiers decide directly, face long investment horizons, and are susceptible to neighbourhood norms and installer outreach. Private landlords face split-incentive problems that depress voluntary investment (Gillingham et al., 2012). Social housing is managed by LAs or housing associations whose retrofit delivery approach are shaped by professionally administered procurement, centralised funding, and geographic targeting, rather than by the individually motivated, norm-driven decision-making that characterises diffusion in owner-occupied markets. Supplier-obligation scheme in Great Britain, principally ECO, ran across four iterations (ECO1–ECO4) throughout the study period and explicitly targeted lower-income and fuel-poor households. Market-led schemes such as FiT, RHI, and Green Deal were structurally more accessible to owner-occupiers with greater financial capital and longer investment horizons. These differences in funding scheme reach and delivery logic suggest that the spatial structure of retrofit adoption may differ between scheme types and tenure categories, yet this has not been tested empirically at scale across multiple technologies.

RESEARCH GAP

Existing spatial analyses of retrofit diffusion typically aggregate across tenure types or focusses on a single technology (Balta-Ozkan et al., 2015; Graziano and Gillingham, 2015). Large-scale administrative datasets such as EPC records offer the potential to disaggregate by tenure, scheme, and technology simultaneously, but have rarely been used for spatial diffusion analysis at the LA scale. This paper exploits the breadth and longitudinal depth of the EPC register in England, Wales, and Scotland to address this gap, providing a comprehensive multi-technology, multi-tenure, multi-scheme analysis of retrofit spatial spillovers conducted at a national scale.

DATA AND METHODS

DATA SOURCES

The primary data source is the EPC register for England and Wales (MHCLG, 2025) and Scotland (Energy Saving Trust, 2025), covering the period 2012–2024. EPC records contain property-level information on floor area, construction date, property type, tenure, energy efficiency rating, and the presence of specific energy efficiency measures. Following established practice (Wenninger et al., 2022), we use longitudinal sequences of EPC lodgements for the same property to infer retrofit events for PV, WI, and HP (similar approach as in Mirzaie and Radmard (2026)).

A retrofit event is identified when a measure is absent in one EPC lodgement and present in a subsequent lodgement for the same property, subject to data quality filters (minimum floor area 20 m², lodgement date within 2012–2024, and a matching funding transaction record). Retrofit events are then classified by scheme type, distinguishing between market-led incentive schemes (FiT, RHI, Green Deal) or the supplier-obligation (ECO) scheme, using EPC transaction type codes. These transaction type documents if the EPC was produced for a property sale, rental, stock condition survey, or in support of any of the aforementioned funding scheme applications.

Tenure is recorded directly from the EPC: we distinguish owner-occupied/private rental from social rented housing. Retrofit events are aggregated by LA, year, technology, scheme type, and tenure, yielding a panel of 349 LAs across 13 years. LAs in England average approximately 190,000 inhabitants, providing a meaningful geographic unit for detecting aggregate diffusion trends across areas, even if underlying peer interactions may operate at finer spatial scales. City of London and Northern Ireland were excluded due to data unavailability. The spatial structure of LAs is defined using the Local Authority District boundaries (LAD May 2025, ONS) and a row-standardised Queen contiguity weights matrix. Six island LAs with no neighbours are treated as isolates in the spatial analysis.

SPATIAL CLUSTERING ANALYSIS

To assess whether retrofit adoption is spatially structured – that is, whether high-adoption areas tend to cluster next to other high-adoption areas rather than being distributed randomly across the map – we compute Global Moran's I annually for each technology–scheme–tenure subgroup. Moran's I is a widely used measure of spatial autocorrelation that summarises the degree to which similar values co-occur in neighbouring areas. It ranges from −1 (perfect dispersion) to +1 (perfect clustering), with values near zero indicating spatial randomness. Significance is assessed using permutation tests (999 simulations). Year-by-year trajectories allow us to characterise how clustering evolves across the study period and how it varies across tenure, scheme, and technology.

DYNAMIC SPATIAL SPILLOVER MODEL

Spatial clustering alone does not establish whether adoption in one area actively stimulates adoption in neighbouring areas over time, or whether high-adoption areas simply share common characteristics such as wealth, climate, or installer availability. To distinguish between these possibilities, we test for dynamic spillover effects – that is, whether higher retrofit adoption in neighbouring local authorities in one year predicts higher adoption in a focal local authority in the following year, after controlling for local momentum and national policy shocks. To test this, we estimate the following dynamic two-way fixed-effects panel model for each technology-scheme-tenure subgroup:

$$\log\left(1 + y_{it}\right) = \alpha_i + \gamma_i + \beta \cdot Wy_{i,t-1} + \rho \cdot \log\left(1 + y_{i,t-1}\right) + \varepsilon_{it}$$

where y_{it} is the count of retrofit events in LA i in year t; $Wy_{i,t-1}$ is the spatially lagged (row-standardised Queen contiguity) adoption in neighbouring LAs in the previous year; $\log(1 + y_{i,t-1})$ is the own temporal lag capturing local momentum; α_i are LA fixed effects absorbing time-invariant area characteristics; and γ_t are year fixed effects absorbing national policy and macroeconomic shocks. Standard errors are clustered by LA. The coefficient β identifies the marginal spillover effect: the degree to which higher neighbouring adoption last year predicts higher focal-LA adoption this year, after controlling for local persistence and common shocks.

To test for asymmetric cross-tenure spillovers, we extend this model by including spatial lags of both tenure channels simultaneously as regressors. For the social housing outcome, we add Wy_owner as a predictor alongside the own-channel social lag; for the owner/private outcome, we add Wy_social. This identifies whether adoption in one tenure channel spills over into the other and whether the effects are symmetric. The specification is estimated separately for each technology–scheme combination, yielding twelve models in total (3 technologies × 2 schemes × 2 tenure equations).

RESULTS

SPATIAL CLUSTERING OF RETROFIT ADOPTION

Table 1 summarises global Moran's I statistics for PV under market incentive schemes by tenure for 2012–24. The contrast between tenure groups is stark. For owner-occupied and private rental housing, Moran's I is very high throughout the FiT period, reaching 0.64 in 2013 and peaking at 0.73 in 2015–2016 (all $p = 0.001$). This indicates that high-adoption LAs were strongly concentrated next to other high-adoption LAs; a pattern consistent with installer clustering, peer visibility effects, and regional supply chain dynamics. Clustering moderates after 2019, particularly during the COVID-19 period (I = 0.20 in 2020), then partially recovers in 2023 (I = 0.48), likely reflecting renewed market activity under rising energy prices.

By contrast, PV adoption in social housing under market incentive schemes shows near-zero and statistically insignificant Moran's I in most years. The exceptions are 2015–2017, when I rises to 0.23–0.30 ($p = 0.001$), coinciding with a concentrated burst of social housing FiT activity. Outside this window, social housing PV adoption under market schemes lacks discernible spatial structure, indicating scheme-specific allocation rather than neighbourhood spillover. Under supplier-obligation schemes, PV clustering for owner/private is strong in 2015–2019 (I ≈ 0.37–0.69) but weaker thereafter, while social housing clustering is moderate in some years and inconsistent overall, and consistent with geographic batching in ECO delivery rather than organic diffusion.

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YEAR	OWNER-OCCUPIED AND PRIVATE RENTAL			SOCIAL HOUSING			SIGNIFICANCE
	I	P	Z	I	P	Z	
2012	0.560	0.001	20.0	–0.000	0.146	0.09	Owner only
2013	0.642	0.001	18.2	–0.008	0.465	–0.28	Owner only
2014	0.580	0.001	17.0	–0.005	0.251	–0.11	Owner only
2015	0.714	0.001	21.7	0.233	0.001	12.1	Both
2016	0.725	0.001	23.2	0.299	0.001	10.8	Both
2017	0.467	0.001	14.8	0.109	0.008	8.1	Both
2018	0.512	0.001	17.4	–0.003	0.255	–0.03	Owner only
2019	0.543	0.001	15.9	–0.006	0.087	–0.43	Owner only
2020	0.199	0.001	5.9	–0.007	0.134	–0.25	Owner only
2022	0.087	0.020	3.4	–0.006	0.115	–0.55	Neither
2023	0.476	0.001	13.9	–0.009	0.076	–0.60	Owner only
2024	0.255	0.001	7.6	–0.013	0.054	–0.4	Owner only

Table 1 Global Moran's I for PV, market incentive schemes, by tenure (2012–24).

Note: Moran's I was computed using row-standardised Queen contiguity weights across 349 LAs. Significance based on 999 permutation simulations.

For WI, clustering is present but lower in magnitude for owner/private under both scheme types (I ≈ 0.10–0.29 under market incentives; stronger and more sustained under supplier obligation), and largely absent for social housing under market incentives. HP clustering is weaker still and more variable across years, reflecting the higher capital cost, heterogeneous installation requirements, and more constrained installer market for HP relative to PV.

WITHIN-TENURE DYNAMIC SPILLOVER RESULTS

Table 2 reports the own-channel spatial lag coefficients from the two-way fixed-effects models, pooling within-tenure results across all three technologies and both scheme types. This summarises the six "diagonal" cells of the full spillover matrix.

	SCHEME	OWNER β	P	SOCIAL β	P	R^2_U
PV	Market incentive	0.0037***	0.002	0.0062†	0.063	0.20/0.06
	Supplier obligation	–0.0008	0.722	–0.0002	0.960	–
WI	Market incentive	0.0114***	<0.001	–0.0023	0.243	–
	Supplier obligation	0.0039***	<0.001	0.0028**	0.035	–
HP	Market incentive	–0.0030**	0.016	0.0026	0.215	–
	Supplier obligation	–0.0027	0.122	–0.0014	0.542	–

Table 2 Within-tenure spatial lag coefficients by technology and scheme type (own-channel β).

Note: Two-way FE (LA + year), clustered SE by LA, N ≈ 4,600–4,700 (349 LAs × 13 periods). R^2 (within) shown for PV market incentive models only as illustration. *** $p < 0.01$; ** $p < 0.05$; † $p < 0.10$.

PV under market incentive schemes shows the strongest within-tenure diffusion. The spatial lag coefficient for owner/private housing is 0.0037 ($p = 0.002$), and own-channel momentum (temporal lag) is substantial ($\rho = 0.28$, $p < 0.001$), with within-R^2 of 0.20. For social housing under market incentives, the spatial lag is positive (0.0062) but only marginally significant ($p = 0.063$), consistent with the Moran's I evidence of weak and intermittent clustering. Under supplier obligations, PV shows no significant within-tenure spillovers for either tenure group, supporting the interpretation of geographically batched delivery rather than organic diffusion.

WI under market incentives shows a positive and significant within-owner spatial lag (0.0114, $p < 0.001$), but no significant effect for social housing. Under supplier obligations, both tenure groups show positive and significant spatial lags, owner/private (0.0039, $p < 0.001$) and social (0.0028, $p = 0.035$), suggesting that ECO-style delivery does generate geographic clustering across both tenure types for WI, even if through a funding scheme delivery mechanism rather than peer diffusion.

HP show a different pattern entirely. Under market incentives, the owner/private spatial lag is negative and significant (–0.0030, $p = 0.016$). Under supplier obligations, both within-tenure coefficients are negative and insignificant. The absence of positive spatial autocorrelation in HP adoption, despite growing aggregate uptake, is consistent with rollout being driven by place-specific constraints, such as boiler suitability, off-gas-grid geography, installer scarcity, rather than neighbourhood imitation processes.

CROSS-TENURE SPILLOVER ASYMMETRY

Table 3 reports the cross-tenure spatial lag coefficients from the joint two-equation models, which test whether adoption in one tenure channel predicts future adoption in the other. The results reveal technology-specific and scheme-specific asymmetries that sharpen the overall interpretation considerably.

	SCHEME	OWNER → SOCIAL β	P	SOCIAL → OWNER β	P	ASYMMETRIC?
PV	Market incentive	+0.0017**	0.021	–0.0054***	<0.001	Yes – strong
	Supplier obligation	+0.0025	0.313	+0.0016	0.492	No
WI	Market incentive	+0.0024	0.538	–0.0022	0.447	No
	Supplier obligation	–0.0010	0.151	+0.0031***	<0.001	Yes – social → owner
HP	Market incentive	–0.0048***	<0.001	–0.0016	0.349	Negative
	Supplier obligation	–0.0026†	0.085	–0.0085***	0.001	Negative

Table 3 Cross-tenure spatial lag coefficients by technology and scheme type.

Note: Two-way FE (LA + year), clustered SE by LA. Cross-tenure β is the coefficient on the spatial lag of the opposite tenure channel. Bold indicates significance at $p < 0.05$. *** $p < 0.01$; ** $p < 0.05$; † $p < 0.10$.

For PV under market incentive schemes, the cross-tenure pattern is the clearest. The spatial lag of neighbouring owner/private adoption predicts social housing adoption positively and significantly ($\beta = 0.0017$, $p = 0.021$), indicating that market-led diffusion in the owner-occupied channel extends, to a modest degree, into the social sector. The reverse effect, which is social housing adoption predicting neighbouring owner/private uptake, is negative and highly significant ($\beta = -0.0054$, $p = 0.0003$). This negative cross-tenure coefficient is consistent with geographic targeting: supplier-assisted social housing activity concentrates in areas that are compositionally different from high-activity owner/private clusters, creating a spatial anti-correlation. Under supplier-obligation schemes for PV, neither cross-tenure coefficient is significant, confirming that this scheme type generates no meaningful spillover in either direction.

For WI, the cross-tenure picture is different. Under market incentives, neither cross-tenure effect is significant, suggesting that the within-owner WI diffusion documented above does not propagate across tenure boundaries under market conditions. Under supplier obligation, however, the social-to-owner direction is positive and highly significant ($\beta = 0.0031$, $p < 0.001$), while the owner-to-social direction is negative and insignificant. This suggests that ECO-style area-based WI delivery in social housing is associated with neighbouring owner/private uptake. This could possibly be due to area-based scheme delivery makes installers and funding scheme awareness available across the local area, reducing access barriers for owner-occupiers in adjacent properties.

HP show a further distinct pattern. Under market incentives, the owner-to-social cross-tenure coefficient is negative and highly significant ($\beta = -0.0048$, $p < 0.001$), while the reverse is not significant. Under supplier obligations, the social-to-owner direction is negative and significant ($\beta = -0.0085$, $p = 0.001$). The absence of positive cross-tenure spillovers for HP, combined with the negative within-owner effect noted in Table 2, points away from a diffusion narrative entirely for this technology. HP adoption appears to be constrained by site-specific factors and funding scheme allocation that do not generate the neighbourhood-level imitation and installer expansion that characterise PV market-led diffusion.

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DISCUSSION

DIFFUSION IS TECHNOLOGY-SPECIFIC

The results demonstrate clearly that spatial diffusion of residential retrofit does not operate uniformly across technologies. PV under market incentive schemes show the strongest and most consistent diffusion signature: high and persistent Moran's I, significant positive within-tenure spatial lags, and significant cross-tenure spillovers. The mechanisms are consistent with those documented in the international literature, visibility, installer network expansion, and social learning (Bollinger and Gillingham, 2012; Müller and Rode, 2013) but they operate primarily within the owner-occupied channel.

WI shows a more modest but detectable diffusion signal, particularly under supplier-obligation delivery where both tenure groups show positive within-channel spatial lags. This is notable because most insulation installations are not readily visible to non-expert observers, suggesting that the classic visibility-driven peer imitation is unlikely to be the dominant mechanism. Instead, the clustering observed under ECO-type delivery is more likely attributable to area-based targeting, where contractors systematically cover entire streets or neighbourhoods to reduce transaction and installation costs. Such delivery approach can generate geographic concentration patterns that resemble diffusion (positive spatial autocorrelation), even when driven primarily by supply-side coordination rather than household-level demand imitation. This interpretation is consistent with previous studies of area-based retrofit delivery and obligated supplier behaviour in Great Britain (Hamilton et al., 2014; Rosenow, 2012).

HP show the most striking divergence from a diffusion narrative. Negative spatial lag coefficients for owner/private HP adoption under market incentives suggest that rollout is relatively dispersed, rather than spatially clustered, concentrated in specific property contexts such as off-gas-grid and rural areas) that do not necessarily neighbour one another. This is consistent with the geography of HP suitability in Great Britain, where eligible properties are scattered rather than spatially contiguous. However, unlike WI, HP installations do retain some degree of external visibility through air-source units, and qualitative evidence from other contexts suggests that neighbour influence and social learning may still play a role in adoption decisions. The absence of strong positive spillovers in our results may therefore partly reflect the still relatively immature UK HP market during the 2012–2024 study period, the comparatively lower prevalence of HP installations relative to PV, and the relatively coarse spatial resolution of LAs, which may obscure street-level peer effects. As the HP market matures and on-gas-grid installations become more common, these spatial patterns may change.

DIFFUSION IS FUNDING SCHEME-SPECIFIC

Market incentive schemes generate stronger diffusion for visible technologies than supplier-obligation scheme, at least for PV. This is consistent with the theoretical expectation: market-led schemes operate through dispersed, household-level decision-making where neighbourhood imitation and installer outreach can play a role. Supplier-obligation scheme, by contrast, operate through centralised contracts between energy suppliers and approved installers, with targeting rules that direct activity toward specific areas or household types. The geographic concentration this produces can generate Moran's I above zero, but it is more plausibly "batching" than diffusion in the social-interaction sense.

The exception to this scheme-type ordering is WI under supplier obligation, where positive spatial lags for both tenure groups and a significant social-to-owner cross-tenure effect were found. This suggests that area-based ECO delivery of WI may function as a local activation mechanism: once an area receives delivery scheme attention, both social and owner-occupied properties may receive installations in the same period, and the installer capacity built up in scheme-targeted areas may generate spillovers into adjacent properties across tenure boundaries. This "capacity spillover" mechanism is distinct from peer diffusion but has similar spatial consequences.

CROSS-TENURE ASYMMETRY AND POLICY IMPLICATIONS

The most policy-relevant finding is the asymmetric cross-tenure spillover for PV under market incentives. Owner/private adoption positively predicts neighbouring social housing uptake

($\beta = +0.0017$, $p = 0.021$), while social housing adoption negatively predicts neighbouring owner/private uptake ($\beta = -0.0054$, $p < 0.001$). The positive owner-to-social direction suggests that market-led diffusion can partially prime conditions for social sector uptake, perhaps through installer network expansion, increased LA awareness, demonstration effects from visible rooftop installations, or housing association investment decisions stimulated by visible local activity. The negative social-to-owner direction likely reflects the geographic targeting of supplier-obligation delivery into areas structurally different from high-activity owner/private clusters.

These findings have several implications for funding scheme policy design. First, relying solely on market-led schemes is likely to produce geographically uneven diffusion concentrated in wealthier, owner-occupied areas, with limited natural extension into social housing. Second, the evidence that owner/private adoption can stimulate neighbouring social housing uptake suggests value in geographic coordination: funding scheme interventions that target mixed-tenure LAs where market activity is already underway may generate multiplicative effects by leveraging positive cross-tenure spillovers. This logic resembles the "one-stop shop" approach increasingly promoted within the European Energy Performance of Buildings Directive (EPBD), where retrofit delivery is coordinated locally across technologies, actors, and housing types to accelerate area-wide uptake (Bertoldi et al., 2021; European Commission, 2026).

Third, the distinct behaviour of HP and WI relative to PV underlines the need for technology-specific rather than generic spatial targeting strategies. The "PV diffusion pattern" identified here refers to the strong positive spatial clustering and positive spatial lag relationships observed particularly for owner-occupied PV adoption under market incentives, likely supported by high visibility, social learning, and installer network effects. By contrast, HP adoption exhibited weak or negative spatial lag relationships, suggesting more geographically dispersed uptake associated with suitability and high upfront cost constraints and the still immature UK HP market. Consequently, spatial targeting strategies calibrated around PV-style diffusion dynamics may not transfer effectively to HP deployment.

More broadly, the results suggest that the spatial monitoring of EPC data, including Moran's I trajectories, spatial lag dynamics, and cross-tenure correlations, could provide policy-relevant early signals about where diffusion is proceeding organically and where targeted intervention may be needed to prevent spatial lock-in of low-retrofit areas.

LIMITATIONS

Several limitations should be noted. EPC records do not capture all retrofit events, and attribution of events to scheme type involves classification assumptions. The analysis uses Queen contiguity weights; alternative specifications may yield different magnitudes. The use of LA-level aggregation means that micro-level peer effects operating at street or neighbourhood scale cannot be directly observed; our spatial lag coefficients capture aggregate diffusion trends across areas rather than individual imitation processes, and results should be interpreted accordingly. The study period spans major policy regime changes (FiT closure, ECO evolution, COVID-19 disruption), which are partially absorbed by year fixed effects but may interact with spatial dynamics in ways not fully captured here. Future work should extend the analysis to sub-LA geographies, incorporate auxiliary variables on installer density and socioeconomic deprivation to identify spillover mechanisms, and examine how cross-tenure spillover patterns change as the HP market matures.

CONCLUSION

This paper has examined how spatial diffusion of residential retrofit varies across technologies, tenure types, and funding schemes in Great Britain, using EPC-derived data on 349 LAs over 2012–2024. Three main findings emerge.

First, PV adoption under market incentive schemes exhibits strong spatial clustering and clear within-owner diffusion, with significant lagged-neighbour effects that persist after controlling for local momentum and national shocks. This is the technology and scheme combination most consistent with a canonical spatial diffusion story mediated by peer effects and installer networks.

Second, WI displays more modest but still detectable spillovers, particularly under supplier-obligation delivery where both tenure groups show positive spatial lags and social-to-owner cross-tenure effects are observed. HP adoption, by contrast, shows little evidence of positive diffusion and several negative spatial lag coefficients, consistent with geographic constraints on suitability rather than neighbourhood imitation.

Third, cross-tenure spillovers are asymmetric and vary by technology. The clearest case is PV under market incentives, where owner/private adoption stimulates neighbouring social-housing uptake, while social-housing retrofit activity is negatively associated with neighbouring owner/private adoption. These asymmetries challenge the assumption that retrofit diffusion operates uniformly across the housing stock and highlight the importance of tenure-aware spatial targeting in retrofit policy design.

DATA ACCESSIBILITY STATEMENT

EPC data for England and Wales are available from the Ministry of Housing, Communities and Local Government open data portal (https://epc.opendatacommunities.org). EPC data for Scotland are available from the Energy Saving Trust (https://www.scottishepcregister.org.uk). Analysis code is available on request from the corresponding author.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **PowerPoint Slides.** PowerPoint Slides relating to this article. DOI: https://doi.org/10.66506/essp.7-043-26.s1

COMPETING INTERESTS

The authors have no competing interests to declare.

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